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Central bank swap lines: micro-level evidence

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Abstract

This paper investigates the impact of central bank swap lines during the 2020 pandemic using micro-level data. Institutions drawing on these swap lines hold higher-quality collateral due to stringent requirements. Using confidential transaction-level data from the Bank of England, we study how swap line drawings affects dealer pricing and exposures in foreign exchange forward and swap contracts. We find that swap line drawings reduce pricing inefficiencies and violations of covered interest parity. These effects result from reduced demand for US dollar liquidity, as dealers use swap lines as a substitute for dollar funding rather than increasing dollar supply through arbitrage.

Key words: Central bank swap lines, foreign exchange swaps, covered interest rate parity, central banking.

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

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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, the Bank of England (BOE), the Bank of Canada (BOC), the European Central Bank (ECB), the Bank of Japan (BOJ) and the Swiss National Bank (SNB).[1]

Swap lines have been used as a policy tool by the Federal Reserve in response to the crisis of 2008, and again in response to the international spillovers of Covid in March 2020. The Federal Reserve acts as a source central bank by exchanging U.S. dollars (USD) for the domicile currency of the counterparty central bank. The primary reason for swap lines is to mitigate the financial stability risks of USD shortages, which can impair the functioning of global markets, spill back into domestic markets, and ultimately lead to significant negative macroeconomic effects (Cesa-Bianchi et al., 2020; Committee on the Global Financial System, 2020). An emerging literature has focused on the effects of swap lines on pricing, with evidence that swap lines lower the ceiling on deviations from covered interest parity (CIP) (Bahaj and Reis, 2022a, 2020; Eren et al., 2020; Goldberg and Ravazzolo, 2021; Choi et al., 2022; Schellekens and Duijm, 2022; Kekre and Lenel, 2024; Bahaj et al., 2024).

While prior studies have documented how swap lines reduce pricing inefficiencies at the aggregate level, their impact on dealer-level exposures and pricing remains less well understood. As noted by Bahaj and Reis (2022c), *"The net effect [of central bank swap lines] is to provide source currency funds for banks in the recipient country. Why they need these funds*

[1]Other swap line networks include the ECB's agreements with the central banks of Bulgaria, Sweden, Denmark, Croatia and China. China's People's Bank of China (PBOC) has extended a network of swap lines with central banks in Asia, Europe and the U.S. with the aim to increase trade invoicing in RMB, see Bahaj and Reis (2022b) for more details.

in the first place is less well understood... Ultimately, research to answer this question will likely have to use bank-level data on drawings." Addressing this gap, our paper provides micro-level evidence on how swap lines influence the pricing and hedging of outstanding FX exposures. We show that swap lines serve as an effective substitute for dollar funding, improving market functioning and alleviating funding pressures during periods of stress.

We use two confidential datasets from the BOE to conduct our analysis. The first contains transaction-level data on USD repurchase auctions conducted by the BOE with private institutions, and the second is the BOE trade repository, which provides detailed information on FX outright forward and swap contracts where one of the counterparties is based in the UK. By merging these datasets, we analyze how dealers receiving liquidity through swap lines adjust their pricing of forward and swap contracts. We test whether swap lines encourage more favorable pricing and examine their effects on supply and demand dynamics in FX markets. Specifically, we investigate whether dealers use swap line liquidity to lend USD or for arbitrage activities, or whether they substitute it for other forms of dollar funding, such as FX outright forward and swap contracts.

To our knowledge, this is the first study to use confidential transaction-level data on the drawings of swap lines. This unique dataset allows us to trace individual dealers' drawings on swap lines, examine their pricing behavior, and measure their gross outstanding exposures, providing new insights into the mechanisms through which central bank interventions influence cross-border dollar funding markets.

We outline three key findings on the role of central bank swap lines in mitigating funding pressures and improving market efficiency. First, we test the determinants of swap line usage. Contrary to the classical lender of last resort (LOLR) theory, which suggests that weaker institutions borrow during liquidity constraints (Bagehot, 1873), our findings reveal that swap line drawings are determined more by collateral quality than by capitalization. Institutions with a higher share of high-quality liquid assets (HQLA), such as government bonds, are more likely to draw on the BOE swap lines. This reflects the stringent collateral requirements imposed by central banks, which discount illiquid and high-risk assets with haircuts exceeding 15% of their collateral value. In contrast, indicators of weaker capitalization, such as proximity to leverage or capital ratio requirements, do not predict swap line drawings. These results support a *collateral channel* rather than a *capitalization channel* for swap line drawings.

Second, we find that swap lines significantly reduce pricing inefficiencies in FX outright forward and swap contracts. Using a difference-in-differences (DiD) approach, we compare forward rates charged by dealers drawing on BOE swap lines to those that do not. Our transaction-level data allows us to account for dealer-counterparty and counterparty-time fixed effects, following Cenedese et al. (2021) and Khwaja and Mian (2008), to control for counterparty-specific hedging demand. Dealers receiving swap line liquidity offer more favorable forward rates at the 1-week and 3-month maturities following the March 18, 2020, announcement of BOE swap line auctions. This reduction in CIP violations suggests that swap lines improve market efficiency by alleviating liquidity pressures. Notably, the pricing effects dissipate over time, reflecting a spillover of liquidity benefits to other market participants.

Third, we examine the mechanisms driving the observed pricing effects by analyzing changes in dealer FX exposures. Specifically, we distinguish between two potential channels: *arbitrage*, where dealers use swap line liquidity to lend USD or engage in arbitrage activities, and *substitution*, where dealers reduce their demand for USD by substituting swap line liquidity for FX market funding. Our DiD analysis shows that dealers drawing on swap lines reduce their gross outstanding FX exposures, particularly their USD Sell exposures at the forward leg of FX forwards and swaps. This supports the substitution channel, indicating that dealers use swap lines as an alternative to seeking USD funding through FX contracts, rather than for USD lending or arbitrage. The substitution is concentrated at maturities of less than 1 week, highlighting the targeted impact of swap lines during periods of stress.

Related Literature: We contribute to an emerging literature on the macro-financial determinants, price, and balance sheet effects of Federal Reserve swap lines (Rose and Spiegel, 2012; Bahaj and Reis, 2022a; Goldberg et al., 2011; Bahaj and Reis, 2020; Goldberg and Ravazzolo, 2021; Aizenman et al., 2022; Choi et al., 2022; Cesa-Bianchi et al., 2023; Bahaj and Reis, 2020; Eren et al., 2020; Schellekens and Duijm, 2022; Aldasoro et al., 2020; Eren et al., 2020; McCrone et al., 2020; Kekre and Lenel, 2024), as well as swap lines in emerging markets (Bahaj and Reis, 2020; Bahaj et al., 2024), theories of the macroeconomic effects of swap lines (Cesa-Bianchi et al., 2020; Bohorquez, 2023; Bacchetta et al., 2023; Dominguez and Gomis-Porqueras, 2023), and the broader literature on lender of last resort (LOLR) lending (Bagehot, 1873; Fischer, 1999; Cecchetti, 2014; Drechsler et al., 2016). Within this literature, our paper relates closely to Bahaj and Reis (2022a), which documents how Federal Reserve swap lines can enforce a ceiling on CIP violations. While Bahaj and Reis (2022a) focuses on aggregate pricing effects, our contribution is to exploit transaction-level data to examine the balance sheet characteristics, pricing behavior, and FX exposures of dealers that drew on the swap line.

A second strand of literature focuses on theories of pricing and balance sheet exposures in the FX market. This research primarily examines the determinants of CIP deviations, including dealer balance sheets and regulatory constraints, segmented market funding costs, hedging demands, liquidity and counterparty risk, and monetary policy (Cenedese et al., 2021; Du et al., 2018; Liao, 2020; Bräuning and Puria, 2017; Avdjiev et al., 2019; Siriwardane et al., 2024; Rime et al., 2022; Andersen et al., 2019; Viswanath-Natraj, 2020; Baba and Packer, 2009; Mancini Griffoli and Ranaldo, 2011; Borio et al., 2016; Ivashina et al., 2015; Iida et al., 2018; Syrstad, 2020; Ben Zeev and Nathan, 2024). Our study complements this literature by providing micro-level evidence of how dealer FX exposures and drawings on swap lines interact to influence FX pricing, particularly during periods of heightened market stress.

Additional topics relevant to our work include the balance sheet exposures of FX derivative positions during quarter-ends (Abbassi and Bräuning, 2020; Kloks et al., 2024a,b), discrimination in derivative pricing with respect to non-financial counterparties (Hau et al., 2021), the role of order flow in price-setting for FX outright forward and swap contracts (Syrstad and Viswanath-Natraj, 2022), and the impact of FX hedging on spot rate dynamics, domestic markets, bank lending, and international capital flows (Liao and Zhang, 2024; Czech et al., 2021; Bräuer and Hau, 2024; Eguren-Martin et al., 2024; Kubitza et al., 2024). Our work aligns closely with Cenedese et al. (2021), which uses transaction-level FX derivative data to explore the impact of Basel III capital regulations on FX derivative pricing, and exploit a change in leverage ratio reporting to identify the effect of intermediary constraints. Similarly, we apply a DiD framework to identify the effect of swap lines on dealer-level FX outright forward and swap contract pricing, controlling for counterparty-related effects following Khwaja and Mian (2008).

Our contribution to this literature differs by documenting, for the first time, that swap lines reduce the magnitude of CIP violations using intraday trades. We also show that dealers drawing on swap lines reduce their outstanding gross FX exposures due to a substitution toward USD liquidity received via swap lines, thus improving market functioning during crises.

Lastly, our analysis complements Kloks et al. (2024b), which highlights substitution dynamics between FX swaps and repos based on balance sheet costs. While their study focuses on quarter-end dynamics, where banks substitute repos with FX swaps, we document a substitution of dollar funding in a different context. During the Covid pandemic, as synthetic dollar funding costs via FX swaps rose, BOE dollar repo operations offered an attractive alternative. These repos, not subject to balance sheet constraints and offered on favorable terms, allowed banks to substitute from FX swaps to repo-based dollar funding. Thus, our paper provides novel evidence on how swap lines act as a substitute source of funding when synthetic dollar funding costs are elevated.

The remainder of the paper is structured as follows. In Section 2 we summarize the institutional details of swap lines, describe the BOE 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 3 we conduct our empirical analysis on swap line drawings, FX outright forward and swap pricing and exposures using detailed dealer-level transaction data. Section 4 concludes.

2 Definitions and Data

2.1 Federal Reserve Swap Line Data

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 illustrated in Figure 1. The process involves four key steps. First, the BOE auctions USD repurchase agreements (repos) to dealers in the UK on the trade date. On the same day, the BOE swaps GBP for USD with the Federal Reserve for the full amount bid by participants. The settlement of the swap typically occurs on a T+1 basis. On the settlement date, the BOE transfers funds and distributes USD to successful auction participant accounts. Finally, at the maturity of the contract, the currencies are re-exchanged by the central banks at the same exchange rate as the initial swap, ensuring that the transaction is free from exchange rate risk.

Crucially, these swap lines are offered at a penalty rate, with the recipient central bank assuming counterparty risk. The penalty rate is typically set as a spread above the US Overnight Index Swap (OIS) rate. In March 2020, the swap line operations underwent significant changes, including the introduction of 3-month maturity auctions, an increase in the frequency of Federal Reserve auctions to daily, and a reduction in the penalty rate from OIS+50 basis points to OIS+25 basis points. Participants in the BOE USD repo auctions are charged the same rate paid by the BOE to the Federal Reserve, set at OIS+25 basis points.

[INSERT FIGURE 1 ABOUT HERE]

Publicly available data from the New York (NY) Federal Reserve contain details on the amount, currency, tenor and counterparty central bank of each auction, and a summary of allotments for the BOE, ECB and BOJ is provided in Appendix A. Using this, we can construct a measure of the outstanding swap lines extended to each counterparty central bank since March 2020. This is calculated as the amount of swap lines drawn minus any that have matured. Based on Figure 2, outstanding swap lines peaked at 142 billion USD for EUR/USD, 196 billion USD for JPY/USD and 38 billion USD for GBP/USD in May 2020.

[INSERT FIGURE 2 ABOUT HERE]

In addition, we obtain a confidential dataset from the BOE which contains detailed individual dealer-level drawings on BOE swap line auctions 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, which we can use to link to dealer transactions in FX outright forward and swap contracts. In Appendix A we verify that the BOE dealer-level drawings are consistent with the publicly available data on BOE swap line allotments provided by the NY Federal Reserve.

Institutions eligible for BOE swap lines are outlined in the Sterling Monetary Framework.[2] In order to draw on the BOE swap line facility, institutions are mandated to provide

[2]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.

collateral. Detailed characteristics of the collateral, such as the types, credit ratings and haircuts are summarized in Table 1. Collateral are categorized into buckets A, B, and C, taking into account both credit ratings and asset types. Bucket A encompasses government securities issued by specific countries, while bucket B comprises securities from other advanced economies and the AAA tranches of mortgage/asset-backed securities. Bucket C, on the other hand, includes lower-rated mortgage/asset-backed securities.

[INSERT TABLE 1 ABOUT HERE]

The sterling monetary framework further refines these collateral categories to include haircuts. For instance, collateral in bucket A, representing government securities from countries like the US, UK, Canada, Germany, France, and the Netherlands, is subject to haircuts on short-term debt at 0.5 percent. In bucket B, which includes sovereign government securities from additional advanced economies and the AAA tranches of mortgage and asset-backed securities, the haircuts typically range from 0.5 to 12 percent. Bucket C, comprising mortgage or asset-backed securities with a tranche rating of A3 or above, carries higher haircuts, generally ranging from 15 to 30 percent for riskier assets like mortgage-backed securities. The differentiation in haircuts is not only dependent on the collateral's credit rating and type but also on the maturity period. For instance, in the case of maturities exceeding 30 years, collateral in bucket A incurs a 15 percent haircut for long-term bonds, while bucket C assets face higher haircuts ranging from 27 to 42 percent. The haircuts are effectively costs incurred by institutions in providing risky assets as collateral to draw on swap lines.

