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Gerardo Ferrara, Philippe Mueller,
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Central bank swap lines: micro-level evidence

Gerardo Ferrara,[1] Philippe Mueller,[2] Ganesh Viswanath-Natraj[3] and Junxuan Wang[4]

Abstract

This paper investigates the impact of central bank swap lines during the 2020 pandemic using micro-level data. Using confidential transaction-level data from the Bank of England, we study how swap line drawings affect dealer pricing and exposures in foreign exchange (FX) forwards and swaps. We find that swap line usage reduces pricing inefficiencies and violations of covered interest parity in both interdealer and customer-dealer markets. Moreover, on average, dealers use swap lines to substitute for expensive synthetic dollar funding obtained through FX derivatives instead of engaging in arbitrage transactions to exploit deviations from covered interest parity.

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.

(1) Bank of England. Email: gerardo.ferrara@bankofengland.co.uk
(2) Warwick Business School. Email: philippe.mueller@wbs.ac.uk
(3) Warwick Business School. Email: ganesh.viswanath-natraj@wbs.ac.uk
(4) Hong Kong University of Science and Technology (Guangzhou). Email: junxuanwang@hkust-gz.edu.cn

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Bank of England, Threadneedle Street, London, EC2R 8AH
Email enquiries@bankofengland.co.uk

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1 Introduction

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 to domestic banks. In this paper, we focus on 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 first been introduced as a policy tool by the Federal Reserve in response to the crisis of 2008 to mitigate the financial stability risks of U.S. dollar (USD) shortages in funding markets, which can impair the functioning of global markets, spill back into domestic markets, and ultimately lead to significant negative macroeconomic effects (Eguren-Martin, 2020; Committee on the Global Financial System, 2020). While the extant literature has documented how swap lines reduce pricing inefficiencies at the aggregate level, mainly in relation to deviations from covered interest parity, we use a much more granular dataset to study the effect of swap lines on dealer-level exposures and the pricing of FX forwards and swaps at the transaction level.

In particular, we assemble the first dealer-identified dataset that matches confidential BOE USD repurchase (repo) auction drawings to transaction-level foreign exchange (FX) forward and swap data, allowing us to study how swap line liquidity affects dealer pricing and exposures around the 18 March 2020 auctions. We make two contributions. First, we show that swap lines compress the wedge between customer-dealer and interdealer forward rates, with the largest effects observed at the one-week tenor, thus providing micro-level evidence that liquidity is passed on to customers and swap lines ease dollar shortages for non-dealer clients. Second, we show that the improvement in pricing efficiency is driven by

[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 (2025) for more details.

a demand effect, as dealers use the dollar liquidity obtained through the central bank swap lines to substitute for expensive synthetic funding through FX swaps rather than expanding arbitrage activity.

Our analysis uses two confidential datasets from the BOE. The first records transaction-level outcomes of the BOE's USD repos with private institutions. The second is the derivative trade repository data, collected under UK European Market Infrastructure Regulation (EMIR), which provides granular information on FX outright forward and swap contracts where at least one counterparty is based in the United Kingdom. Merging these two sources allows to observe both dealers' swap line drawings along with their contemporaneous pricing of FX forward and swap contracts. To our knowledge, this is the first study to use transaction-level data on swap line drawings. The unique panel dataset allows us to trace individual dealers' auction participation, examine their quoted forward prices to both dealers and customers, and measure gross outstanding exposures at the forward leg. These features enable a detailed analysis of how U.S. dollar liquidity obtained via central bank swap lines maps into forward pricing and the supply and demand for U.S. dollars in FX derivative markets.

We first ask whether improved funding conditions are passed through from dealers to non-dealer customers in the customer-dealer segment of the FX derivatives market. Pricing in this segment is more opaque and less competitive than in the interdealer market, so a narrowing of the gap between customer–dealer and interdealer quotes would indicate that swap line liquidity eases dollar shortages not only for dealer banks but also for non-dealer clients, thus providing novel evidence that the benefits of central bank swap lines extend beyond major financial institutions that have direct access.

Second, we study how swap line usage alters the composition of dealer exposures in FX forward and swap contracts. We consider two mechanisms that both exploit the fact that central bank swap lines decrease the U.S. dollar funding costs for dealer banks with direct access through the respective central bank. Under *arbitrage*, dealers borrow dollars

via the swap line to exploit CIP deviations by selling USD spot while taking long positions in USD forward, thus leading to an increase in forward USD purchases. Alternatively, under *substitution*, dealers use the cheaper repo-based U.S. dollar funding through the central bank swap lines to replace the more expensive synthetic U.S. dollar funding through FX swaps, thus leading to a reduction in forward sales of U.S. dollars. While both channels imply an equivalent effect on net forward dollar purchases, the underlying adjustment occurs either through higher forward purchases in the case of arbitrage and through lower forward sales in the case of substitution. Our data allows us to uniquely distinguish between these two mechanisms.

We find that swap lines significantly reduce pricing inefficiencies in FX outright forward and swap contracts. Transaction-level data around the 18 March 2020 BOE dollar repo auction show a pronounced narrowing of *annualized* CIP deviations across major currency pairs, with the largest effects at the one-week maturity.[2] Using median forward rates over the 24 hours before and after the auction timestamp, EUR/USD customer–dealer deviations improve by 149 basis points (from –260 bps to –111 bps). Improvements at longer maturities are smaller, consistent with the short-term focus of the operations. The relatively larger gains in the customer–dealer segment indicate meaningful pass-through of improved funding conditions to non-dealer clients, suggesting that swap line liquidity not only eases stress in the interdealer market but also mitigates price discrimination, thereby enhancing overall market efficiency.

To distinguish the mechanisms behind the improvement in price efficiency, we analyze changes in dealer FX exposures. Such improvements can stem from either demand- or supply-side effects. On the demand side, dealers may treat swap lines as a substitute source of USD funding, reducing their reliance on FX forwards and swaps to obtain dollars. On the supply side, dealers may use swap line funding to engage in arbitrage, lending USD through FX

[2]On 18 March 2020, the BOE drew USD 8.21bn at the one-week tenor and USD 7.25bn at the three-month tenor. On the same date, the ECB and BOJ drew substantially more at the three-month tenor. See Appendix A for detailed allotment data. The larger share of one-week allotments for the BOE on this date is particularly relevant for FX liquidity in the London market.

swaps to profit from CIP violations. While both channels imply an increase in net forward dollar purchases, they have opposite implications for forward positions, with substitution predicting a decline in USD forward sales and arbitrage predicting an increase in USD forward purchases.

Evidence from dealer positions over 18–20 March 2020 shows large reductions in short-term exposures, especially at maturities of less than one week. For BOE swap line users, USD forward purchases fell by approximately USD 168 bn and USD forward sales by USD 158 bn during this window, with no evidence of the increase in purchases that would be consistent with arbitrage.

While informative, aggregate dealer exposures cannot fully account for counterparty-specific factors or differences in client demand. To address this, we use the Khwaja and Mian (2008) framework at the dealer–counterparty–month level. The difference-in-differences design compares how the same counterparty allocates exposures across different dealers within a given month. We define treated dealers as those that drew USD from the BOE swap line at least once during the period March to May 2020, and control dealers as those that did not. We restrict the sample to counterparties that transact with multiple dealers so that, within a month, we can difference out each counterparty's demand and compare how the same counterparty allocates exposures across treated and control dealers. Identification comes from two sets of fixed effects: dealer–counterparty fixed effects, which absorb time-invariant features of each trading relationship, and counterparty–time fixed effects, which absorb month-specific shifts in each counterparty's overall demand.

Using this framework, we find that treated dealers reduce gross USD forward *sales* by about 15% relative to control dealers, while gross USD forward *purchases* do not change significantly. The (log) Buy-to-Sell ratio increases by about 12% because sales fall more than purchases. These results are consistent with dealers substituting away from short-term USD obtained via private FX swaps and toward BOE repo funding, rather than expanding positions that would rely on additional USD forward purchases.

In sum, we show that swap lines improve price efficiency and substitute for private FX swap funding, easing dollar shortages for both dealers and their clients during crises.

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, 2025), as well as swap lines in emerging markets (Bahaj and Reis, 2020; Bahaj et al., 2024), theories of the macroeconomic effects of swap lines (Eguren-Martin, 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 forward pricing and FX exposures of dealers that drew on the swap line. Our paper is the first to study central bank swap lines with such granular data, also following the call of Bahaj and Reis (2022b) who note that the *"net effect [of central bank swap lines] is to provide source currency funds for banks in the recipient country. Why they need these funds in the first place is less well understood... Ultimately, research to answer this question will likely have to use bank-level data on drawings."*

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., 2025; 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; Khetan, 2025). Our study complements this literature by providing micro-level evidence of how dealer FX pricing, exposures, and drawings on swap lines interact, particularly during periods of heightened market stress.

Closely related work examines specific frictions that shape FX derivative markets, including balance sheet exposures at quarter-ends (Abbassi and Bräuning, 2020; Kloks et al., 2024, 2025), 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), the impact of FX hedging by both dealer and non-dealer clients on spot rate dynamics (Eguren-Martin et al., 2024; Hacıoğlu-Hoke et al., 2024), and the implications for international capital flows and CIP deviations (Liao and Zhang, 2025; Czech et al., 2021; Bräuer and Hau, 2024; Kubitza et al., 2025; Nenova et al., 2025). Within this literature, our work follows a similar framework to 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 exploits 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 exposures, controlling for counterparty-related effects following Khwaja and Mian (2008).

Lastly, our analysis complements Kloks et al. (2025), 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 away 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. Section 2 summarizes the institutional details of swap lines, describes the BOE data sources, and presents stylized facts on price and volatility based on benchmark rates. Section 3 sets out the research hypotheses and their testable implications for pricing and dealer exposures. Section 4 develops the empirical strategy and reports results on FX outright forward and swap pricing, and exposures using dealer-level transaction data. Section 5 concludes.

2 Institutional Details 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, trade 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.[3] In order to draw on the BOE swap line facility, institutions are mandated to provide

[3]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 UK EMIR 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 EMIR 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).[4] 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).[5]

The UK EMIR 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 state reports 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 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 auction on 18 March and the

[4]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.

[5]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.

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.[6]

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.

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 UK EMIR trade repository data. For a dealer i and counterparty j, we calculate a transaction-level CIP deviation based

[6]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.

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 4.1.1, 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 information on total assets (USD), liabilities (USD), risk-weighted assets (USD), and Tier 1 capital (USD), as well as leverage ratios from Bloomberg and credit default swap (CDS) spreads (basis points) from Refinitiv Eikon. To create monthly datasets from the quarterly balance sheet 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.

[INSERT TABLE 2 ABOUT HERE]

3 Research Hypotheses

3.1 Dealer Pricing

Much of the literature on central bank swap lines has focused on benchmark FX rates, which primarily reflect pricing in the interdealer market. The theory linking swap lines to CIP deviations follows from a simple no-arbitrage condition (Bahaj and Reis, 2020). When CIP deviations exceed the cost of borrowing USD via swap lines, arbitrage becomes profitable. This threshold, referred to in Bahaj and Reis (2022a) as the *CIP ceiling*, depends on the overnight index swap (OIS) rate, the penalty rate δ charged on swap line drawings, and frictions in the interbank market.

In our setting, a dealer can draw USD from the Federal Reserve through the BOE at an interest rate of $i^{USD}_{\text{OIS}} + \delta$, and lend them in the FX swap market while hedging the GBP leg using an OIS contract. Let the *OIS-based CIP deviation* be defined as:

$$x_{\text{OIS}} \equiv f - s + i^{GBP}_{\text{OIS}} - i^{USD}_{\text{OIS}}, \tag{2}$$

where f is the forward exchange rate (the log price of GBP in USD for settlement at maturity), s is the spot exchange rate (the log price of GBP in USD for immediate settlement), i_{OIS} denotes the relevant OIS interest rate, and δ is the swap line penalty rate charged above the USD OIS rate.

As shown in Appendix B.1, the arbitrage profit from drawing on the swap line, converting USD to GBP in the spot market, investing GBP reserves at the central bank, and hedging interest rate risk via an OIS contract is:

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

where i^{GBP}_{reserve} is the BOE reserve remuneration rate and $i^{GBP}_{\text{interbank}}$ is the unsecured interbank (LIBOR) rate. Profits are positive when the deviation exceeds the penalty plus the spread

between interbank and reserve rates. Under no-arbitrage conditions, this implies a ceiling on CIP deviations:

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

This framework shows how the swap line rate and interbank market frictions jointly determine an upper bound on observed CIP deviations. A lower penalty rate reduces the ceiling, all else equal, while higher interbank–reserve spreads raise it. Empirically, swap line auctions lower CIP deviations and improve forward pricing between dealers, particularly during periods of USD funding stress (Bahaj and Reis, 2020, 2022a; Eren et al., 2020; Goldberg and Ravazzolo, 2021; Choi et al., 2022; Schellekens and Duijm, 2022). High-frequency evidence in Kekre and Lenel (2025) further shows that these effects can materialize rapidly.

Whether these improvements extend to the customer–dealer segment, where trades are bilateral and pricing is more opaque, remains unclear. The interdealer segment, comprising large dealer banks, is central to price discovery and liquidity provision, while customers such as hedge funds, corporates, asset managers, and other non-bank financial institutions transact with dealers to obtain FX liquidity (King et al., 2012; Chaboud et al., 2023). From a policy perspective, pass-through to customers is critical. If swap lines lower USD funding costs only for dealers, the benefits may remain concentrated in the interdealer market. If passed through to clients, they can help ease USD shortages more broadly across the market.

We use transaction-level data from the BOE to test whether dealers offered more favorable forward rates to customers after the March 18 swap line auction. This speaks to pass-through, segmentation between dealer and customer markets, and the scope for price discrimination. As shown by Hau et al. (2021), customers often face wider spreads than dealers, and clients linked to distressed intermediaries may face worse pricing outcomes (Ferrara and Hall, 2025). These frictions suggest that improvements in benchmark pricing may not automatically extend to customers. We therefore formalize the following hypothesis:

H1 (Customer–Dealer Pricing Pass-Through): *Following the March 18 2020 swap line auction, dealers offered more favorable forward rates to customers in the FX market.*

3.2 Dealer Exposures

We now turn to the mechanisms through which swap lines affect dealer behavior and FX exposures in forward and swap contracts. We hypothesize two distinct channels through which swap lines could affect dealer exposures. The arbitrage channel and the substitution channel both imply an increase in net U.S. dollar purchases at the forward leg and an improvement in dealer pricing of forward contracts, but they differ in their implications for gross Buy and Sell FX exposures.

The arbitrage channel posits that dealers draw on swap lines to exploit violations of CIP. Whenever the CIP ceiling in equation (4) is violated, dealers that draw on swap lines have a clear arbitrage opportunity. They can borrow USD from the central bank, sell those dollars for pounds at the spot leg of an FX swap, and simultaneously agree to repurchase the USD at the forward leg. This allows them to lock in a riskless profit, net of the penalty and hedging costs, which is defined in equation (3).

This behavior has clear implications for dealer FX exposures. By selling USD at the spot leg of an FX swap and purchasing them back at the forward leg, dealers simultaneously increase the supply of dollars in the spot market and the demand for dollars in the forward market. These transactions do not necessarily reflect a desire to hedge foreign exchange risk, but instead indicate a trading strategy aimed at profiting from deviations from CIP. Under this arbitrage channel, we expect to observe an increase in forward purchases of USD, with no corresponding increase in forward sales. The net effect is a rise in dealers' forward dollar exposures. We test this hypothesis by examining whether swap line-eligible dealers show increased forward dollar purchases after the March 2020 swap line activation.

H2.1 (Arbitrage Channel): *Dealers drawing on swap lines use borrowed USD*

to arbitrage covered interest parity violations by selling dollars at the spot leg of FX swaps and purchasing dollars forward, resulting in higher net forward dollar purchases.

The substitution channel suggests a different mechanism. Rather than exploiting pricing inefficiencies, dealers use the swap line to replace more expensive dollar funding sources, particularly synthetic funding via FX swaps. For example, a dealer facing significant dollar shortages may obtain dollar funding *synthetically* by obtaining dollars at the spot leg of an FX swap, with an agreement to sell USD forward at maturity of the swap contract. However, synthetic funding during the March 2020 liquidity crisis became expensive, as FX swap rates deteriorated significantly, reflecting elevated CIP deviations. In this environment, central bank swap lines, and especially the BOE's repo-based facility, offered more attractive terms. These repos carried no counterparty credit risk, received zero risk weights for leverage ratio calculations, and imposed minimal demands on balance sheet capacity, making them an efficient source of USD liquidity.