2.2 BOE Trade Repository Data

The 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 UK trade repository data contains details on the FX derivative trades for all transactions with at least one counterparty in the UK, with coverage representing over 42% of the entire outstanding global FX derivative contracts (Cenedese et al., 2021).[3] 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). For confidentiality reasons, we are unable to disclose the full details of our dataset. However, we can confirm that our sample consists of 20 dealers, some of which have multiple branches. Notably, our sample includes 13 of the 17 dealer banks used in Cenedese et al. (2021).[4]

The trade repository data can be broadly divided into two types of reports: a) state reports, which contain trade information on the cumulative outstanding amount of derivative trades between individual counterparties, or stock; and b) activity reports, which contain trade information on new intraday trades of derivative contracts, or flow. We use the state reports collected within the trade repository data to collect all the outstanding derivative positions in the FX outright forward and swap contracts at the end of each month from September 2019 to November 2020. Additionally, we leverage activity reports

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

[4] The list of 17 dealers used in Cenedese et al. (2021) includes: Bank of America Merrill Lynch, Barclays, BNP Paribas, Citi, Crédit Agricole, Credit Suisse, Deutsche Bank, Goldman Sachs, HSBC, JP Morgan, Morgan Stanley, Nomura, Royal Bank of Scotland, Société Générale, Standard Chartered, State Street, UBS.

to capture all intraday trades in FX outright forward and swap contracts during the period from 17 to 20 March 2020. This period includes the principal swap line announcement on 18 March and the auctions conducted on 19 March.

We can use the dataset to construct the aggregate outstanding FX exposures of dealers. This aggregates dealer exposures with all (non-dealer) counterparty sectors: asset managers, (non-dealer) commercial banks, hedge funds, ICPF and LDI, non-financial, and other financial institutions.[5]

To calculate aggregate exposures, we track each dealer's FX outright forward and swap transactions in the dataset. Each transaction includes an identifier specifying whether the counterparty is buying or selling USD in the forward leg of the swap. A dealer purchasing USD and selling GBP forward is classified as a *Buy* transaction, while a dealer selling USD and buying GBP forward is classified as a *Sell* transaction. These transactions are recorded at the dealer-client level and can then be aggregated to obtain outstanding *Buy* and *Sell* exposures for each dealer. Additionally, we calculate the *Net* USD exposure, defined as the difference between USD *Buy* and *Sell* transactions in the forward leg of all outright forward and swap transactions.

[5]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 defense; 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 organizations and bodies.

2.3 Other Data

2.3.1 Forward Prices and CIP Deviations

For our main empirical analysis, we construct a transaction-level measure of CIP deviations based on outright forward and swap contracts from the BOE repository. 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, as shown in equation (1),

$$x_{\$/d,i,j,t} = 1 + r^f_{\$,t} - \frac{F_{i,j,t}}{S_t}(1 + r^f_{d,t}) \tag{1}$$

where S_t is the spot rate, $F_{i,j,t}$ is the forward rate (both expressed in USD per unit of foreign currency), and $r^f_{\$}$ and r^f_d are the risk-free rates in USD and domestic currency, respectively. A negative $x_{\$/d,i,j,t}$ indicates that synthetic USD borrowing costs exceed local borrowing costs.

For the motivating evidence presented in Section 2.4, we use daily spot, forward, and OIS benchmark rates available from Bloomberg. We also use intraday forward rates to measure realized volatility, specifically at 5-minute intervals, sourced from Reuters Refinitiv. This measure of intraday volatility is derived by taking the square root of the sum of squared returns for each 5-minute interval, averaged over the course of a day.

2.3.2 Balance Sheets

We collect quarterly information on total assets, liabilities, Tier 1 capital, leverage ratios, and risk-weighted assets from Bloomberg. To create monthly datasets from the quarterly data, we use the data from the end of a quarter for each month within that quarter. For instance, the balance sheet figures for October and November 2019 are identical to those at the end of the quarter (December 2019). The minimum requirements for Common Equity Tier 1 (CET1) capital and leverage ratios follow the banking regulations of the country where the parent firm's headquarters are located. Table 2 presents summary statistics of balance sheet characteristics at the parent company level. All data are presented in USD.

[INSERT TABLE 2 ABOUT HERE]

2.4 Motivating Evidence using Benchmark Rates

Before we turn to our transaction-level evidence, we present motivating evidence on the effects of swap lines on market efficiency using benchmark rates.

Fact #1: *The reduction in the penalty rate on COVID swap lines, from OIS + 50 basis points to OIS + 25 basis points, lowered the ceiling on CIP deviations.*

Following Bahaj and Reis (2020), we test whether there is a decline in the ceiling of CIP deviations due to the penalty rate reduction on 19 March 2020, from 50 basis points above OIS to 25 basis points. The ceiling on CIP deviations using the OIS rate as a benchmark, x_{ois}, is expressed in equation (8).[6]

The no-arbitrage condition suggests that any breaches of the ceiling would allow dealers to execute a favorable arbitrage trade. For example, a dealer could borrow USD through the swap line at the penalty rate δ, swap USD into a foreign currency (e.g., GBP), and lend out reserves at the Bank of England.

$$x_{ois} \leq \delta + i^{GBP}_{\text{interbank}} - i^{GBP}_{\text{reserve}} \tag{2}$$

Panel A of Figure 3 illustrates the ceiling for 1-week CIP deviations for the EUR/USD, GBP/USD, and JPY/USD pairs, derived from equation (8). The dotted line marks the penalty rate reduction on 19 March 2020, and our analysis shows a lower ceiling on CIP deviations after this reduction.

[6]For more details on the derivation of the ceiling in equation (8), we refer readers to Appendix B.

Fact #2: *There is a decline in the magnitude and intraday volatility of CIP deviations in the currencies of central banks following drawings on the swap lines.*

Panel B of Figure 3 presents CIP deviations (benchmark OIS rate) for advanced economies with 1-week maturities. After an initial spike in CIP deviations in March for the EUR/USD, GBP/USD, and JPY/USD pairs, when USD liquidity became scarce, we observe a sharp reversal in CIP deviations following the introduction of swap line arrangements between the Federal Reserve and counterparty central banks. We also plot the intraday forward rate volatility for the same currency pairs with 1-week maturity. An increase in volatility is observed in the days leading up to the swap lines settled on 19 March 2020, followed by a reversal of volatility shortly after, consistent with the price effects.

For additional statistical tests supporting our findings on CIP deviations and forward rate volatility, we refer readers to Appendix B.[7]

[INSERT FIGURE 3 ABOUT HERE]

3 Empirical Evidence

3.1 Predictors of swap line drawings

Classical lender of last resort (LOLR) theory dates back to Bagehot (1873), which states that in a crisis, the lender of last resort should lend freely, at a penalty rate, on the basis of collateral that is marketable in the ordinary course of business when there is no panic. Crucially, central bank swap lines provide the role as an international lender of last resort, and in principle can be used by institutions to meet USD liquidity shortages (Cecchetti,

[7] In Appendix B.1, we include a statistical test on CIP ceiling breaches. In Appendix B.2 and B.3, we use a DiD and synthetic control approach to compare CIP deviations between countries that activated Federal Reserve swap lines and a control group that did not. The results show that the allocation of swap lines in March 2020 led to a reduction in 3-month CIP deviations by approximately 13 basis points compared to the control group. In Appendix B.4, using a HAR analysis, we find a significant reduction in realized volatility across all currencies and maturities two days after swap settlement, with the most substantial effect observed in the EUR/USD pair. Interestingly, volatility increases on the day of settlement, possibly due to heightened market activity during swap line auctions.

2014; Fischer, 1999). For the design and operation of swap lines, it is important to understand the dealer characteristics that lead to swap line drawings. We outline two key channels through which dealers activate swap lines, which we refer to as the *capitalization* and *collateral* channels of swap line drawings.

H1.1: *Capitalization: Dealers that are weakly capitalized use swap lines an alternative source to provide USD funding to mitigate shortages in liquidity.*

The pandemic led to a dramatic increase in the demand for USD liquidity, as witnessed in the selling of U.S. Treasuries by pension funds in an episode referred to as a *dash for cash* (Cesa-Bianchi et al., 2023). A dealer can obtain USD liquidity by borrowing USD directly in money markets or through FX swap transactions. If they are weakly capitalized, they are less able to borrow USD to meet the liquidity shortfall due to regulations on the level of Tier 1 capital and leverage ratio (Fatouh et al., 2024). For example, if a dealer is weakly capitalized, they are constrained in borrowing in direct USD markets as it would directly impact their leverage requirement. In contrast, swap line borrowing is a USD Repo with a counterparty central bank, therefore it has negligible counterparty risk, and a zero weight for the calculation of leverage ratio. Therefore, in principle UK Banks subject to the prudential regulatory authority (PRA) can utilize swap lines without affecting their leverage ratio.[8]

Alternatively, weakly capitalized banks may use swap line funding as a way to engage

[8]For more information we refer readers to the policy statement released by the BOE on its recommendation to exclude central bank lending from the leverage ratio rule, see https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/policy-statement/2017/ps2117.pdf. The relevant passages in clause 1.3 and 1.4 states:

1.3 At its meeting on 20 September 2017, and following consultation, the FPC recommended to the PRA that its rules on the leverage ratio: (i) exclude from the calculation of the total exposure measure those assets constituting claims on central banks, where they are matched by deposits accepted by the firm that are denominated in the same currency and of identical or longer maturity; and (ii) require a minimum leverage ratio of 3.25%.

1.4 Central bank claims for these purposes include reserves held by a firm at the central bank, banknotes and coins constituting legal currency in the jurisdiction of the central bank, and assets representing debt claims on the central bank with a maturity of no longer than three months.

in risky lending behavior, leading to potential moral hazard implications of the LOLR function. For example, Drechsler et al. (2016) find empirical evidence that during the Euro debt crisis banks with weaker capitalization are more inclined to borrow from the central bank. We can test the capitalization using the distance to the CET1 capital ratio and leverage ratio requirement. A higher distance to the minimum leverage ratio indicates that a bank is more capitalized.[9]

H1.2: *Collateral: Dealers that use swap lines have more liquid and high quality assets on their balance sheet which they provide as collateral due to strict collateral requirements.*

Classic LOLR theory requires that collateral be marketable during non-crisis periods. Since swap line borrowing functions similarly to repos, commonly used collateral includes government bonds and other HQLA. As discussed in the collateral requirements in Table 1, less liquid assets face stringent haircuts, making Federal Reserve swap lines a more expensive source of USD funding. We can test whether dealer drawings on swap lines depends on the availability of good quality collateral by examining the share of risk-weighted assets on bank balance sheets and using dealer holdings of UK public sector assets as a proxy for the level of HQLA.

To test the capitalization and collateral channels, we identify potential determinants of swap line usage using equation (3). The outcome variable, D_{treat}, is a dummy variable indicating whether a dealer activated the BOE swap line. Explanatory variables include the distance from the CET1 capital and leverage ratio requirements, and the share of risk-weighted assets. All balance sheet variables are taken as of December 2019, making them *ex ante* measures that are not influenced by the uptake of swap line borrowing in March 2020.

[9] For example, the PRA handbook states that a firm must hold sufficient tier 1 capital to maintain, at all times, a minimum leverage ratio of 3.25%. For more details on the leverage ratio calculation we refer readers to `https://www.prarulebook.co.uk/pra-rules/`. Note that based on the way our variable is defined, a leverage ratio of 4.25% implies a distance to leverage ratio of 1%.

$$D_{treatment,i} = \beta x_t + \epsilon_{i,j,t} \quad (3)$$

Table 3 presents the results. Columns (I) and (II) test the capitalization channel, and use the distance to the CET1 capital and leverage ratio as explanatory variables. We find no significant effect of the level of capitalization on swap line drawings. Therefore, contrary to hypothesis 1.1, dealers are not necessarily using swap lines due to leverage constraints.

We test the collateral channel in columns (III) and (IV) using the share of risk-weighted assets and a measure of public sector assets held by dealers. The findings suggest that dealers drawing on swap lines typically possess a lower share of risk-weighted assets and a larger quantity of UK public sector assets. This aligns with the data in Table 1, which shows lower haircuts for high-quality collateral, indicating that institutions holding a greater proportion of safe assets incur lower costs when providing collateral to draw on swap lines.[10]

Our findings on the users of central bank swap lines differ from patterns typically observed in other forms of central bank lending, which often address liquidity shortages. We explain these differences by considering the collateral costs associated with drawing on swap lines. Due to significant haircuts applied to riskier mortgage and asset-backed securities, dealers using swap lines tend to hold a smaller proportion of risk-weighted assets.

One limitation of our analysis is that both the capitalization and collateral channels cannot speak to the role of currency mismatches on bank balance sheets and their gross FX exposures. While dealers receiving USD may not be weakly capitalized and distressed firms, we argue that these firms may still face significant USD shortages on their balance sheet. If so, swap lines have clear implications for the pricing and FX exposures of dealers,

[10] This uses dealer-level balance sheet data on level 1 tradeable assets, which is defined as UK central or regional government, local authority, or public sector entity assets. More information can be found at https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/regulatory-reporting/banking/pra110-instructions.pdf.

to which we now turn.