This mechanism is closely related to the substitution effects documented by Kloks et al. (2025), who show that when the cost of repo funding increases, such as at quarter-end, banks substitute toward FX swaps as an alternative dollar funding source. Our setting captures the reverse dynamic. During March 2020, dollar repo funding via the BOE's swap line auctions became the cheaper and more balance sheet efficient option, allowing dealers to substitute away from FX swaps, which had become the more expensive source of funding. In other words, while Kloks et al. (2025) describe substitution from repo to swaps in periods of elevated repo costs, we hypothesize substitution from swaps to repo-based funding when synthetic funding costs spike during periods of market stress.

Dealers facing capital or leverage constraints may prefer to borrow dollars directly from the central bank and scale back FX swap activity. Under this substitution channel, both spot purchases and forward sales of USD decline, as dealers no longer rely on FX swaps for dollar funding. Net forward USD exposure still increases, but the adjustment comes from

reduced forward sales rather than higher forward purchases.

> **H2.2 (Substitution Channel):** *Dealers drawing on swap lines substitute borrowed USD for FX swap funding by reducing purchases of dollars at the spot leg and sales of dollars at the forward leg, resulting in higher net dollar forward purchases.*

To summarize, both channels predict an increase in net USD forward purchases, but via different mechanisms. The arbitrage channel reflects an active trading strategy to exploit pricing anomalies, while the substitution channel reflects passive balance sheet reallocation. These hypotheses generate distinct testable implications for Buy, Sell, and Net positions at the forward leg of FX swap and outright forward contracts. We summarize these predictions in the table below.

Hypothesis	**Mechanism**	**Buy**	**Sell**	**Net**
Arbitrage	Spot sale of USD and forward purchase	(+)	0	(+)
Substitution	Reduced swap usage and forward sales	0	(−)	(+)

4 Empirical Evidence

4.1 Price Effects

4.1.1 Dealer Benchmark Forward Rates

Before turning to our transaction-level analysis, we present motivating evidence using benchmark forward rates to examine whether central bank swap lines improved FX market efficiency. This descriptive evidence helps establish a link between the theoretical arbitrage ceiling and observed market pricing, and allows us to corroborate findings from earlier studies on deviations from CIP.

We begin by examining how the swap line auctions on March 18, 2020, with a reduced penalty rate from OIS plus 50 basis points to OIS plus 25 basis points, affected the arbitrage

ceiling. As shown in Equation (4), the CIP ceiling is determined by the cost of borrowing U.S. dollars from the central bank and frictions in local interbank markets. This ceiling defines a threshold above which arbitrage becomes profitable and therefore constrains the extent of CIP deviations in equilibrium. When the penalty rate falls, the ceiling becomes tighter, limiting the scope for mispricing.

Figure 3, Panel A, shows the implied ceiling for one-week CIP deviations for EUR/USD, GBP/USD, and JPY/USD. We observe a clear downward shift in the ceiling following the March 18 auctions. This pattern is consistent with the theoretical prediction and the analysis in Bahaj and Reis (2020), supporting the view that swap line pricing imposes a binding constraint on deviations from no-arbitrage conditions.

Next, we assess how actual pricing in the forward market responded to the March 18 auctions. Panel B of Figure 3 plots one-week CIP deviations for the same currency pairs. These deviations spike during the first half of March 2020, reflecting heightened dollar demand and funding stress. After the March 18 policy intervention and the subsequent settlement of swap line auctions, we observe a sharp decline in deviations, suggesting that the provision of official-sector dollar liquidity helped close the arbitrage gap.

Panel B also shows intraday volatility in forward rates for each pair. Volatility increases in the days leading up to the March 18 auction but drops shortly afterward. This pattern is consistent with swap line auctions reducing pricing stress in FX markets. The largest effects are visible in EUR/USD and GBP/USD, the two most liquid currency pairs with active swap line arrangements.

Overall, this benchmark rate evidence is consistent with the arbitrage ceiling theory and supports earlier findings on CIP deviations during the COVID-19 crisis (Bahaj and Reis, 2020, 2022a; Goldberg and Ravazzolo, 2021; Schellekens and Duijm, 2022). Additional statistical tests—including ceiling violation probabilities, difference-in-differences comparisons across countries, and realized volatility regressions using HAR models—are reported in Appendix B. These results confirm that the March 18 swap line policy had a measurable impact on both

pricing levels and volatility in the FX market.

[INSERT FIGURE 3 ABOUT HERE]

4.1.2 Dealer Transaction-level Forward Rates

In this analysis, we exploit transaction-level heterogeneity in dealer forward prices and construct intraday, transaction-level CIP deviations within an event window around the 18 March 2020 swap line auctions. We focus on this date because it featured the largest BOE U.S. dollar repo operations during the COVID-19 period, with allotments of USD 8.21 billion at the 1-week tenor and USD 7.25 billion at the 3-month tenor. The large share of short-maturity allotments is particularly relevant for FX liquidity in the London market. The timing also coincided with major coordinated USD auctions by the ECB and the BOJ. The trade date for the BOJ auctions was 17 March, while 18 March marked the auctions for both the BOE and the ECB. For the BOE, 18 March was the trade date for both the 84-day and 7-day USD repo operations (Table A1), with settlement for all three central banks' operations taking place on 19 March 2020.[7]

Our focal point is the BOE auction timestamp on 18 March 2020 at 08:47:00 UTC, when dealers bid for USD liquidity in the BOE's dollar repo operation. We use a symmetric 24-hour window around this timestamp to compute median transaction prices, capturing trading activity both before and after the auction. This allows us to test whether access to swap line funding is associated with changes in forward pricing and CIP deviations at the dealer level.

We calculate median forward prices separately for interdealer trades and for transactions between dealers and non-dealer clients. The latter include asset managers, commercial banks, hedge funds, ICPF and LDI, non-financial corporations, and other financial institutions. Our transaction sample pools all dealers, without distinguishing between those that drew on swap lines and those that did not. The majority of trades are executed by dealers that draw on swap lines, with approximately 96.9% of EUR/USD transactions, 95.5%

[7]On the same date, the ECB allotted USD 75.820 billion (84-day) and USD 36.265 billion (7-day), while the BOJ allotted USD 30.272 billion (84-day) and USD 2.053 billion (7-day); see Tables A3 and A2 in Appendix A.

of GBP/USD transactions, and 99.0% of JPY/USD transactions. Given the limited number of control-group observations, especially at shorter maturities, we conduct a descriptive analysis by pooling observations from all dealer transactions. Over the two-day event window, the dataset contains 12,878 transactions, of which 83.3% are interdealer and 16.7% are dealer–client. By maturity, 20.6% of trades are at one week, 24.7% at one month, and 54.7% at three months. By currency, EUR/USD accounts for 42.9% of transactions, GBP/USD for 30.0%, and JPY/USD for 27.1%.

Using the median forward prices, we compute the forward premium and the CIP deviation for EUR/USD, GBP/USD, and JPY/USD at maturities of 1 week, 1 month, and 3 months. Table 3 reports the median forward premium and CIP deviation, in basis points, before and after the largest auction, measured over the 24-hour window on each side of the auction. The CIP violation is defined as in equation (1). As deviations are typically negative, a positive change implies an improvement in market efficiency and a reduction in the magnitude of CIP violations. Consistent with our evidence based on benchmark rates, we hypothesize a decline in the forward premium and a positive change in the CIP violation following the March 18 auctions. Panel A reports results for the 1-week maturity. Before the auction, CIP deviations were negative across all currencies and trading segments, indicating that CIP held with a bias toward cheaper dollar borrowing via FX swaps. The largest absolute deviations are observed in the dealer–client GBP/USD segment (–695 bps before the auction). This is intuitive. Following the auction, deviations narrow substantially in all cases, with the largest improvements in EUR/USD dealer–client trades (from –261 bps to –111 bps) and GBP/USD dealer–client trades (from –695 bps to –140 bps).

Panel B presents the 1-month maturity. Before the auction, CIP wedges are again negative for all currencies and segments, though magnitudes are generally smaller than for the 1-week tenor. After the auction, deviations narrow in most cases, especially in the interdealer market for EUR/USD (–269 bps to –154 bps) and GBP/USD (–253 bps to –161 bps). The exception is the JPY/USD dealer–client segment, where the wedge becomes more negative (–315 bps

to –382 bps).

Panel C reports the 3-month maturity. Here, CIP deviations are closer in magnitude across interdealer and dealer–client segments, suggesting less scope for price discrimination at longer maturities. Before the auction, deviations range from –93 bps (GBP/USD interdealer) to –194 bps (JPY/USD dealer–client). Post-auction changes are modest relative to the shorter tenors in annualized terms, with some narrowing in EUR/USD and GBP/USD, and a slight widening in JPY/USD interdealer trades.

Comparing interdealer and dealer–client quotes reveals clear evidence of price discrimination in FX forward markets, consistent with Hau et al. (2021). Across all maturities and currency pairs, CIP deviations are larger in absolute value for dealer–client trades than for interdealer transactions, indicating that non-dealer customers face higher implicit dollar funding costs. This gap is particularly pronounced at the 1-week tenor before the auction, with the largest deviation observed in GBP/USD dealer–client trades (–695 bps), compared with –84 bps in the interdealer market. Following the auction, deviations narrow more sharply in the dealer–client segment, especially for the 1-week maturity, where the wedge falls by 150 bps in EUR/USD and 554 bps in GBP/USD. The stronger convergence of dealer–client pricing toward interdealer benchmarks at shorter maturities suggests significant pass-through of swap line liquidity to non-dealer customers. In markets where initial price discrimination is greatest, swap lines appear particularly effective in mitigating dollar shortages and reducing the costs of obtaining USD via FX swaps for peripheral market participants.

These results provide support for H1, namely that following the March 18, 2020 swap line auctions, dealers offered more favorable forward rates to customers. The forward premium declines across all currency pairs, with the largest and most consistent effects concentrated at the 1-week maturity—the primary operational maturity for the swap lines—resulting in a direct reduction in price dislocations in this segment (Goldberg and Ravazzolo, 2021). The relatively larger decline in forward premia for customer–dealer transactions than for interdealer trades, particularly at the 1-week tenor, is consistent with the notion that pricing

in the customer–dealer segment is more susceptible to price discrimination during periods of market stress (Hau et al., 2021; Ferrara and Hall, 2025). Once the swap line is activated, the improved funding conditions appear to reduce these inefficiencies, enhancing price efficiency for both interdealer and customer–dealer markets.

Taken together, our results indicate that price efficiency improves not only in the interdealer market but also in the customer–dealer segment. The evidence suggests that funding stress in March 2020 generated larger dislocations in the customer–dealer market, and that swap lines can play an important role in mitigating these disruptions by improving the pricing available to non-dealer clients facing constraints in USD funding.

[INSERT TABLE 3 ABOUT HERE]

4.2 Outstanding Derivative Exposures

4.2.1 Snapshot of Exposures around March 18 Auctions

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 4 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 less than one 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 an 18 billion USD decrease in Buy exposures and a 4 billion USD decrease in Sell exposures.

We classify dealers as *treated* if they drew U.S. dollars in the Bank of England's USD swap line auctions on 18 March 2020 (at either the 1-week or 3-month tenor). *Control* dealers are those that did not draw in these auctions.[8]

In panel B, we disaggregate total exposures by treated and control dealers. For treated dealers there was a notable decrease in outstanding Buy and Sell exposures at the 1-week maturity relative to control dealers. Exposures with a maturity less than or equal to 7 days fell by 168 billion USD (Buy) and 158 billion USD (Sell), indicating that most of the short-maturity decline is reflected in treated dealers' positions.

[INSERT TABLE 4 ABOUT HERE]

The snapshot shows the largest declines at short maturities. Sell exposures with maturities of less than one week fall the most, consistent with pandemic-era shortages of short-term USD liquidity and with the March 18 allotments being largest at the 1-week tenor, followed by the 3-month tenor.[9] The pricing evidence aligns with this maturity profile. The largest post-auction drop in forward premia and the sharpest narrowing of negative CIP deviations occur at the 1-week tenor. This pattern is consistent with dealers substituting swap line dollars for private FX swaps, which reduces the need to obtain USD by selling forward. As dealers supply fewer dollars at the forward leg, forward premia compress and CIP wedges narrow. Further evidence on the heterogeneity in dealer–client pricing is provided in Appendix C, which separately reports results for trades where the dealer buys versus sells dollars at the

[8]This event-time definition is specific to the snapshot analysis; the DiD framework in Section 4.2.2 uses a longer window and classifies treatment based on drawings over March–May 2020.
[9]See Appendix A for BOE swap line amounts.

forward leg. The decline in the forward premium following the March 18 auctions is evident in both Buy and Sell trades, but the effect is more pronounced when dealers sell dollars forward. As dealers reduced their forward USD sales, this led to a compression of forward premia and a decline in the magnitude of CIP violations, particularly at shorter maturities where dislocations were most acute.

We find little support for Hypothesis **H2.1**. If dealers used swap lines to expand arbitrage supply, Buy exposures would rise; instead, they decline. On aggregate, dealers do not report an increase in gross USD forward purchases.

Taken together, the quantity and price evidence favor the substitution channel (Hypothesis **H2.2**) over an expansion of arbitrage supply (Hypothesis **H2.1**). We now test this mechanism formally using a DiD framework following Khwaja and Mian (2008).

4.2.2 Monthly Exposures with Counterparty Controls

To address this concern, we adopt the Khwaja and Mian (2008) differences-in-differences (DiD) identification and follow its application to FX in Cenedese et al. (2021). In that paper, leverage ratio requirements are treated as shifts in dealers' balance-sheet costs. By focusing on counterparties that transact with multiple dealers in the same month, Cenedese et al. (2021) differences out client-specific demand and attributes cross-dealer variation to supply-side constraints, using dealer–counterparty and counterparty–time fixed effects. We implement the same logic here. We drop dealer–counterparty pairs where the counterparty trades with only one dealer and retain only counterparties that transact with multiple dealers. With dealer–counterparty and counterparty–time fixed effects, we compare, within a counterparty–month, how exposures differ across dealers by treatment status (drawing on the swap line). This allows us to isolate the effect of swap line drawings on FX exposures through our proposed channels, namely dealer arbitrage by lending dollars via FX forwards and swaps (Hypothesis **H2.1**) or substitution toward swap line funding (Hypothesis **H2.2**).

To implement this framework, we study dealer i and counterparty j at month-end t and measure outstanding USD Buy and Sell positions at the forward leg of FX forwards and

swaps. Outstanding FX derivative exposures are computed at each month-end from September 2019 to November 2020 and aggregated across asset managers, non-dealer commercial banks, hedge funds, ICPF and LDI, non-financials, and other financial institutions. We restrict attention to maturities of 95 days or less, consistent with the 1-week and 3-month swap line tenors, and retain only counterparties that transact with multiple dealers as described above. Dealers are classified as treated if they drew on the BOE USD swap line in March, April, or May 2020; dealers that did not draw in these months are control.

Figure 5 plots aggregate Buy, Sell, and net exposures for each group, with March 2020 indicated by a dotted line. For both control and treated dealers, Buy exposures are systematically larger than Sell exposures, implying that dealers are on average net buyers of USD forward. This pattern is consistent with evidence in Hacıoğlu-Hoke et al. (2024), which shows that non-dealer clients such as funds and asset managers are typically net short forward USD in order to hedge their net USD asset positions. Dealers absorb these client forward sales by taking the opposite side and net demanding USD forward. Hence, the sign of our positions aligns with the analysis of Hacıoğlu-Hoke et al. (2024). We next use these exposures to construct outcome variables for our DiD design.

[INSERT FIGURE 5 ABOUT HERE]

Outcome variables are $\log(\text{Buy}_{i,j,t})$, $\log(\text{Sell}_{i,j,t})$, and $\log(\text{Buy}_{i,j,t}/\text{Sell}_{i,j,t})$, with logs reducing skewness following Czech et al. (2023). We estimate

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

where $D_{\text{swapline},t} = 1$ in March, April, and May 2020 and 0 otherwise, and $D_{\text{treatment},i} = 1$ for dealers that drew on BOE swap lines in any of these months and 0 for dealers that did not. The interaction term is the parameter of interest. For our analysis, we use a symmetric six-month window around March 2020, i.e., September 2019 through October 2020. We include dealer–counterparty and counterparty–time fixed effects and report results with dealer-level

controls, including distance to capital requirement, leverage ratio, share of risk-weighted assets, and CDS spreads. This design compares, within a counterparty and month, exposures at treated versus control dealers while holding counterparty demand constant.

Before turning to results, we assess design validity. Pre-trend plots in Figure 5 show parallel trends for treated and control dealers in Buy and Sell exposures before March 2020, supporting the parallel-trends assumption. In addition, unreported regressions indicate that the set of balance-sheet controls listed above does not jointly predict treatment status, reducing concerns about selection on observables.