[INSERT TABLE 3 ABOUT HERE]

3.2 Intraday Price Effects

H2: *Dealers that receive swap line funding charge more favorable forward rates relative to dealers that did not receive swap line funding.*

In this analysis, we exploit transaction-level heterogeneity in forward prices charged by dealers. Using a DiD framework, we classify dealers as 'treated' if they draw on swap lines from the BOE. This framework allows us to test whether treated dealers offer more favorable forward rates compared to a 'control' group of dealers that did not draw on the swap line. Our hypothesis is that dealers drawing on the swap line gain additional USD liquidity, enabling them to provide more competitive pricing in intraday FX outright forward and swap contracts. As a result, we expect a reduction in CIP violations for treated dealers relative to control dealers.

We construct intraday, transaction-level CIP deviations for the period from 17 to 20 March 2020. These dates correspond to the largest allotment of swap line auctions during the pandemic. On 17 March, the Bank of Japan announced its auctions, while 18 March marked the announcement for the BOE and the ECB. The settlement date for the auctions across all three counterparty central banks was 19 March. In our analysis, we use all transactions between dealer and non-dealer clients. This includes asset managers, (non-dealer) commercial banks, hedge funds, ICPF and LDI, non-financial and other financial. We subdivide our sample into a control and treated group, where treated dealers draw on BOE swap lines during the period from 18 to 20 March 2020.

We estimate a DiD model, as specified in equation (4), to assess the impact of swap lines on pricing inefficiencies in the FX market, using transaction-level CIP deviations for the EUR/USD, GBP/USD, and JPY/USD currency pairs. Following Khwaja and Mian (2008) and Cenedese et al. (2021), we incorporate both dealer-counterparty and counterparty-time fixed effects to account for the idiosyncratic hedging demands of counterparties. Crucially, our specification includes only counterparties that trade with multiple dealers. This approach enables us to isolate the effect of a counterparty trading with a dealer who draws on a swap line, relative to a dealer who does not.

The outcome variable is the transaction-level CIP deviation measured at the dealer-counterparty level. D_{treat} is a dummy variable for dealers that activated the BOE swap line. $D_{03/18}$, $D_{03/19}$ and $D_{03/20}$ are dummy variables for 18, 19 and 20 March, which correspond to the day of announcement, settlement and the day after settlement.

$$Y_{i,j,t} = \alpha_{i,j} + \alpha_{j,t} + \sum_{j=1}^{3} \delta_j D_{03/17+j} \times D_{treatment,i} + \epsilon_{i,j,t} \tag{4}$$

Table 4 details the results for 1-week and 3-month maturities in transactions involving dealers and all counterparties. For the 1-week maturity, columns (I) to (III) cover EUR/USD, GBP/USD, and JPY/USD, respectively. The analysis extends to the 3-month maturity in columns (IV) to (VI). The key variables of interest are the interactions of each day of swap line drawings (18 to 20 March 2020) with the indicator for swap line drawings.

Since CIP deviations are negative for EUR/USD, GBP/USD, and JPY/USD, a positive coefficient on the interaction variable indicates a reduction in the magnitude of the CIP deviation. The most notable effect is observed for EUR/USD at the 1-week maturity, where the magnitude of the CIP deviation decreases by 112 basis points (annualized) on 18 March and 56 basis points (annualized) on 19 March. For the 3-month maturity, GBP/USD exhibits the strongest results, with positive coefficients of 23, 19, and 16 basis points on 18, 19 and 20 March, respectively. Overall, dealers drawing on BOE swap lines experienced a net decline in forward rate mispricing relative to the control group in the days following the announcement.

An interesting finding is that most pricing effects occurred on the announcement day and diminished over time as markets arbitraged price differences across dealers. For example, in columns (1) and (4) of Table 4, the coefficient on $D_{\text{treat}} \times D_{\text{time}}$ for EUR/USD (1W) and GBP/USD (3M) decreases from 18 to 20 March. This suggests that the pricing difference between treated and control dealers narrowed over time. One possible explanation is that the swap line initially allowed treated dealers to charge more favorable forward prices of FX contracts, followed by spillovers to other dealers and the broader market. This is consistent with our hypothesis that the swap line enhances USD liquidity for the entire market, with micro-level data providing insights into the timing of this effect.

Another notable finding is the strong results for EUR/USD at the 1-week horizon, which may seem surprising given the focus on BOE swap lines. This can be attributed to the offshore nature of the EUR/USD market. For instance, estimates from the Bank for International Settlements indicate that a significant portion of EUR trading occurs offshore, with 77.6% of EUR transactions conducted offshore, compared to 18.6% in cross-border transactions with residents and only 3.8% in onshore transactions between residents (Caballero et al., 2022).

Additionally, spillover effects from swap lines activated by the ECB may contribute to the observed EUR/USD results. On 19 March, the BOE drew 7.2 billion USD at the 3-month maturity and 8.2 billion USD at the 1-week maturity. In contrast, the ECB drew 36.3 billion USD at the 1-week maturity and 75.8 billion USD at the 3-month maturity, while the BOJ drew 30.2 billion USD at the 3-month maturity and 2.05 billion USD at the 1-week maturity.[11] Although we lack dealer-level data on ECB swap line usage, Euro Area dealers in the London derivatives market can draw on USD funding from their parent institutions in the Euro Area. Evidence from interoffice flows suggests that swap lines channel USD funding from parent to subsidiary branches (Aldasoro et al., 2020). Consequently, the EUR/USD effects may partly reflect spillovers from ECB swap lines to the London market.

Lastly, our findings highlight market segmentation and inertia in dealer-client relationships. In theory, dealers drawing on swap lines should offer more favorable pricing,

[11] See Appendix A for further details on the date, amount, and terms of swap line auctions.

leading customers to shift toward them and equalizing prices. However, dealer-client relationships exhibit inertia in our sample, and previous studies have documented price discrimination in these markets (Hau et al., 2021; Cenedese et al., 2021). For example, Cenedese et al. (2021) show that dealers subject to the leverage ratio rule introduced in 2015 charge higher forward prices than those not subject to the rule. In contrast, our analysis demonstrates that drawing on swap lines alleviates USD liquidity constraints, enabling dealers to offer more competitive forward pricing.

[INSERT TABLE 4 ABOUT HERE]

3.3 Outstanding Derivative Exposures

We have shown that drawing on swap lines leads to more favorable pricing of FX forward and swap contracts. However, the distribution of USD liquidity from swap lines remains less clear. To explain the observed price effects, we propose two potential channels: the *arbitrage* and *substitution* channels. While both channels are consistent with the pricing effects, they imply contrasting implications for dealer FX exposures and the relative demand and supply of USD in outright forward and FX swap contracts.

H3.1: *Arbitrage: Dealers that draw on the BOE swap line engage in arbitrage by selling USD at the spot leg of FX swap contracts and purchasing USD forward.* Dealers can use USD obtained from swap lines to exploit deviations from CIP through arbitrage. Specifically, when CIP deviations exceed the ceiling outlined in Bahaj and Reis (2022a), dealers can execute profitable arbitrage trades.[12]

First, dealers borrow USD from the swap line at a penalty rate set above the risk-free rate. Second, they sell the borrowed USD for foreign currency (e.g., GBP) at the spot leg of an FX swap contract. Finally, they repurchase USD at the forward leg of the same contract. This sequence of transactions enables dealers to capture arbitrage profits when

[12]For a detailed derivation of the ceiling on CIP deviations, see Appendix B.1.

CIP deviations are sufficiently large to offset the costs of swap line usage, including the penalty rate.

Through these activities, dealers supply additional USD in the spot market and increase demand in the forward market. This behavior reduces CIP deviations and the extent of mispricing in FX markets, thereby enhancing market efficiency. Under this channel, we expect to observe an increase in net USD purchases at the forward leg of FX swap transactions and outright forward contracts.

H3.2: *Substitution: Dealers drawing on the BOE swap line reduce their reliance on the FX swap market to meet USD liquidity needs, leading to fewer USD purchases at the spot leg and a reduction in USD sales forward.*

Periods of elevated synthetic dollar funding costs, such as the Covid-19 pandemic, make FX swaps less attractive due to unfavorable forward pricing (Eguren-Martin et al., 2024). For instance, prior to the swap line announcement, CIP deviations widened for major currency pairs, including USD/GBP, USD/EUR, and USD/JPY, indicating heightened USD scarcity in FX markets.[13]

Swap lines offer an alternative source of USD liquidity with favorable terms and lower balance sheet costs. As discussed earlier, BOE repos are a particularly efficient funding option due to their negligible counterparty risk, zero risk weighting for leverage ratio calculations, and minimal impact on balance sheet constraints. Dealers drawing on the BOE swap line can substitute away from FX swaps, resulting in fewer USD purchases at the spot leg and reduced USD sales at the forward leg of outright forward and swap contracts.

We summarize the implications of these channels for Buy, Sell, and Net USD exposures at the forward leg of outright forward and swap contracts in the table below. Both channels lead to an increase in Net USD exposures, but they operate through different mechanisms. The arbitrage channel increases USD supply in the spot market and raises USD purchases

[13]See Section 3 for more details on CIP deviations during March 2020.

forward, while the substitution channel reduces USD demand in the spot market and decreases USD sales forward.

Hypothesis	Instrument	Buy	Sell	Net
Arbitrage	FX swap and outright forward	(+)	0	(+)
Substitution	FX swap	0	(−)	(+)

3.3.1 Outstanding FX Exposures in March 2020

As a starting point, we plot the gross outstanding FX exposures for different maturities in March 2020 in Figure 4. Panel A reports Buy positions, while panel B reports Sell positions. A Buy position occurs when the dealer buys USD and sells GBP, EUR, or JPY at the forward leg of an FX outright forward or swap contract. Conversely, a Sell position is recorded when the dealer sells USD and buys GBP, EUR, or JPY at the forward leg.

The aggregate gross outstanding Buy and Sell positions are approximately 1.25 trillion USD each day for the EUR/USD pair, and closer to 1 trillion and 0.5 trillion USD each day for the GBP/USD and JPY/USD pairs, respectively. A dotted line marks 18 March 2020, the trade date for the swap line auctions. The key pattern is a decline in gross outstanding positions on 18 March 2020, for dealers trading in all currency pairs. Examining the maturities in Figure 4, we observe that most of the decline in Buy and Sell positions comes from maturities of less than 1 week.

[INSERT FIGURE 4 ABOUT HERE]

Table 5 provides a breakdown of dealer outstanding Buy and Sell exposures by maturity during the period from 17 to 20 March 2020. For exposures with maturities under 1 week, Buy exposures decreased by 218 billion USD, and Sell exposures decreased by 203 billion USD, from 17 March to the average of 18 to 20 March. For maturities between 1 month and 3 months, we observe a 18 billion USD decrease in Buy exposures and a 4 billion USD decrease in Sell exposures. In panel B, we can dis-aggregate total exposures by treated and control dealers. For treated dealers that activated the BOE swap lines on March 18, there was a notable decrease in outstanding Buy and Sell exposures across the 1 week maturity compared to control dealers. Exposures with a maturity less or equal to 7 days saw a decrease of 168 billion USD in Buy exposures and 158 billion USD in Sell exposures. This suggests most of the decline in Buy and Sell exposures for the 1 week maturity is reflected in treated dealer exposures.

[INSERT TABLE 5 ABOUT HERE]

Taken together, the snapshot of outstanding FX exposures during the period from 17 to 20 March supports the substitution channel outlined in Hypothesis H3.2, as evidenced by a decline in gross outstanding Sell exposures, primarily driven by short-term maturities of less than 1 week. This aligns with the pandemic-induced shortage of short-term USD liquidity, and the fact that swap line allotments were largest for the 1-week maturity, followed by the 3-month maturity on 18 March 2020.[14]

Interestingly, we find little support for Hypothesis H3.1, which suggests that dealers would use swap lines to lend USD and engage in arbitrage activities in FX outright forward and swap contracts. Arbitrage would lead to an increase in Buy exposures; however, we observe a decline. Thus, on aggregate, dealers do not report an increase in gross USD forward purchases, indicating they are not using swap lines to conduct arbitrage in FX swap markets.

3.3.2 Long-term Effects on Outstanding FX Exposures

A limitation of our previous analysis is that, by aggregating outstanding FX exposures at the dealer level, we cannot appropriately control for the idiosyncratic hedging demands of counterparties. Therefore, we identify the effect of outstanding FX exposures of dealers that received a swap line relative to dealers that did not, using a similar DiD framework to our analysis based on transaction-level prices.

[14] See Appendix A for more details on BOE swap line amounts.

We measure the outstanding Buy and Sell positions of USD at the forward leg of FX forwards and swap contracts. Outstanding FX derivative exposures are computed at the end of each month from September 2019 to November 2020. We aggregate exposures across all counterparty sectors, including asset managers, (non-dealer) commercial banks, hedge funds, ICPF and LDI, non-financials, and other financial institutions. Our model specification classifies dealers as 'treated' if they drew on the swap line during March, April, or May 2020. Dealers that did not draw on swap lines during this period are classified as 'control'. We aggregate exposures across maturities of less than or equal to 95 days, consistent with swap lines being extended from 1 week to 3 months. Figure 5 plots aggregate Buy, Sell, and Net exposures for each set of dealers with respect to all counterparties. The dotted line indicates March 2020, when the COVID swap lines were activated.