Table 5 reports the results. Columns (I), (III), and (V) examine the effects on gross outstanding FX exposures—Buy, Sell, and the Buy–Sell ratio—without controls. The remaining columns add controls, including dealer balance-sheet characteristics such as the leverage ratio and the share of risk-weighted assets. Without controls, both gross Buy and Sell exposures for treated dealers decline significantly, by 11.8% and 24.7%, respectively. When controls are included in columns (II) and (IV), the decline in Sell exposures remains statistically significant at 16.2%, while the effect on Buy exposures (–4.0%) is small and statistically insignificant.

Columns (V) and (VI) use the (log) ratio of Buy to Sell exposures as the outcome. In the specification with controls, we find a statistically significant increase of 11.7%. These results support the view that swap lines substitute for dollar liquidity obtained via the FX swap market. Institutions drawing USD from the BOE reduce their reliance on synthetic funding, lowering USD spot purchases and USD forward sales through FX swap contracts.

Our findings are consistent with **H2.2** (substitution channel) and not with **H2.1** (arbitrage channel), which predicts that institutions would supply USD spot and buy USD forward to exploit CIP violations. This substitution mechanism accords with Kloks et al. (2025), who document similar dynamics at quarter-ends when there is a substitution from repo funding, which has high balance sheet costs due to leverage, to FX swaps, which are off balance sheet. In contrast, we find evidence for a substitution from expensive synthetic funding to cheaper

repo funding through the swap line. During systemic stress, when synthetic dollar funding costs are elevated, dealers turn to swap lines rather than expanding arbitrage positions.

In sum, when FX markets are disrupted and swap line dollars are available at a relative cost advantage, swap lines act as a substitute source of dollar funding. By shifting funding away from private FX swaps toward central bank facilities, they alleviate dollar funding pressures, support price efficiency for non-financial customers, and channel liquidity to institutions facing tighter constraints, thereby reducing systemic risk. This mechanism is consistent with the substitution channel (Hypothesis **H2.2**).

[INSERT TABLE 5 ABOUT HERE]

5 Conclusion

This paper provides micro-level evidence on how central bank swap lines affect pricing and dealer behavior in FX outright forward and swap markets. Using two confidential datasets from the BOE, namely transaction-level records of USD repo auctions and the UK EMIR trade repository data, we link dealers' access to swap line liquidity to the prices they quote and to their outstanding derivative exposures. To our knowledge, this is the first study to exploit transaction-level data on swap line drawings.

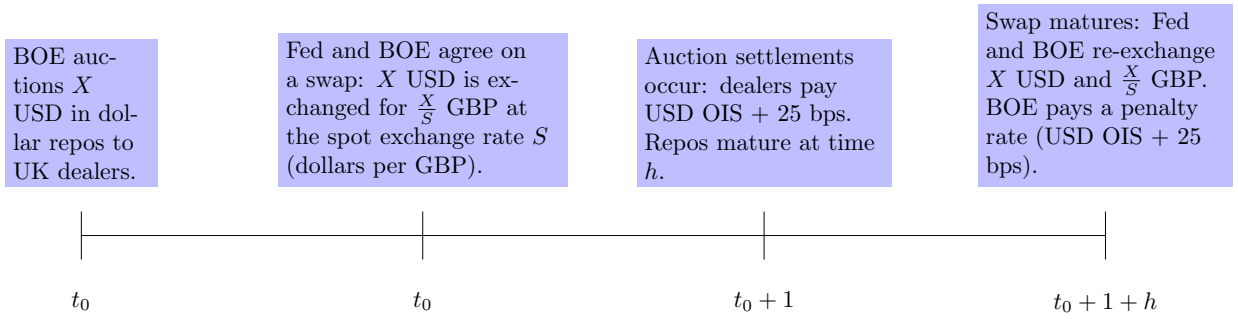
We document two main results. First, swap line usage is associated with a significant reduction in pricing inefficiencies. Around the 18 March 2020 BOE dollar repo auction, annualized deviations from covered interest parity narrow sharply, with the largest effects at the one-week tenor. Pass-through is economically meaningful in the customer–dealer segment, with EUR/USD at one week showing a 149 basis point improvement in the customer–dealer deviation over the 24-hour event window, alongside a compression in the gap between customer–dealer and interdealer pricing. These patterns indicate that swap line liquidity eases dollar shortages beyond financial institutions with access to the facility and mitigates price discrimination faced by non-dealer clients.

Second, we assess whether these improvements arise from an *arbitrage* or *substitution* channel. Under arbitrage, dealers would use swap line dollars to expand FX swap lending, increasing forward purchases. Under substitution, dealers would replace more expensive synthetic dollar funding from FX swaps with cheaper repo funding, reducing forward sales. Using a difference-in-differences framework with counterparty–dealer and counterparty–time fixed effects, we find a clear net decline in forward sales and no significant change in purchases. This pattern is consistent with the substitution channel and offers little support for an arbitrage-driven expansion in dollar supply.

Our findings have several policy implications. Swap lines achieve their intended goal of alleviating USD liquidity pressures in FX outright forward and swap markets by lowering the ceiling on CIP deviations, thereby reducing bank currency exposures and mitigating dollar shortages during financial crises. The strongest effects at short maturities are consistent with the operational design of the facilities and the short-term nature of funding stress. Meaningful pass-through to customers indicates that benefits extend beyond the interdealer market, reducing funding costs for non-dealer clients.

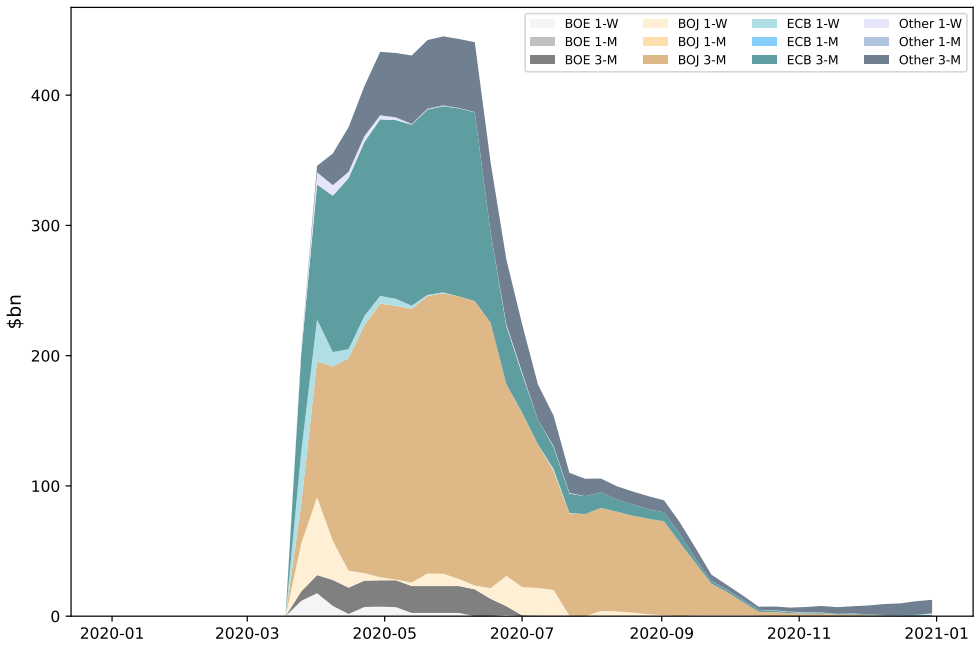
Figures

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.

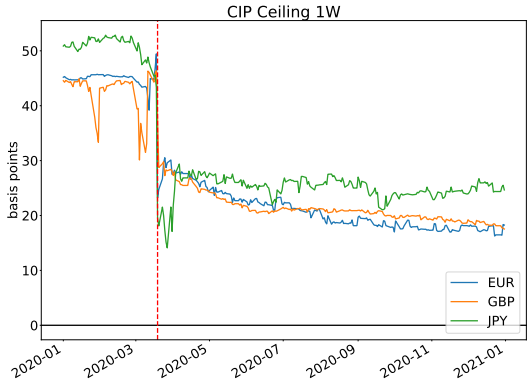
Figure 2: Swap Line Allotments during Covid



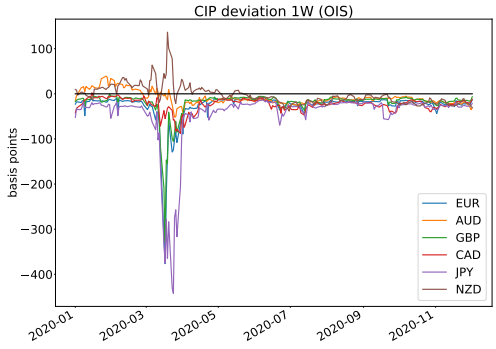
Note: Figure presents outstanding Federal Reserve Swap Lines made to Bank of Japan (BOJ), Bank of England (BOE), European Central Bank (ECB) and other central banks (Other) during 2020. Maturities are 1 week, 1 month and 3 month. Data is taken from the NY Federal Reserve.

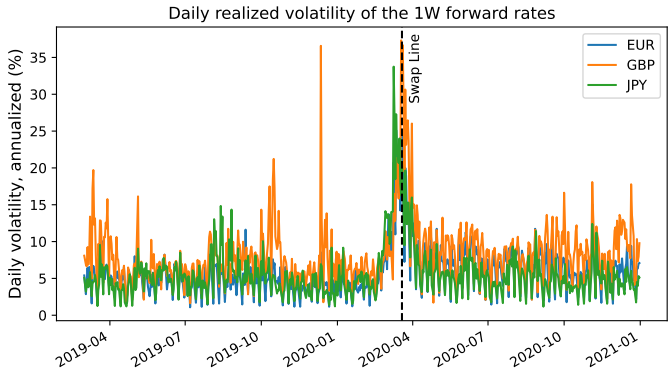
Figure 3: 1 Week Maturity: CIP Deviations and Forward Rate Volatility during Covid

Panel A: CIP Ceiling Test



Panel B: Price and Volatility Effects

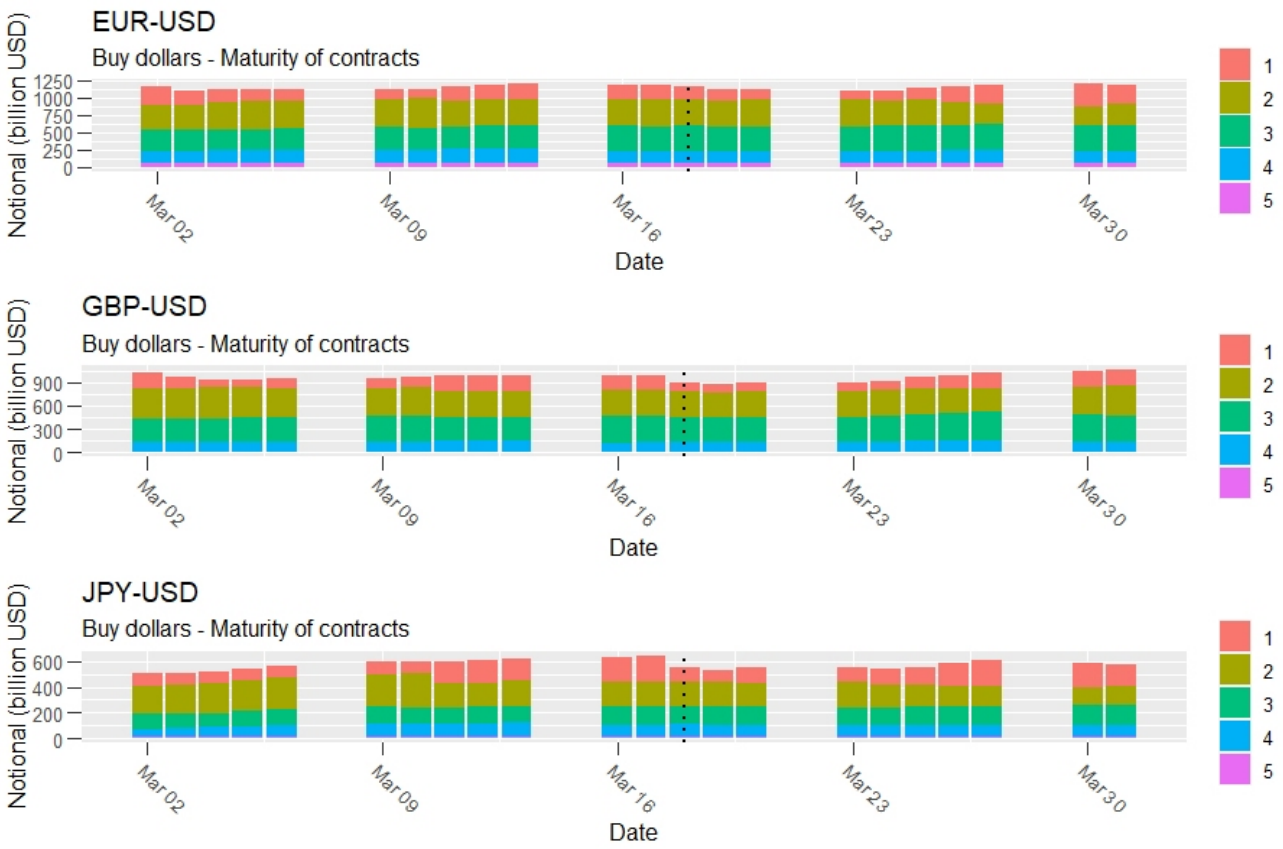




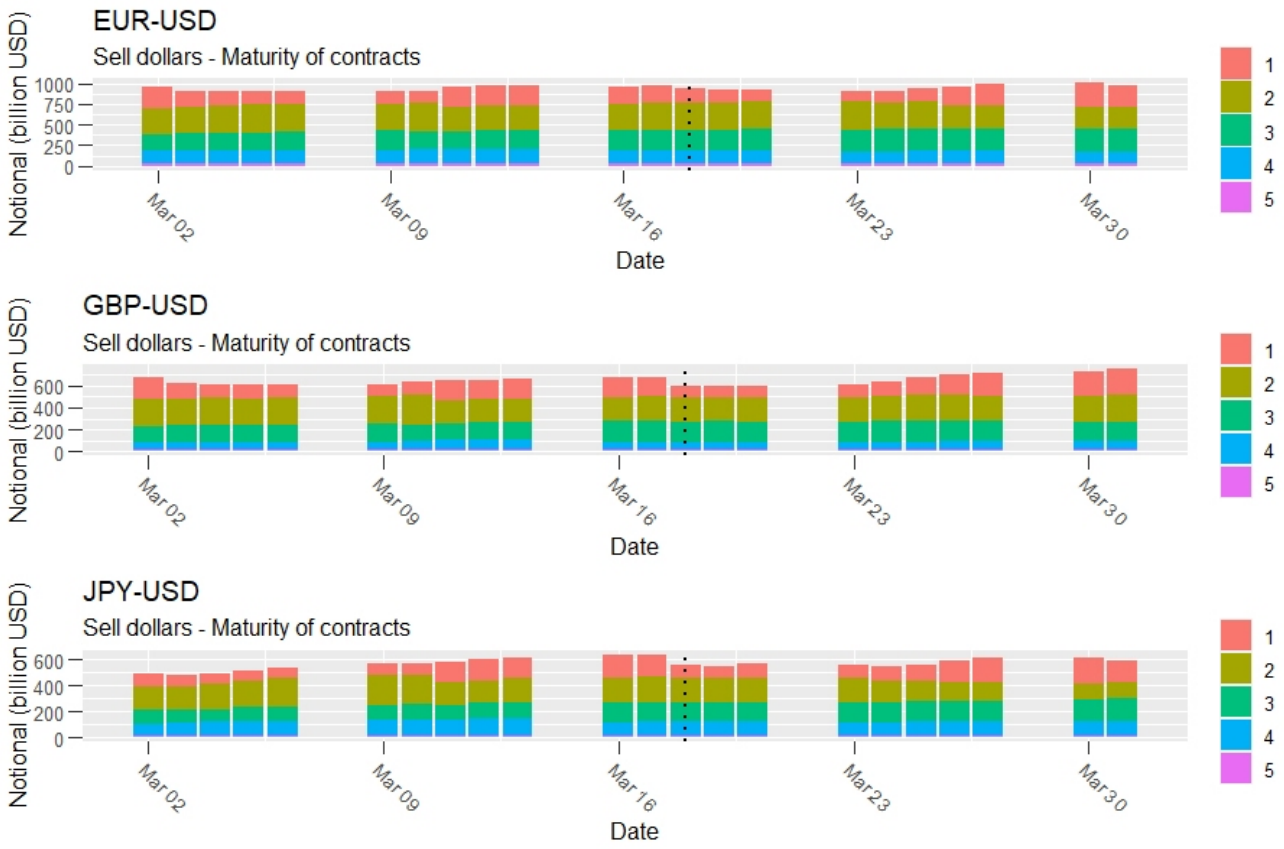
Note: The Figure presents data for CIP deviations at the 1 week maturity during the Covid period. Panel A shows the ceiling on CIP deviations for advanced economies. Panel B shows CIP deviations (benchmark OIS rate) for a set of advanced economies, and daily realized volatility of the EUR/USD, GBP/USD, 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