[INSERT FIGURE 5 ABOUT HERE]

In our model specification, we follow Khwaja and Mian (2008) and Cenedese et al. (2021), focusing on a dealer i and counterparty j at the end of month t. The outcome variables include gross outstanding (log) Buy, (log) Sell, and (log) the ratio of Buy to Sell exposures for dealer i and counterparty j in month t. Following Czech et al. (2023), we take the logarithm of Buy and Sell exposures to reduce skewness in the data. The specification we test is shown in equation (5),

$$Y_{i,j,t} = \alpha_{i,j} + \alpha_{j,t} + \gamma D_{swapline,t} + \delta(D_{swapline,t} \times D_{treatment,i}) + \text{controls}_{i,t} + \epsilon_{i,j,t} \tag{5}$$

Where the variable $D_{swapline,t}$ takes a value of 1 during the months of March, April, and May 2020, while $D_{treatment,i}$ is set to 1 for dealers that drew on BOE swap lines during these same months. The primary variable of interest is the interaction term $D_{swapline,t} \times D_{treatment,i}$. Our analysis uses a six-month pre- and post-window around March 2020, resulting in a sample period from September 2019 to September 2020. Similar to our model specification for price effects, we control for idiosyncratic customer demands by including counterparty-dealer and counterparty-time fixed effects, ensuring that the dataset includes only counterparties that trade with multiple dealers. This specification allows us to test how the exposures of a given counterparty differ when trading with a dealer that draws on the swap line versus a dealer that does not. Table 6 presents the results. Columns (I), (III), and (V) examine the effects on gross outstanding FX exposures, including Buy, Sell, and the ratio of Buy to Sell, without including controls. The remaining columns incorporate controls, such as dealer-level balance sheet characteristics like the leverage ratio and the share of risk-weighted assets. Our estimates indicate that, in the absence of controls, both gross Buy and Sell exposures for treated dealers decline significantly by 9.8 and 22.8 percentage points, respectively. However, when controls are added in columns (II) and (IV), we observe a statistically significant decline only in Sell exposures, which drop by 15.3 percentage points.

Columns (V) and (VI) present results using the (log) ratio of Buy to Sell exposures as the outcome variable. We report a statistically significant increase of 11.7 percentage points in the specification that includes controls. These findings support the hypothesis that swap lines play a crucial role in substituting the demand for dollar liquidity in the FX swap market. As institutions draw USD from the BOE via the swap line, they reduce their reliance on USD funding in the FX swap market. This shift results in a decrease in USD spot purchases and USD forward sales through FX swap contracts, which is consistent with our empirical results.

In contrast, we find no evidence to suggest that institutions use swap lines to supply USD spot and buy USD forward, conducting arbitrage activity. Instead, the substitution channel aligns with findings from Kloks et al. (2024b), which document substitution dynamics during quarter-ends, where repo funding replaces FX swaps due to balance sheet cost advantages. Our analysis complements this by demonstrating substitution toward dollar funding via swap lines during systemic stress periods when synthetic dollar funding costs are elevated.

In summary, these findings highlight the critical role of swap lines in alleviating dollar funding pressures and stabilizing global markets during crises. By providing a cost-effective and balance-sheet-efficient alternative to FX swaps, swap lines ensure liquidity flows to institutions facing heightened funding constraints, reducing broader systemic risks.

[INSERT TABLE 6 ABOUT HERE]

4 Conclusion

In this paper, we provide micro-level evidence on the workings of central bank swap lines. To our knowledge, we are the first to use granular, transaction-level data to examine the effects of swap lines on pricing and trading behavior, and to clarify the mechanisms through which swap lines influence demand and supply in the FX swap market.

We combine BOE swap line drawings during the COVID-19 pandemic of 2020 with transaction-level data on FX outright forward and swap contracts. Using this data, we present three key findings on the pricing and trading behavior of market participants during the provision of swap line liquidity.

First, we test the dealer characteristics that determine swap line drawings. Are dealers using it to meet liquidity shortages or as a capital buffer, or are they restricted by collateral quality? We find that capitalization measures like the CET1 ratio and leverage ratio do not predict swap line drawings. Instead, institutions with a lower share of risk-weighted assets and a higher holding of UK government bonds are more likely to draw on the swap line, likely due to the BOE's stringent collateral requirements for swap line liquidity.

Second, we find that swap line drawings reduce pricing inefficiencies in the FX market. Using a DiD model specification, we show that dealers drawing on the swap line offer more favorable forward rates compared to those that do not, consistent with a reduction in CIP violations and improved market efficiency.

Third, we examine whether the observed price effects stem from dealers using swap lines to supply USD for arbitrage, or from a substitution channel, where swap lines serve as an alternative to USD funding via FX contracts. Our results support the latter, with dealers substituting swap lines for USD funding rather than engaging in arbitrage activities.

Our work has several policy implications. We point to collateral requirements as an important factor in determining drawings on swap lines. Swap lines achieve the intended goal of alleviating USD liquidity in FX outright forward and swap contracts through lowering the ceiling on CIP deviations, and can be used as a tool to reduce bank currency exposures and mitigate dollar shortages during financial crises.

Finally, we point to future areas of research. Do swap lines, by alleviating USD liquidity shortages through the substitution channel, lead to increased lending activity in the real economy? Further research using dealer-level swap line data could offer valuable insights into the macroeconomic and financial stability implications, as well as the impact on risk-taking behavior, lending, and the funding of bank balance sheets.

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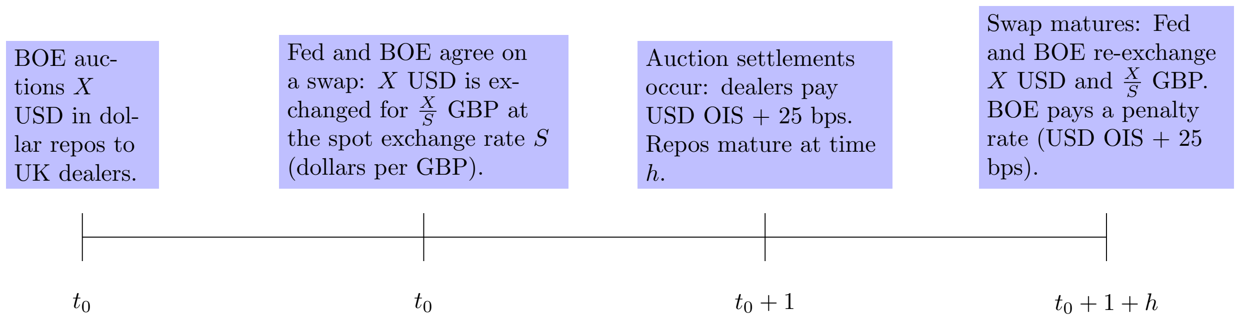
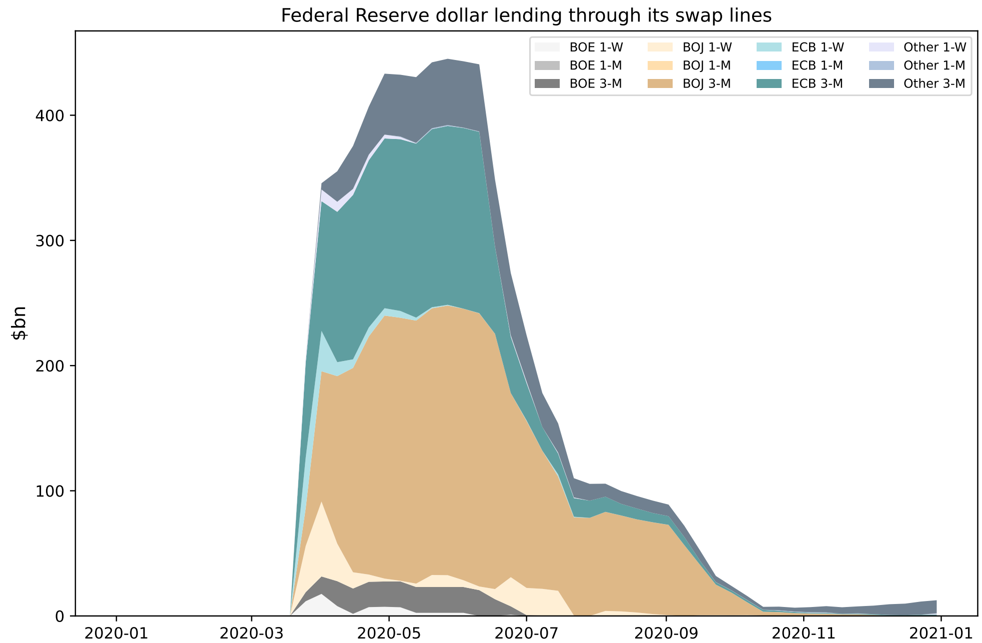
Figures

Figure 1: Swap Line Auctions Timeline



Note: Figure presents timeline of swap line auctions between the Federal Reserve and BOE. 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.

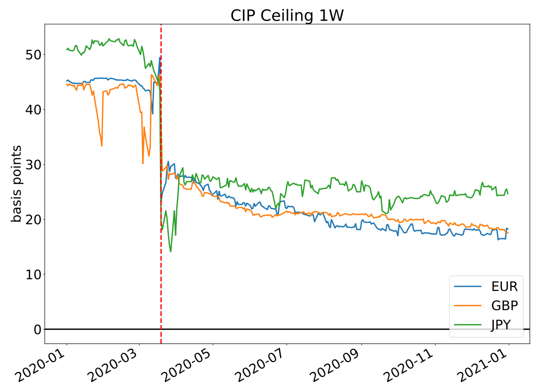
Figure 2: Swap Line Allotments during Covid



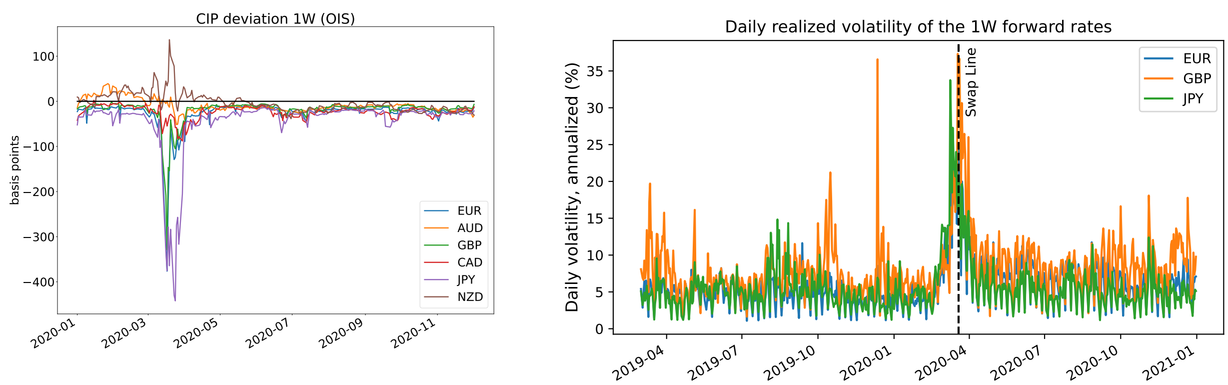
Note: Figure presents outstanding Federal Reserve Swap Lines made to Bank of Japan, Bank of England, European Central Bank and other central banks during 2020. Maturities are 1 week, 1 month and 3 month. Data is taken from the NY Federal Reserve.

Figure 3: 1 Week Maturity: CIP Deviations and Forward Rate Volatility during Covid