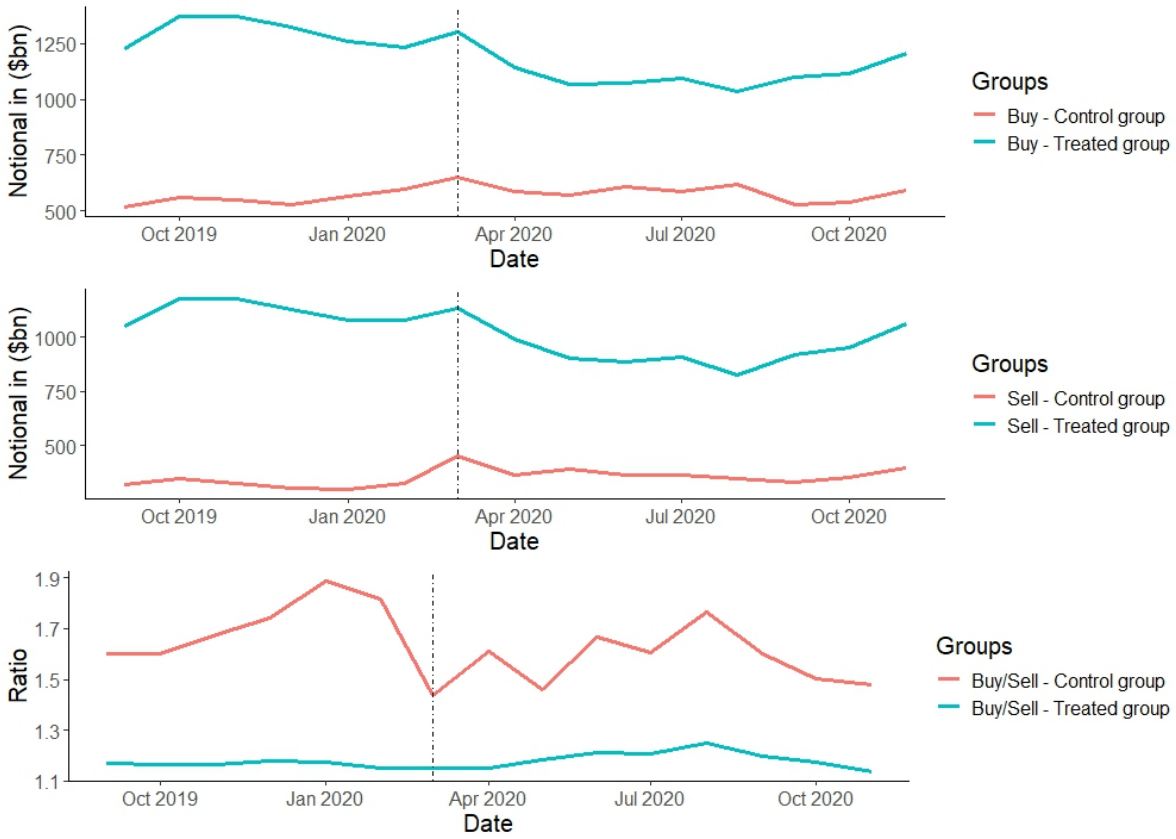


Panel B: Sell Exposures



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
CDS (bps)	496	54.93	24.99	19.53	37.71	50.98	64.56	221.49

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

Table 3: Median Forward Premium and CIP Wedge (bps) Before and After Auction

Panel A: 1 Week	Tx Count	**Forward Premium (bps)**			**CIP Wedge (bps)**		
		Before	After	Δ	Before	After	Δ
Interdealer							
EUR-USD	804	234	47	-187	-166	22	188
GBP-USD	532	86	53	-33	-84	-49	35
JPY-USD	968	34	24	-10	-8	5	13
Dealer/Client							
EUR-USD	103	329	181	-149	-261	-111	150
GBP-USD	146	696	145	-552	-695	-140	554
JPY-USD	98	143	22	-121	-117	7	124
Panel B: 1 Month	Tx Count	**Forward Premium (bps)**			**CIP Wedge (bps)**		
		Before	After	Δ	Before	After	Δ
Interdealer							
EUR-USD	1171	332	216	-116	-269	-154	115
GBP-USD	820	254	162	-92	-253	-161	92
JPY-USD	549	329	309	-20	-307	-288	20
Dealer/Client							
EUR-USD	275	322	209	-112	-258	-148	111
GBP-USD	240	147	158	11	-146	-157	-11
JPY-USD	132	337	403	66	-315	-382	-67
Panel C: 3 Months	Tx Count	**Forward Premium (bps)**			**CIP Wedge (bps)**		
		Before	After	Δ	Before	After	Δ
Interdealer							
EUR-USD	2688	200	179	-21	-137	-119	18
GBP-USD	1802	93	86	-7	-93	-86	7
JPY-USD	1389	203	215	12	-183	-197	-14
Dealer/Client							
EUR-USD	486	214	190	-24	-150	-130	20
GBP-USD	326	137	88	-49	-136	-88	48
JPY-USD	349	215	212	-2	-194	-193	1

Note: Table reports median forward premiums and CIP wedges, in basis points, by currency pair, tenor, and market segment (interdealer versus dealer–client), using transaction-level data in a symmetric 24-hour window around the BOE USD auction timestamp (18 March 2020, 08:47:00 UTC). "Before" refers to the 24 hours preceding the timestamp (evaluated with OIS closing rates as of 17 March 2020); "After" refers to the 24 hours following (OIS closing rates as of 18 March 2020). Forward premiums are annualized and reported in basis points. The CIP deviation is defined as in equation (1). Δ denotes After minus Before. Tx Count is the number of trades in each currency–tenor–segment cell, pooled across both the "Before" and "After" 24-hour windows.

Table 4: 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
$\leq$ 7 days	\$606B	\$389B	-\$218B	\$575B	\$372B	-\$203B
$\geq$ 8 days $\leq$ 30 days	\$912B	\$906B	-\$6B	\$738B	\$741B	\$3B
$\geq$ 31 days $\leq$ 90 days	\$837B	\$819B	-\$18B	\$592B	\$587B	-\$4B
$\geq$ 91 days $\leq$ 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
$\leq$ 7 days	\$365B	\$197B	-\$168B	\$323B	\$164B	-\$158B
$\geq$ 8 days $\leq$ 30 days	\$382B	\$380B	-\$2B	\$359B	\$351B	-\$9B
$\geq$ 31 days $\leq$ 90 days	\$335B	\$335.4B	-\$0.4B	\$350B	\$346B	-\$4B
$\geq$ 91 days $\leq$ 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: 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 5: Dealer FX Exposures for Maturities $\leq$ 95 Days: All Counterparties

	I	II	III	IV	V	VI
	Buy	Buy	Sell	Sell	$\frac{Buy}{Sell}$	$\frac{Buy}{Sell}$
D_{treat}	0.117**	0.463***	0.285***	0.811***	-0.027	-0.178***
	(0.045)	(0.070)	(0.055)	(0.080)	(0.041)	(0.068)
$D_{swap\ line} \times D_{treat}$	-0.118***	-0.040	-0.247***	-0.162***	0.126**	0.117**
	(0.045)	(0.045)	(0.051)	(0.051)	(0.058)	(0.058)
$\frac{RWA}{Assets}$		2.573***		2.804***		-0.169
		(0.199)		(0.199)		(0.199)
$distance_{CET1\ Ratio}$		0.105***		0.051***		0.055***
		(0.015)		(0.016)		(0.014)
$distance_{Leverage\ Ratio}$		-0.262***		-0.282***		-0.014
		(0.027)		(0.029)		(0.027)
CDS	0.009***	0.004***	0.008***	0.003**	0.001	0.000
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
constant	2.634***	1.295***	2.303***	1.276***	0.304***	0.041
	(0.086)	(0.170)	(0.101)	(0.179)	(0.083)	(0.162)
R^2	0.642	0.653	0.670	0.682	0.414	0.415
N	58186	58180	44980	44980	32829	32829