Panel A: CIP Ceiling Test



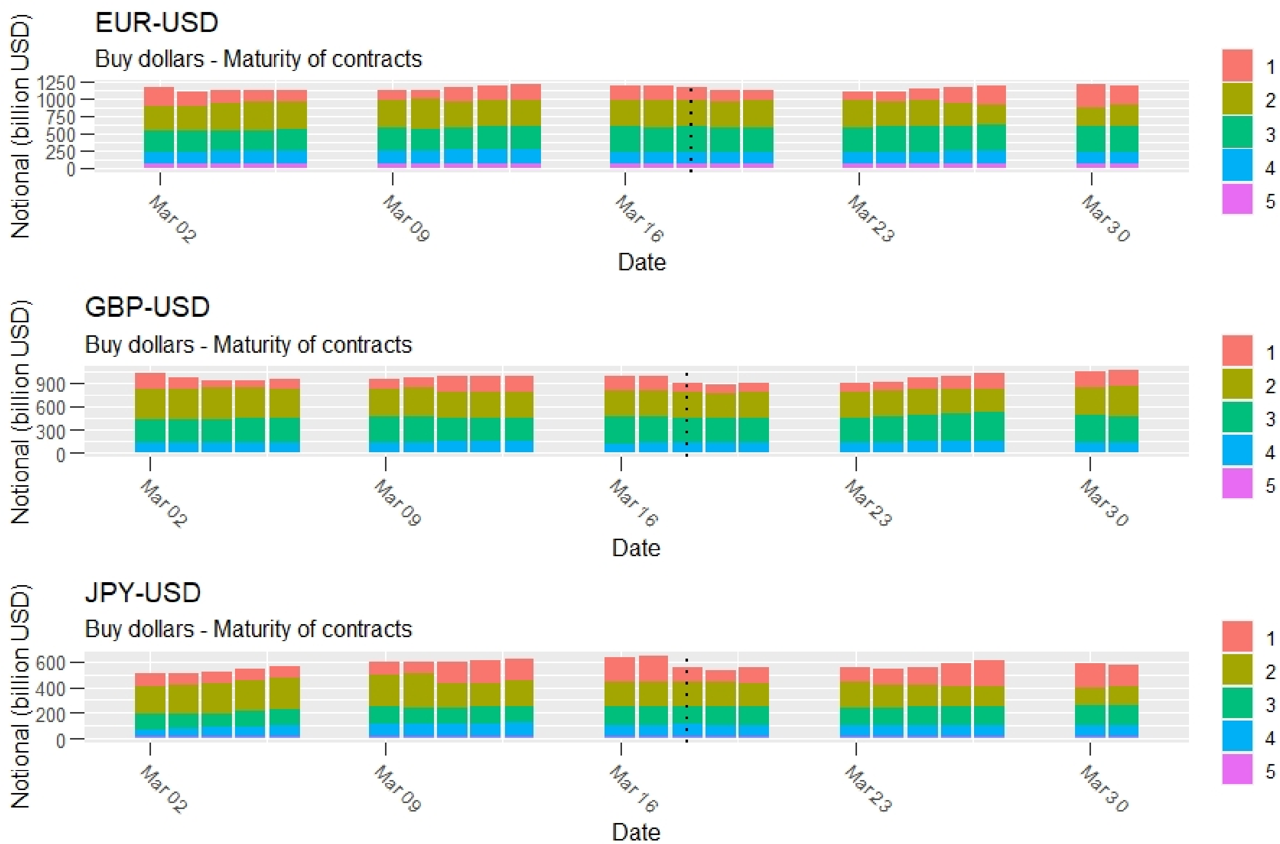
Panel B: Price and Volatility Effects



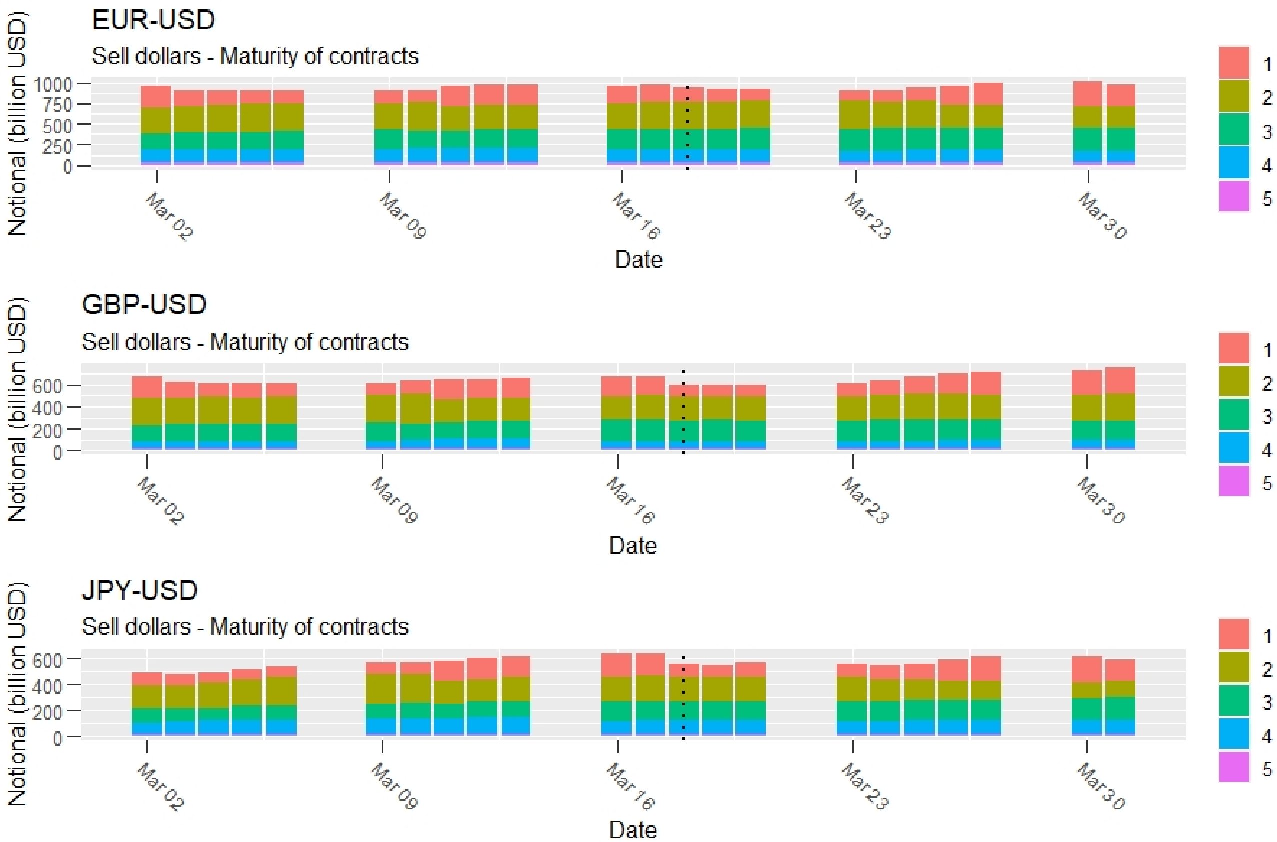
Note: The Figure presents data for CIP deviations at the 1 week maturity during the Covid period. Panel A shows the ceiling on CIP deviations for advanced economies. Panel B shows CIP deviations (benchmark OIS rate) for a set of advanced economies, and daily realized volatility of the EUR/USD, GBP/USD, and JPY/USD forward rate. The data is daily and covers the year 2020. Sources include Bloomberg and Thomson Reuters tick history.

Figure 4: Outstanding FX Exposures (Gross Notional) by Maturity: Buy USD (Panel A) and Sell USD (Panel B)

Panel A: Buy Exposures

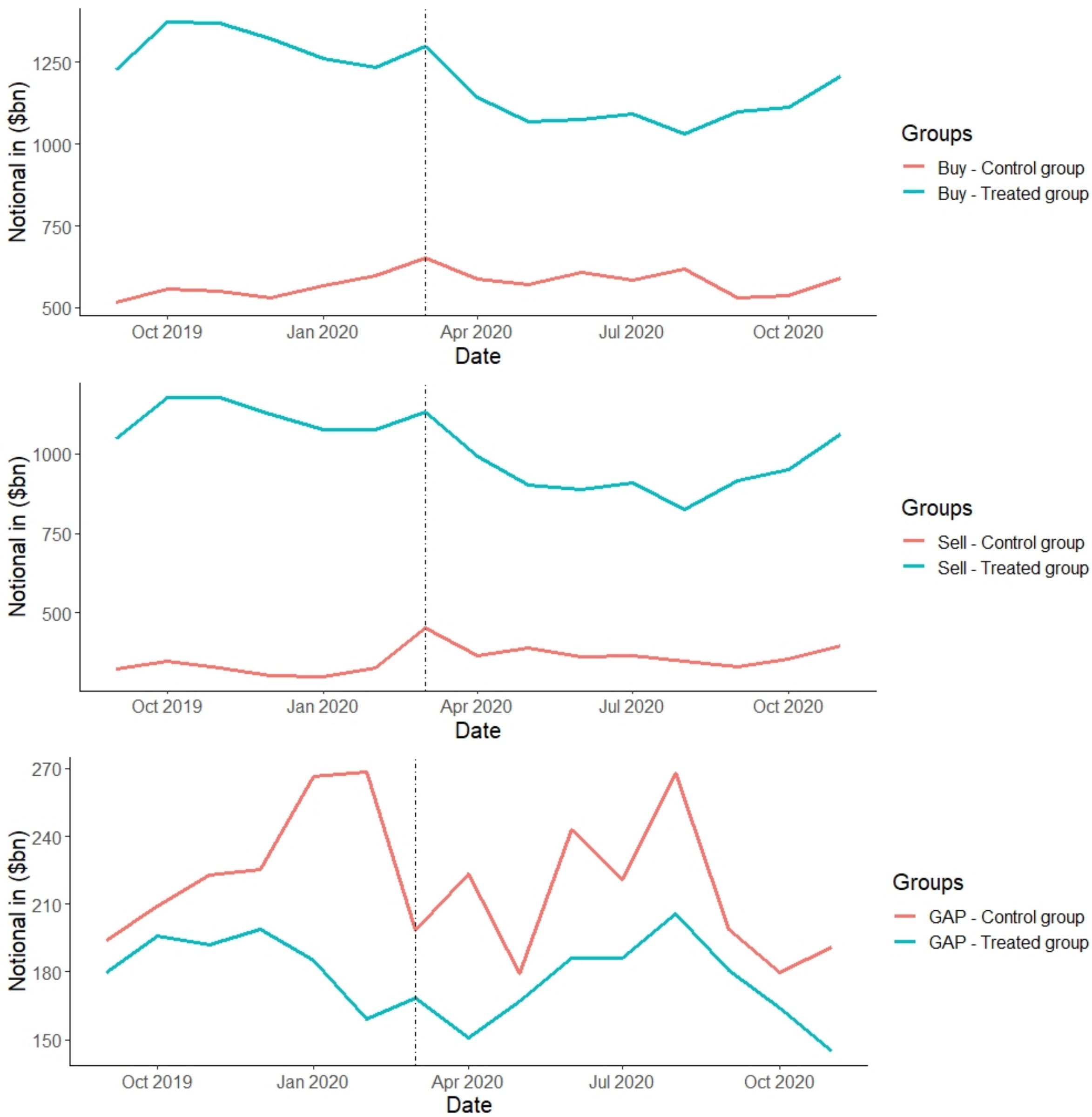


Panel B: Sell Exposures



Note: The 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 than 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. Outstanding FX exposures are aggregated across all maturities and are the outstanding notional positions at the end of each day. Panel A shows outstanding notional positions in which dealers buy USD and sell EUR, GBP, and JPY at the forward leg. Panel B shows outstanding notional positions in which dealers sell USD and buy EUR, GBP, and JPY at the forward leg. The sample period is from 1 March to 31 March 2020. The dotted line indicates 18 March 2020, the date when Covid swap lines were first announced.

Figure 5: Dealer Outstanding FX Exposures: All Counterparties



Note: Figure presents aggregate Buy, Sell and Net FX exposures for dealers with respect to all (non-dealer) counterparty sectors: this includes asset managers, (non-dealer) commercial banks, hedge funds, ICPF and LDI, non-financial and other financial. Dealers that have drawn on BOE swap lines are classified as 'treated', and the set of dealers that did not draw on BOE swap lines are 'control'. Outstanding FX exposures at a maturities less than or equal to 95 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 Balance Sheet Variables

	count	mean	std	min	25%	50%	75%	max
Total Assets (USD Billion)	496	1344.3	797.3	182.3	725.7	1101.3	1900.3	3386.1
$\frac{Loan}{Asset}$	496	0.43	0.16	0.08	0.33	0.40	0.52	0.81
$\frac{RWA}{Asset}$	496	0.36	0.13	0.12	0.27	0.35	0.47	0.65
$\text{distance}_{\text{CET1 Ratio}}$ (%)	496	9.48	3.97	5.88	7.31	8.30	10.20	30.00
$\text{distance}_{\text{Leverage Ratio}}$ (%)	496	2.14	1.05	0.90	1.40	1.90	2.55	8.40

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

Table 3: Determinants of Swap Line Drawings

	I	II	III	IV
	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$	$\mathbb{D}_{\text{treat}}$
$\text{distance}_{\text{CET1 Ratio}}$	0.169			
	(0.165)			
$\text{distance}_{\text{Leverage Ratio}}$		0.675		
		(0.192)		
$\frac{RWA}{Assets}$			-5.284**	
			(0.017)	
UK Government Bonds				0.0002*
				(0.079)
constant	-1.704	-1.316	1.633**	-0.815
	(0.121)	(0.138)	(0.047)	(0.133)
N	36	36	36	19

Note: The table presents estimates from a panel probit specification to test the determinants of drawings on BoE repos. Outcome variables D_{treat} is a dummy variable for dealers that activated the BoE dollar repo in March or April 2020. Explanatory variables include the distance from the leverage ratio and CET1 ratio, and the share of risk-weighted assets. All balance sheet variables are taken from March and April 2020. UK government bonds held by dealers is defined as UK central or regional government, local authority or public sector entity assets, and are denominated in GBP Million. 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 4: Transaction-Level CIP Deviations for EUR/USD, GBP/USD and JPY/USD: All Counterparties

	I	II	III	IV	V	VI
	EUR 1W	GBP 1W	JPY 1W	EUR 3M	GBP 3M	JPY 3M
$D_{treat} \times D_{03/18}$	111.614***	-55.729	7.391	4.034	22.293***	13.656*
	(13.876)	(36.863)	(19.257)	(11.748)	(4.832)	(7.721)
$D_{treat} \times D_{03/19}$	56.329***	20.851		-2.898	18.864**	-4.043
	(17.752)	(45.369)		(7.235)	(9.255)	(8.256)
$D_{treat} \times D_{03/20}$				-2.776	16.828*	14.305
				(10.198)	(9.086)	(15.071)
constant	-91.051***	-93.888***	-25.527***	-132.182***	-104.727***	-202.634***
	(3.966)	(8.274)	(2.187)	(2.053)	(2.217)	(2.488)
R^2	0.267	0.194	0.199	0.328	0.226	0.473
N	1034	567	590	2155	1383	1097

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. Transactions are between dealers and all counterparty sectors: asset managers, commercial banks, hedge funds, ICPF and LDI, non-financial and other financial. Outcome variables include individual currency CIP deviations measured using transaction level data at the dealer-counterparty level. For columns (I) to (III), the maturity is 5 days, which corresponds to a 1 week forward or FX swap contract. For columns (IV) to (VI), the maturity is 85-95 days, which corresponds to the 3 month maturity. 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 March 18, 19 and 20 respectively. March 18 corresponds to the day in which the Federal Reserve announced the swap line auctions, which is known as the trade date, and March 19 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. Missing coefficients in columns (I), (II) and (III) are due to small sample selection and insufficient data on 1W forward contracts for the select dealer-counterparty pairs.

Table 5: Buy and Sell Exposures by Maturity: 17th-20th March 2020

Panel A: Maturity - All Dealers

	Buy			Sell		
	17 March	18-20 March	Δ	17 March	18-20 March	Δ
≤ 7 days	\$606B	\$389B	-\$218B	\$575B	\$372B	-\$203B
≥ 8 days ≤ 30 days	\$912B	\$906B	-\$6B	\$738B	\$741B	\$3B
≥ 31 days ≤ 90 days	\$837B	\$819B	-\$18B	\$592B	\$587B	-\$4B
≥ 91 days ≤ 360 days	\$393B	\$402B	\$9B	\$333B	\$337B	\$4B
> 360 days	\$71.8B	\$71.4B	-\$0.4B	\$56.9B	\$57.2B	\$0.3B

Panel B: Maturity Treated minus Control

	Buy			Sell		
	17 March	18-20 March	Δ	17 March	18-20 March	Δ
≤ 7 days	\$365B	\$197B	-\$168B	\$323B	\$164B	-\$158B
≥ 8 days ≤ 30 days	\$382B	\$380B	-\$2B	\$359B	\$351B	-\$9B
≥ 31 days ≤ 90 days	\$335B	\$335.4B	-\$0.4B	\$350B	\$346B	-\$4B
≥ 91 days ≤ 360 days	\$178.7B	\$178.5B	-\$0.2B	\$187B	\$188B	\$2B
> 360 days	\$30.1B	\$30B	-\$0.1B	\$10.5B	\$10.6B	\$0.1B

Note: This table reports Buy and Sell exposures by maturity, aggregated across all counterparty sectors, including asset managers, commercial banks, hedge funds, ICPF and LDI, non-financial entities, and other financial institutions. Data are presented for March 17 and the average over March 18-20. March 18 marks the trade date when the Federal Reserve announced the swap line auctions, while March 19 is the settlement date. The difference, Δ, is calculated as the change in exposures between March 18-20 and March 17 for each counterparty sector. Panel A displays the aggregate Buy and Sell exposures for all dealers. Panel B shows the aggregate Buy and Sell exposures for treated dealers minus control dealers. Treated dealers are defined as those that activated the BOE dollar repo on March 18, 2020.

Table 6: Dealer FX Exposures for Maturities ≤ 95 Days: All Counterparties

	I	II	III	IV	V	VI
	Buy	Buy	Sell	Sell	$\frac{Buy}{Sell}$	$\frac{Buy}{Sell}$
D_{treat}	0.126***	0.449***	0.287***	0.798***	-0.026	-0.179***
	(0.046)	(0.069)	(0.056)	(0.080)	(0.041)	(0.068)
$D_{swap\ line} \times D_{treat}$	-0.098**	-0.031	-0.228***	-0.153***	0.130**	0.117**
	(0.044)	(0.044)	(0.051)	(0.050)	(0.058)	(0.058)
$\frac{RWA}{Assets}$		2.572***		2.803***		-0.169
		(0.199)		(0.198)		(0.199)
$\text{distance}_{\text{CET1 Ratio}}$		0.116***		0.061***		0.055***
		(0.015)		(0.017)		(0.013)
$\text{distance}_{\text{Leverage Ratio}}$		-0.275***		-0.295***		-0.014
		(0.027)		(0.030)		(0.027)
constant	3.165***	1.452***	2.775***	1.435***	0.394***	0.044
	(0.023)	(0.157)	(0.028)	(0.164)	(0.020)	(0.137)
R^2	0.640	0.653	0.669	0.682	0.414	0.415
N	58187	58181	44981	44981	32830	32830

Note: This table estimates a difference-in-differences specification to examine the effects of swap lines on FX exposures. The analysis aggregates GBP/USD, EUR/USD, and JPY/USD FX swaps with maturities of 95 days or less. Outcome variables include the (log) Buy, (log) Sell, and (log) Ratio of FX exposures for dealers with respect to all (non-dealer) counterparty sectors: asset managers, commercial banks, hedge funds, ICPF and LDI, non-financial entities, and other financial entities. D_{treat} is a dummy variable for dealers that activated the BOE dollar repo. $D_{swapline}$ is a dummy variable for March, April, and May 2020, when the BOE repo lines were drawn. Controls include the distance to leverage ratio and CET1 requirements, as well as the ratio of risk-weighted assets to total assets. The sample is monthly from September 2019 to November 2020. White heteroscedasticity-robust standard errors are reported in parentheses, clustered at the dealer-counterparty level. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

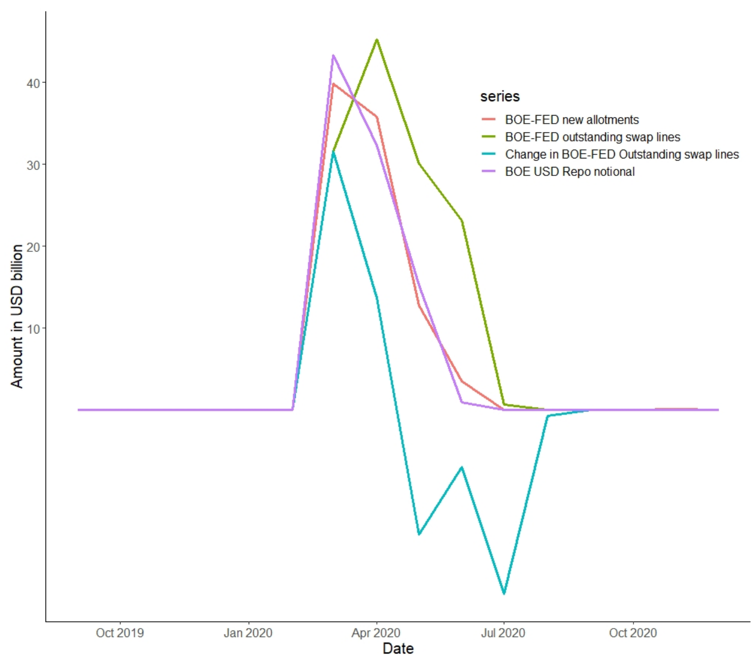
Online Appendix to

"Central Bank Swap Lines: Micro-Level Evidence"

Appendix A: Swap Line Drawings

To validate the accuracy of the BOE swap line data used in our analysis, we construct an aggregate measure of the total USD repo auctions conducted by the BOE across all dealers and maturities. This measure should align with the outstanding swap line allotments between the Federal Reserve and the BOE.

Figure A1: Validation of BOE Swap Line Drawings Using NY Fed Data



Note: The figure compares two measures of USD swap line usage by the BOE. The first measure, labeled "BOE USD Repo Notional," aggregates the notional amounts of USD repos auctioned by the BOE to dealers across all maturities. The second measure is based on publicly available data from the New York Federal Reserve, which reports the total swap line allotments to the BOE. The first differences of the NY Federal Reserve data are included to show changes in outstanding swap line allotments. Data are aggregated for 1-week, 1-month, and 3-month swaps at a monthly frequency.

Figure A1 illustrates the comparison between the BOE's reported USD repo auctions and the Federal Reserve's publicly available data on swap line allotments to the BOE. The "BOE USD Repo Notional" represents the aggregate USD amounts bid at BOE dealer auctions, while the Federal Reserve data provide an independent measure of swap line usage. The close alignment between the two measures validates the consistency of the confidential BOE data with publicly available Federal Reserve data.

Tables A1, A2, and A3 provide details of the swap line allotments for the BOE, ECB and BOJ respectively. Each table includes the trade date, settlement date, maturity date, term (in days), amount (in USD million), and interest rate. The interest rate reflects the standard swap line terms, typically 25 basis points above the USD OIS rate.

Table A1: Central Bank Swap Lines Allotments to the Bank of England

Counterparty	Trade Date	Settlement Date	Maturity Date	Term (Days)	Amount (USD mil)	Interest Rate (%)
Bank of England	03/18/2020	03/19/2020	06/11/2020	84	7245.00	0.38
Bank of England	03/18/2020	03/19/2020	03/26/2020	7	8210.00	0.45
Bank of England	03/23/2020	03/24/2020	03/31/2020	7	5.00	0.38
Bank of England	03/24/2020	03/25/2020	04/01/2020	7	3555.00	0.38
Bank of England	03/25/2020	03/26/2020	06/18/2020	84	6685.00	0.35
Bank of England	03/25/2020	03/26/2020	04/02/2020	7	7705.00	0.36
Bank of England	03/26/2020	03/27/2020	04/03/2020	7	905.00	0.34
Bank of England	03/27/2020	03/30/2020	04/06/2020	7	500.00	0.32
Bank of England	03/30/2020	03/31/2020	04/07/2020	7	5005.00	0.32
Bank of England	03/31/2020	04/01/2020	04/08/2020	7	3505.00	0.33
Bank of England	04/01/2020	04/02/2020	06/25/2020	84	6000.00	0.32
Bank of England	04/01/2020	04/02/2020	04/09/2020	7	7850.00	0.32
Bank of England	04/06/2020	04/07/2020	04/14/2020	7	5.00	0.31
Bank of England	04/08/2020	04/09/2020	07/02/2020	84	300.00	0.33
Bank of England	04/08/2020	04/09/2020	04/16/2020	7	1700.00	0.30
Bank of England	04/09/2020	04/14/2020	04/21/2020	7	5.00	0.31
Bank of England	04/15/2020	04/16/2020	04/23/2020	7	2045.00	0.30
Bank of England	04/17/2020	04/20/2020	04/27/2020	7	5000.00	0.30
Bank of England	04/20/2020	04/21/2020	04/28/2020	7	5.00	0.30
Bank of England	04/22/2020	04/23/2020	04/30/2020	7	2045.00	0.29
Bank of England	04/24/2020	04/27/2020	05/04/2020	7	5250.00	0.31
Bank of England	04/27/2020	04/28/2020	05/05/2020	7	15.00	0.32
Bank of England	04/28/2020	04/29/2020	05/06/2020	7	5.00	0.32
Bank of England	04/29/2020	04/30/2020	07/23/2020	84	395.00	0.32
Bank of England	04/29/2020	04/30/2020	05/07/2020	7	1700.00	0.32
Bank of England	05/04/2020	05/05/2020	05/12/2020	7	5255.00	0.30
Bank of England	05/11/2020	05/12/2020	05/19/2020	7	2500.00	0.30
Bank of England	05/18/2020	05/19/2020	05/26/2020	7	2500.00	0.30
Bank of England	05/22/2020	05/26/2020	06/02/2020	7	2500.00	0.30
Bank of England	05/29/2020	06/02/2020	06/09/2020	7	2500.00	0.30

Table A2: Summary of Swap Line Allotments to the European Central Bank

Counterparty	Trade Date	Settlement Date	Maturity Date	Term (Days)	Amount (USD mil)	Interest Rate (%)
European Central Bank	03/04/2020	03/05/2020	03/12/2020	7	58.00	1.58
European Central Bank	03/11/2020	03/12/2020	03/19/2020	7	45.00	1.24
European Central Bank	03/18/2020	03/19/2020	03/26/2020	7	36265.00	0.45
European Central Bank	03/18/2020	03/19/2020	06/11/2020	84	75820.00	0.38
European Central Bank	03/23/2020	03/24/2020	03/31/2020	7	20.00	0.38
European Central Bank	03/24/2020	03/25/2020	04/01/2020	7	4115.00	0.38
European Central Bank	03/25/2020	03/26/2020	04/02/2020	7	17267.00	0.36
European Central Bank	03/25/2020	03/26/2020	06/18/2020	84	27810.00	0.35
European Central Bank	03/26/2020	03/27/2020	04/03/2020	7	3205.00	0.34
European Central Bank	03/27/2020	03/30/2020	04/06/2020	7	2165.00	0.32
European Central Bank	03/30/2020	03/31/2020	04/07/2020	7	6650.00	0.32
European Central Bank	03/31/2020	04/01/2020	04/08/2020	7	2950.00	0.33
European Central Bank	04/01/2020	04/02/2020	04/09/2020	7	6850.20	0.32
European Central Bank	04/01/2020	04/02/2020	06/25/2020	84	16468.00	0.32
European Central Bank	04/02/2020	04/03/2020	04/09/2020	6	925.00	0.32
European Central Bank	04/03/2020	04/06/2020	04/14/2020	8	165.00	0.32
European Central Bank	04/06/2020	04/07/2020	04/14/2020	7	2270.00	0.31
European Central Bank	04/07/2020	04/08/2020	04/15/2020	7	943.00	0.30
European Central Bank	04/08/2020	04/09/2020	04/16/2020	7	5922.30	0.30
European Central Bank	04/08/2020	04/09/2020	07/02/2020	84	11230.70	0.33
European Central Bank	04/09/2020	04/14/2020	04/21/2020	7	463.00	0.31
European Central Bank	04/14/2020	04/15/2020	04/22/2020	7	485.00	0.31
European Central Bank	04/15/2020	04/16/2020	07/09/2020	84	2260.20	0.33
European Central Bank	04/15/2020	04/16/2020	04/23/2020	7	4805.50	0.30
European Central Bank	04/16/2020	04/17/2020	04/24/2020	7	440.00	0.30
European Central Bank	04/17/2020	04/20/2020	04/27/2020	7	205.00	0.30
European Central Bank	04/20/2020	04/21/2020	04/28/2020	7	1740.00	0.30
European Central Bank	04/22/2020	04/23/2020	07/16/2020	84	2003.00	0.32
European Central Bank	04/22/2020	04/23/2020	04/30/2020	7	3814.00	0.29
European Central Bank	04/23/2020	04/24/2020	05/04/2020	10	920.00	0.30
European Central Bank	04/24/2020	04/27/2020	05/04/2020	7	200.00	0.31
European Central Bank	04/27/2020	04/28/2020	05/05/2020	7	1868.00	0.32
European Central Bank	04/29/2020	04/30/2020	07/23/2020	84	1610.00	0.32
European Central Bank	04/29/2020	04/30/2020	05/07/2020	7	3005.30	0.32
European Central Bank	04/30/2020	05/04/2020	05/11/2020	7	500.00	0.29
European Central Bank	05/04/2020	05/05/2020	05/12/2020	7	1721.30	0.30
European Central Bank	05/05/2020	05/06/2020	05/13/2020	7	200.00	0.29
European Central Bank	05/06/2020	05/07/2020	07/30/2020	84	1795.00	0.29
European Central Bank	05/06/2020	05/07/2020	05/14/2020	7	2291.50	0.30
European Central Bank	05/07/2020	05/11/2020	05/18/2020	7	5.00	0.30
European Central Bank	05/11/2020	05/12/2020	05/19/2020	7	76.30	0.30
European Central Bank	05/13/2020	05/14/2020	05/22/2020	8	791.60	0.31
European Central Bank	05/13/2020	05/14/2020	08/06/2020	84	3245.00	0.30
European Central Bank	05/15/2020	05/18/2020	05/26/2020	8	10.00	0.30
European Central Bank	05/18/2020	05/19/2020	05/26/2020	7	94.30	0.30
European Central Bank	05/20/2020	05/22/2020	05/28/2020	6	442.00	0.31
European Central Bank	05/20/2020	05/22/2020	08/13/2020	83	600.00	0.31
European Central Bank	05/22/2020	05/26/2020	06/02/2020	7	184.00	0.30
European Central Bank	05/27/2020	05/28/2020	06/04/2020	7	50.50	0.30
European Central Bank	05/27/2020	05/28/2020	08/20/2020	84	1510.00	0.30
European Central Bank	05/29/2020	06/02/2020	06/09/2020	7	5.00	0.30

Table A3: Summary of Swap Line Allotments to the Bank of Japan

Counterparty	Trade Date	Settlement Date	Maturity Date	Term (Days)	Amount (USD mil)	Interest Rate (%)
Bank of Japan	03/17/2020	03/19/2020	03/26/2020	7	2053.00	0.41
Bank of Japan	03/17/2020	03/19/2020	06/11/2020	84	30272.00	0.37
Bank of Japan	03/23/2020	03/25/2020	04/01/2020	7	34850.00	0.38
Bank of Japan	03/24/2020	03/26/2020	04/02/2020	7	15465.00	0.36
Bank of Japan	03/24/2020	03/26/2020	06/18/2020	84	73805.00	0.35
Bank of Japan	03/25/2020	03/27/2020	04/03/2020	7	4950.00	0.34
Bank of Japan	03/26/2020	03/30/2020	04/06/2020	7	2265.00	0.32
Bank of Japan	03/27/2020	03/31/2020	04/07/2020	7	13100.00	0.34
Bank of Japan	03/30/2020	04/01/2020	04/08/2020	7	24100.00	0.32
Bank of Japan	03/31/2020	04/02/2020	04/09/2020	7	9285.00	0.32
Bank of Japan	03/31/2020	04/02/2020	06/25/2020	84	29724.00	0.32
Bank of Japan	04/01/2020	04/03/2020	04/10/2020	7	950.00	0.32
Bank of Japan	04/02/2020	04/06/2020	04/13/2020	7	1135.00	0.32
Bank of Japan	04/03/2020	04/07/2020	04/14/2020	7	5750.00	0.32
Bank of Japan	04/06/2020	04/08/2020	04/15/2020	7	12880.00	0.31
Bank of Japan	04/07/2020	04/09/2020	04/16/2020	7	9360.00	0.30
Bank of Japan	04/07/2020	04/09/2020	07/02/2020	84	29442.00	0.33
Bank of Japan	04/08/2020	04/10/2020	04/17/2020	7	1080.00	0.30
Bank of Japan	04/09/2020	04/13/2020	04/20/2020	7	998.00	0.31
Bank of Japan	04/10/2020	04/14/2020	04/21/2020	7	600.00	0.30
Bank of Japan	04/13/2020	04/15/2020	04/22/2020	7	931.00	0.30
Bank of Japan	04/14/2020	04/16/2020	04/23/2020	7	2210.00	0.31
Bank of Japan	04/14/2020	04/16/2020	07/09/2020	84	26958.00	0.33
Bank of Japan	04/15/2020	04/17/2020	04/24/2020	7	1260.00	0.30
Bank of Japan	04/16/2020	04/20/2020	04/27/2020	7	664.00	0.30
Bank of Japan	04/17/2020	04/21/2020	04/28/2020	7	640.00	0.30
Bank of Japan	04/20/2020	04/22/2020	04/30/2020	8	1020.00	0.30
Bank of Japan	04/21/2020	04/23/2020	04/30/2020	7	1290.00	0.30
Bank of Japan	04/21/2020	04/23/2020	07/16/2020	84	19903.00	0.32
Bank of Japan	04/22/2020	04/24/2020	05/07/2020	13	971.00	0.31
Bank of Japan	04/23/2020	04/27/2020	05/07/2020	10	722.00	0.30
Bank of Japan	04/24/2020	04/28/2020	05/07/2020	9	310.00	0.31
Bank of Japan	04/27/2020	04/30/2020	05/07/2020	7	541.00	0.32
Bank of Japan	04/28/2020	04/30/2020	07/16/2020	77	1016.00	0.33
Bank of Japan	04/28/2020	04/30/2020	05/14/2020	14	6670.00	0.32
Bank of Japan	04/30/2020	05/07/2020	05/14/2020	7	2042.00	0.29
Bank of Japan	05/07/2020	05/11/2020	05/18/2020	7	400.00	0.30
Bank of Japan	05/08/2020	05/12/2020	05/19/2020	7	200.00	0.30
Bank of Japan	05/11/2020	05/13/2020	05/20/2020	7	86.00	0.30
Bank of Japan	05/12/2020	05/14/2020	08/06/2020	84	2890.00	0.30
Bank of Japan	05/12/2020	05/14/2020	05/21/2020	7	9489.00	0.31
Bank of Japan	05/18/2020	05/20/2020	05/27/2020	7	118.00	0.30
Bank of Japan	05/19/2020	05/21/2020	08/13/2020	84	2373.00	0.31
Bank of Japan	05/19/2020	05/21/2020	05/28/2020	7	9292.00	0.31
Bank of Japan	05/22/2020	05/27/2020	06/03/2020	7	164.00	0.30
Bank of Japan	05/26/2020	05/28/2020	06/04/2020	7	5250.00	0.30
Bank of Japan	05/27/2020	05/29/2020	08/20/2020	83	1501.00	0.30

Appendix B: Motivating Evidence using Benchmark Rates

B.1 Ceiling Test

Bahaj and Reis (2022a, 2020) establish a no-arbitrage condition, demonstrating that CIP deviations are determined by the discount rate on USD borrowings from the Federal Reserve. They consider a scenario where a dealer borrows USD via the BOE swap line, uses the borrowed dollars in the FX swap market to exchange USD for GBP, and invests the GBP at the BOE excess reserve rate, denoted as $i^{GBP}_{reserve}$. The duration of the loan matches the swap auction maturity, which may be one week, one month, or three months. To hedge against interest rate risk the dealer enters into an OIS contract. The associated cost equals the spread between the OIS rate and the interbank (LIBOR) rate, expressed as $i^{GBP}_{ois} - i^{GBP}_{interbank}$. The dealer's net profit, Π, is given by:

$$\Pi = f - s + i^{GBP}_{reserve} + i^{GBP}_{ois} - i^{GBP}_{interbank} - i_{swapline} \tag{6}$$

The swap line interest rate is defined as $i_{swapline} = i^{USD}_{ois} + \delta$, where δ represents the penalty rate for borrowing. By defining the CIP deviation based on OIS interest rates as $x_{ois} = f - s + i^{GBP}_{ois} - i^{USD}_{ois}$, the dealer's arbitrage profit can be rewritten as:

$$\Pi = x_{ois} - \delta + i^{GBP}_{reserve} - i^{GBP}_{interbank} \tag{7}$$

This formulation implies that the penalty on the swap line interest rate sets an upper limit on CIP deviations. Under no-arbitrage conditions, $\Pi \leq 0$, leading to the following ceiling equation:

$$x_{ois} \leq \delta + i^{GBP}_{interbank} - i^{GBP}_{reserve} \tag{8}$$

The ceiling is determined by two factors: the Federal Reserve's penalty rate and frictions in interbank markets. A lower penalty rate reduces the ceiling on CIP deviations, holding other factors constant. Conversely, higher costs of hedging against interest rate risk, captured by the spread between the interbank rate and the reserve rate, increase the ceiling.

We test this hypothesis using a probit specification shown in equation (9), where $x_{i,j,t}$ represents the CIP deviation for currency i and maturity j, and $Post_t$ is a dummy variable equal to 1 from 19 March 2020, the first settlement day following the Federal Reserve's swap policy announcement. Using the OIS rate as a benchmark, we test for ceiling violations in EUR/USD, GBP/USD, and JPY/USD at swap line maturities of 1 week, 1 month, and 3 months. The outcome variable is a dummy that equals 1 if the CIP deviation exceeds the ceiling threshold, with the penalty rate set at $\delta = 25$ basis points. For interbank rates, we use the LIBOR reference rate for each maturity, and for reserve remuneration rates, we use the BOE bank rate, the ECB deposit facility rate, and the BOJ policy rate.

$$\mathbb{1}[|x_{i,j,t}| > 25bp + i^{i}_{interbank} - i^{i}_{reserve}] = \beta Post_t + \epsilon_{i,j,t} \tag{9}$$

The results, presented in Table A4, show that the probability of ceiling violations decreases following the reduction in the penalty rate across currency pairs and maturities. The largest declines are observed for EUR/USD and JPY/USD at 1-week and 1-month maturities, suggesting that swap lines effectively reduce mispricing in the FX market. However, limited evidence of a reduction in 3-month JPY/USD CIP deviations indicates potential limits to arbitrage at longer maturities, possibly due to increased hedging demand by non-financial counterparties in JPY/USD FX markets.

Table A4: 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)
N	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 19 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 1 2020 to November 20 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.

B.2 DiD Specification

While we have shown the Federal Reserve 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 (10), 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. (2021), we use controls of the first differences in the VIX and the difference in OIS interest rates between the foreign currency and USD. In addition, we use the change in the broad USD index based on Avdjiev et al. (2019), which is connected to CIP deviations through bank leverage according to Bruno and Shin (2015). Changes in the bid-ask spread are indicators of illiquidity and volatility in foreign exchange markets. The final determinant of CIP deviations that we use is the intermediary capital ratio factor utilized 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 intermediary capital ratio factor utilized are in first-differences.

$$\Delta x_{i,t} = \alpha_i + \alpha_c + \beta \times Post_t \times SwapLine_i + controls_{i,t} + \epsilon_{i,t} \tag{10}$$

Table A5 reports the results. With controls, the DiD coefficient estimates a statistically significant net reduction in synthetic funding costs of 12.98 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 billion USD. A 1 billion USD increase in swap line allotments reduces the spread between synthetic and direct USD funding costs by 0.48 basis points. This is economically significant: aggregate swap line allotments reached a peak of approximately 142 billion USD for EUR/USD, 196 billion USD for JPY/USD and 38 billion USD for GBP/USD. Using our coefficient estimate of 0.486 or the effect of allotments on the change in CIP deviations, our results would attribute a narrowing of CIP deviations by approximately 70 basis points for the EUR/USD, 100 basis points for the JPY/USD pair and 20 basis points for the GBP/USD pair.

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 USD borrowing costs, and therefore choose not to draw on the swap line for USD funding. Instead, we can compare CIP deviations involving the EUR, GBP, and JPY to currencies that experienced an increase in CIP deviations vis-a-vis the USD during the pandemic but were not supported by swap line arrangements. We find our results are robust to using an alternative control group, the DKK and SEK. Table A6 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 19 March 2020, which could be problematic due to a number of confounding events during the pandemic. In Table A7, we run placebo tests using alternative treatment dates, February 1, 2020 and May 1, 2020, and find insignificant treatment effects using these dates. Finally, we test long-term maturities of 1 year, 5 year and 10 year. Consistent with swap lines providing USD at 1 week to 3 month, we find a significantly smaller magnitude of treatment effects on longer-term maturities.

Table A5: Panel Differences-in-Differences Specification: CIP Deviations (OIS)

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
$\text{Swapline}_i \times \text{Post}_t$	13.675**	12.982**		
	(3.821)	(3.514)		
$\text{Allotment}_{i,t} \times \text{Post}_t$			0.486***	0.475***
			(0.120)	(0.089)
Post_t	-0.895	-5.484**	7.760*	2.702
	(1.286)	(1.599)	(3.537)	(2.167)
$\Delta\ (i - i_{us})$		-0.715***		-0.725***
		(0.170)		(0.175)
Δ log(broad dollar)		-4.583*		-4.449**
		(1.981)		(1.658)
Δ log(VIX)		-0.279**		-0.277**
		(0.083)		(0.083)
Δ fwd bid-ask		0.558		0.266
		(2.287)		(2.138)
HKM		-107.912**		-109.979**
		(30.834)		(30.514)
constant	-4.444**	-0.206	-4.444*	-0.219
	(1.218)	(0.797)	(1.767)	(0.689)
R^2	0.03	0.09	0.03	0.08
N	756	756	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. Controls include daily first differences in the broad dollar index (expressed in percentage), the VIX index (expressed in percentage), the difference in overnight indexed swap (OIS) interest rates between the foreign currency and USD (expressed in basis points), 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. Estimation period is a 1 month pre and post the swap line settlement date of March 19, 2020.

Table A6: Panel Differences-in-Differences Specification: CIP Deviations (OIS): Alternative Control Group with DKK and SEK Currencies

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
$\text{Swapline}_i \times \text{Post}_t$	3.032	3.519		
	(4.009)	(3.230)		
$\text{Allotment}_{i,t} \times \text{Post}_t$			0.453**	0.443***
			(0.116)	(0.083)
Post_t	9.748***	1.902	11.337***	3.939**
	(1.770)	(1.791)	(2.312)	(1.330)
$\Delta\,(i - i_{us})$		-0.862***		-0.856***
		(0.124)		(0.121)
Δ log(broad dollar)		-6.280**		-6.106**
		(1.903)		(1.588)
Δ log(VIX)		-0.407***		-0.409***
		(0.066)		(0.066)
Δ fwd bid-ask		0.066		0.076
		(0.133)		(0.138)
HKM		-143.883***		-144.554***
		(27.068)		(26.156)
constant	-6.312***	0.161	-6.312***	0.058
	(1.235)	(0.433)	(1.166)	(0.602)
R^2	0.03	0.10	0.04	0.10
N	756	756	756	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. Controls include daily first differences in the broad dollar index (expressed in percentage), the VIX index (expressed in percentage), the difference in overnight indexed swap (OIS) interest rates between the foreign currency and USD (expressed in basis points) 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. Estimation period is a 1 month pre and post the swap line settlement date of March 19, 2020.

Table A7: 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 (IBOR)
$\text{Swapline}_i \times \text{Post}_t$	0.368	-2.717***	1.140***
	(1.063)	(0.611)	(0.229)
Post_t	-1.570	0.277	-0.571*
	(1.133)	(0.164)	(0.242)
$\Delta\ (i - i_{us})$	-0.533**	-0.179	-0.012
	(0.147)	(0.492)	(0.028)
Δ log(board dollar)	0.795	1.262	-0.427
	(1.351)	(1.390)	(0.239)
Δ log(VIX)	0.071*	-0.056	-0.023
	(0.028)	(0.060)	(0.012)
Δ fwd bid-ask	-3.416**	-1.644*	0.103
	(1.125)	(0.769)	(0.141)
HKM	74.499***	-12.385	-7.993*
	(15.941)	(8.579)	(3.438)
constant	0.969***	1.594***	-0.080
	(0.208)	(0.145)	(0.168)
R^2	0.08	0.08	0.04
N	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 LIBOR-based 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.3 Synthetic Control Method

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

$$Y_{i,t}^{I} = \begin{cases} Y_{i,t}^{I*}, & 1 \leq t \leq T_0 - 1 \\ Y_{i,t}^{I*} + \delta_t, & T_0 \leq t \leq T \end{cases} \tag{11}$$

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

$$Y_{i,t}^{I} = Y_{i,t}^{I*} = w_0 + \sum_{i} w_i Y_{i,t}^{N} + \epsilon_t, \quad 1 \leq t \leq T_0 - 1 \tag{12}$$

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 A2, we plot the actual and counterfactual values for the EUR/USD, GBP/USD and JPY/USD CIP deviations, using 19 March 2020 as the date of the intervention in the analysis.[15]

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

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]

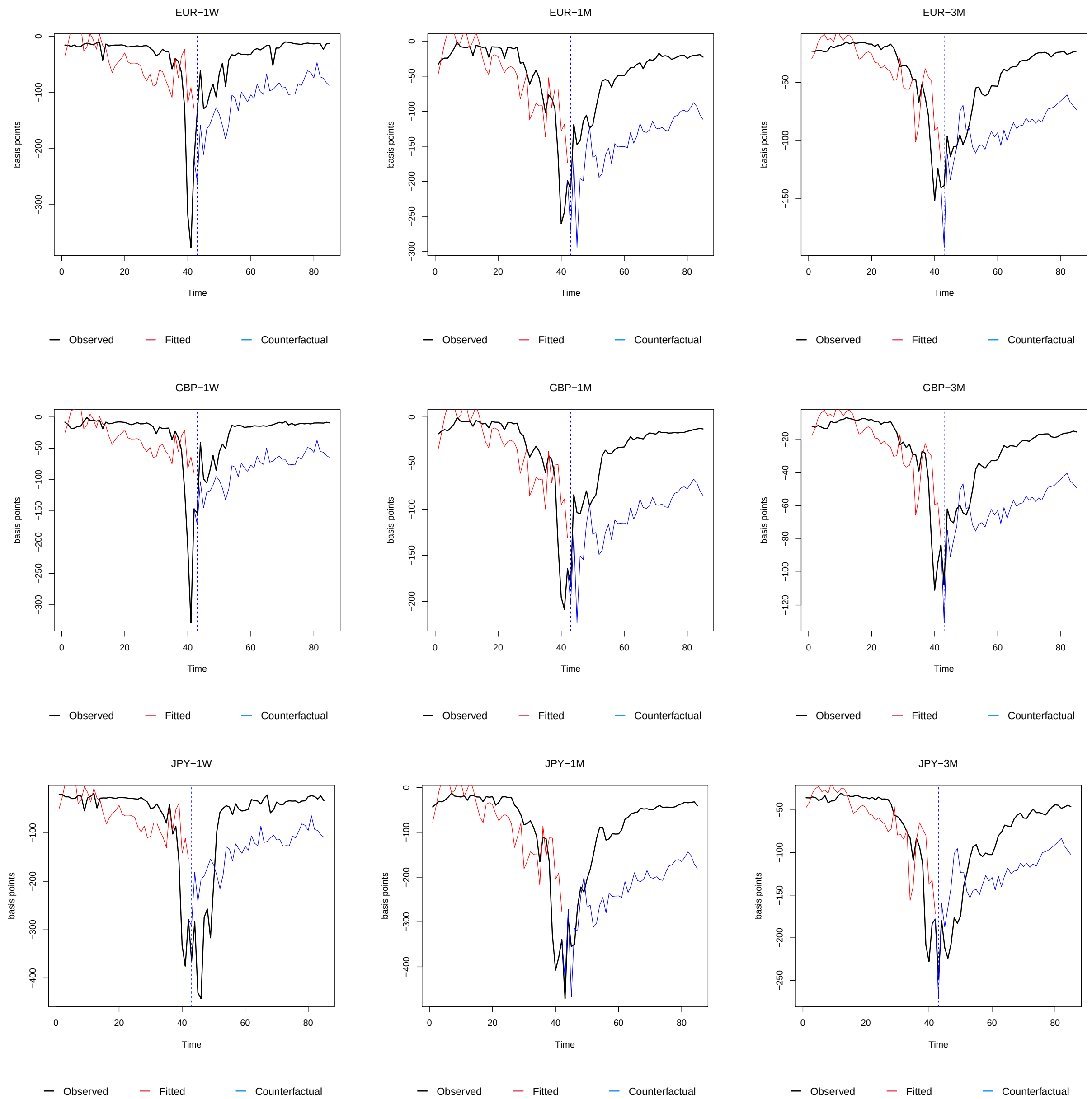
$$H_0 : \Delta_T = \frac{1}{T - T_0 + 1} \sum_{t=T_0}^{T} \tau_t = 0, \quad T_0 \leq t \leq T \tag{13}$$

Table A8 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 120 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, with the largest effects associated with the JPY/USD, followed by the EUR/USD and GBP/USD pairs respectively.

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 $lag = .75 * (T - T_0 + 1)^{1/3}$

Figure A2: 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 19 March 2020.

Table A8: 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***	88.8***	90.41***	88.09***
GBP-1M	57.24***	46.51**	60.99***	68.14***	69.9***	70.79***	69.05***
JPY-1M	3.26	7.63	74.20	96.85**	110.31***	117.96***	119.28***
EUR-3M	25.4**	6.93	19.72	29.15	35.07*	38.8**	39.63***
GBP-3M	17.13**	7.54	15.24	21.98	25.42**	27.48***	27.68***
JPY-3M	-20.08	-44.3***	-11.28	5.78	18.81	26.11	29.93

Note: Table estimates the δ_t over different horizons, where δ_t measures the average 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 19 2020. 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.

B.4 Volatility Effects

An aggregate measure of price-quote dispersion is used to assess the effects of swap lines on realized volatility. We employ the Heterogeneous Autoregressive (HAR) model introduced by Corsi (2009), specified in equation (14). The outcome variable, RV_t, represents the daily realized volatility of forward rates, calculated from intraday data as the square root of the sum of squared log returns over 5-minute intervals.

The HAR model includes lags of realized volatility as controls: $RV_{t-1:t-6}$ represents the average realized volatility over the past week, while $RV_{t-1:t-26}$ represents the average over the past month. The variable Swap $\text{line}_{set,t}$ is a dummy that takes a value of 1 on the settlement day of the swap line. To control for the impact of the COVID-19 pandemic, we include Covid_{t-1} and $\text{Covid}_{US,t-1}$, which measure the change in hospitalizations due to COVID-19 symptoms in the corresponding country and the United States, respectively. The estimation period spans 1 March 2020 to 30 September 2020, excluding days with no trading activity.[17]

$$
\begin{aligned}
RV_t = \alpha + \beta_d RV_{t-1} + \beta_w RV_{t-1:t-6} + \beta RV_{t-1:t-26} + \delta_1 \text{Swap line}_{set,t} + \delta_2 \text{Swap line}_{set,t-1} \\
+ \delta_3 \text{Swap line}_{set,t-2} + \gamma_1 \text{Covid}_{t-1} + \gamma_2 \text{Covid}_{US,t-1} + \epsilon_t \quad (14)
\end{aligned}
$$

Table A9 presents the results. Columns (I) to (III) report the estimates for 1-week EUR/USD, GBP/USD, and JPY/USD forward rates. Subsequent columns show results for 1-month and 3-month maturities. Across all currencies and maturities, we find a significant negative effect on realized volatility two days after the swap line settlement. The largest decline in volatility is observed for EUR/USD (2.9%), while the smallest decline occurs for JPY/USD (1.6%). Interestingly, there is a positive effect on volatility on

[17] The U.S. FX market is closed from Friday 5pm EST to Sunday 5pm EST; thus, Saturdays are excluded from the analysis.

the settlement day itself.

One explanation for the delayed reduction in volatility is the endogenous timing of swap line auctions. Central banks often conduct these auctions during periods of heightened volatility and elevated USD funding costs in interbank markets. This endogenous response may contribute to the observed positive effect on the settlement day, followed by a delayed decline in volatility.

Table A9: HAR Model Results: Forward Volatility 1W, 1M and 3M

	I EUR 1W	II GBP 1W	III JPY 1W	IV EUR 1M	V GBP 1M	VI JPY 1M	VII EUR 3M	VIII GBP 3M	IX JPY 3M
RV_{t-1}	-0.024	0.170*	0.307**	-0.023	0.171*	0.310***	-0.011	0.172*	0.300**
	(0.068)	(0.096)	(0.12)	(0.067)	(0.096)	(0.119)	(0.067)	(0.096)	(0.122)
$RV_{t-1:t-6}$	1.196***	0.914***	0.684***	1.196***	0.914***	0.680***	1.171***	0.913***	0.694***
	(0.165)	(0.146)	(0.155)	(0.165)	(0.146)	(0.155)	(0.164)	(0.147)	(0.158)
$RV_{t-1:t-26}$	-0.256*	-0.201*	-0.117	-0.255*	-0.201*	-0.115	-0.255*	-0.201*	-0.121
	(0.143)	(0.112)	(0.098)	(0.143)	(0.112)	(0.098)	(0.143)	(0.112)	(0.099)
Swap $line_{set,t}$	2.212***	1.722**	0.970***	2.213***	1.731**	0.961***	2.167***	1.721**	0.968***
	(0.399)	(0.874)	(0.346)	(0.398)	(0.872)	(0.345)	(0.397)	(0.87)	(0.348)
Swap $line_{set,t-1}$	0.327	0.575	-0.150	0.322	0.561	-0.148	0.324	0.553	-0.134
	(0.384)	(0.882)	(0.358)	(0.384)	(0.88)	(0.358)	(0.38)	(0.877)	(0.36)
Swap $line_{set,t-2}$	-2.878***	-2.704***	-1.645***	-2.880***	-2.707***	-1.650***	-2.853***	-2.694***	-1.641***
	(0.358)	(0.988)	(0.366)	(0.358)	(0.986)	(0.367)	(0.355)	(0.984)	(0.37)
$Covid_{t-1}$	-1.337**	-1.772***	-0.083	-1.340**	-1.772***	-0.079	-1.245*	-1.772***	-0.083
	(0.654)	(0.464)	(0.429)	(0.658)	(0.463)	(0.429)	(0.668)	(0.465)	(0.427)
$Covid_{US,t-1}$	0.200	0.058	-0.076	0.200	0.058	-0.077	0.181	0.059	-0.075
	(0.164)	(0.244)	(0.093)	(0.164)	(0.244)	(0.093)	(0.16)	(0.244)	(0.093)
constant	0.776	1.240	1.133***	0.766	1.233	1.130***	0.877	1.236	1.137***
	(1.168)	(1.255)	(0.373)	(1.173)	(1.25)	(0.372)	(1.144)	(1.248)	(0.377)
R^2	0.67	0.64	0.74	0.67	0.64	0.74	0.67	0.64	0.74
N	184	184	184	184	184	184	184	184	184

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.