Note: 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–May 2020, when the BOE repo lines were drawn; the interaction captures treated dealers' exposure changes in those months. Controls include the ratio of risk-weighted assets to total assets, distance to CET1 and Leverage requirements, and dealers' CDS spreads. The sample is monthly from September 2019 to November 2020. Standard errors in parentheses are clustered at the dealer–counterparty level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

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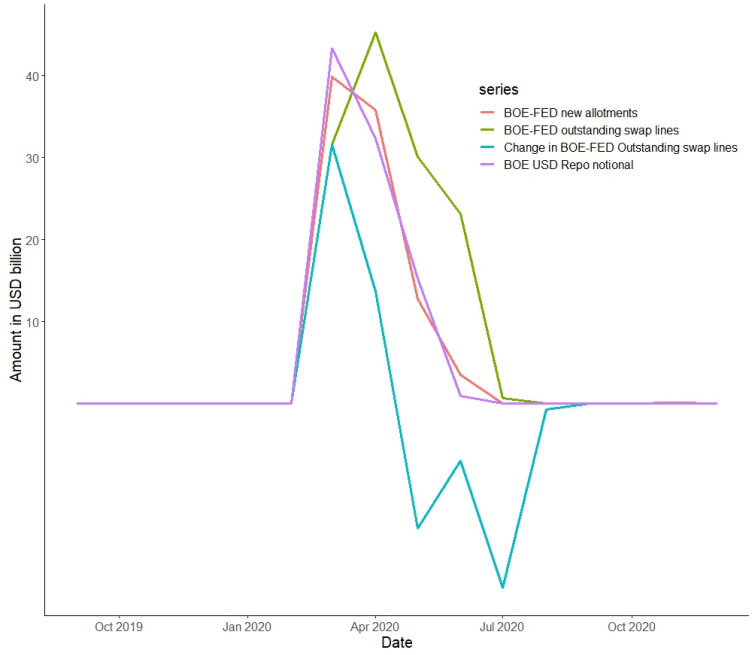
Online Appendix to

"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: 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 A1, 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 A1: CIP Deviations: Ceiling Test

	I	II	III	IV	V	VI	VII	VIII	IX
	EUR 1W	GBP 1W	JPY 1W	EUR 1M	GBP 1M	JPY 1M	EUR 3M	GBP 3M	JPY 3M
post	-1.19***	-0.41	-1.38***	-1.65***	-0.44*	-2.06***	-1.05***	-1.44***	
	(0.25)	(0.28)	(0.23)	(0.23)	(0.26)	(0.23)	(0.25)	(0.42)	
constant	1.35***	1.47***	1.15***	0.99***	1.35***	0.73***	1.35***	2.10***	0.92***
	(0.24)	(0.25)	(0.22)	(0.20)	(0.24)	(0.19)	(0.24)	(0.40)	(0.20)
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. Standard errors are reported in parentheses. *** 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 A2 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 A3 reports the results. For the interaction term of $Allotment_{i,t} \times Post_t$, the DiD coefficient estimates are quantitatively similar to using AUD and NZD as the control group.

Another concern is our selection of the treatment date of 19 March 2020, which could be problematic due to a number of confounding events during the pandemic. In Table A4, we run placebo tests using alternative treatment dates, February 1, 2020 and May 1, 2020, and find insignificant treatment effects using 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 A2: Panel Differences-in-Differences Specification: CIP Deviations (OIS)

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
Swapline$_i$ × Post$_t$	13.675**	12.982**		
	(3.821)	(3.514)		
Allotment$_{i,t}$ × 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)
Δ $(i - i_{us})$		-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 A3: Panel Differences-in-Differences Specification: CIP Deviations (OIS): Alternative Control Group with DKK and SEK Currencies

	I	II	III	IV
	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$	$\Delta x_{i,j,t}$
$\text{Swapline}_i \times \text{Post}_t$	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 A4: Panel Differences-in-Differences Specification: CIP Deviations (OIS): Placebo Tests using Alternative Treatment Dates and Maturity

	I	II	III
	Date Placebo (Feb 1, 2020)	Date Placebo (May 1, 2020)	Maturity Placebo (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 A1, 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.[10]

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

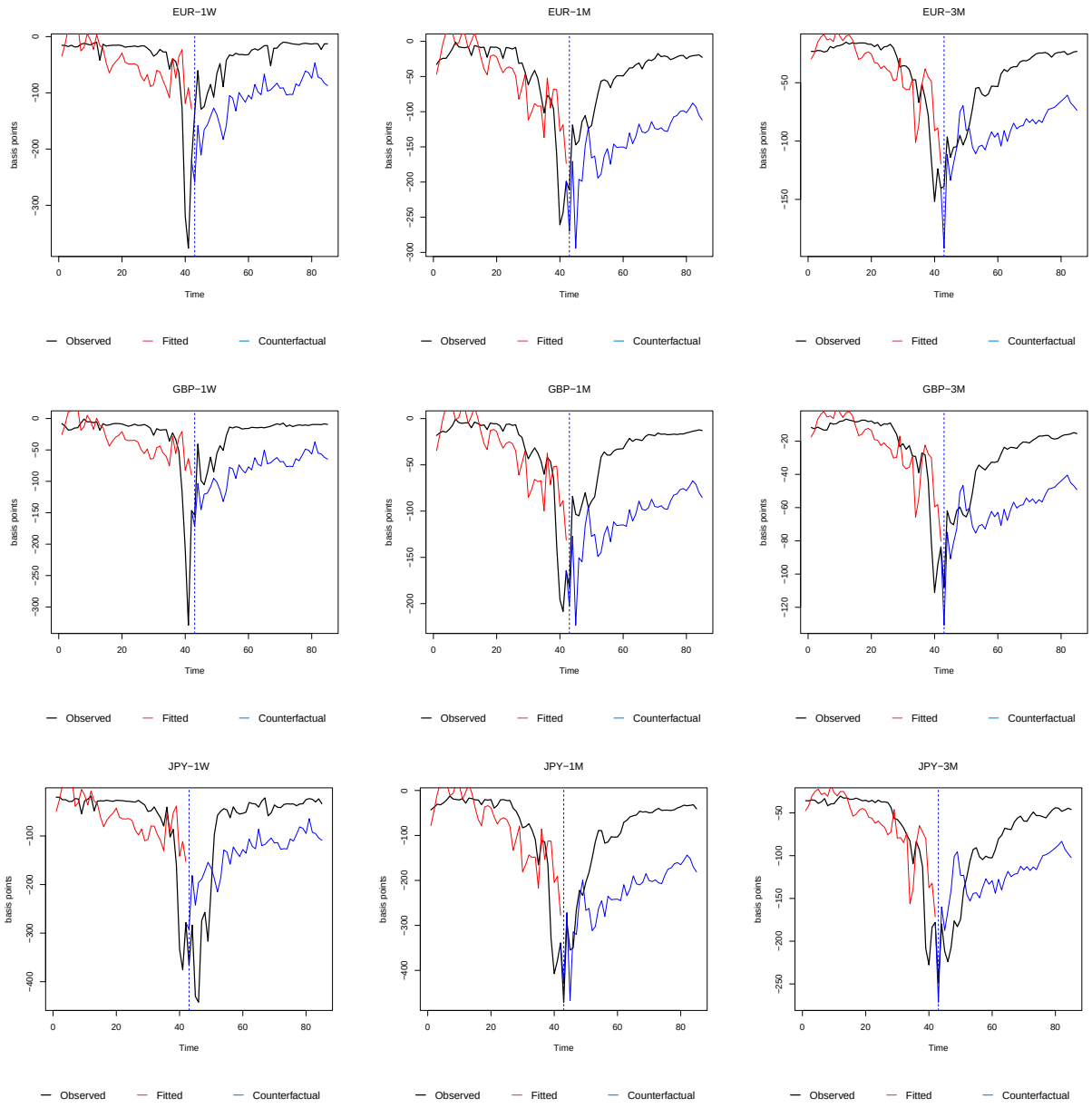
We then proceed to test the hypothesis that the difference between the actual and counterfactual values are statistically significant over different horizons. Defining the actual and counterfactual variable at each time as τ_t, we can test the joint significance of the average τ_t over a defined period 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 $\Delta_T = 0$.[11]

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

Table A5 presents the results of Δ_T and its statistical significance for different horizons. Consistent with our hypothesis, we observe a significant difference between the observed values and the counterfactual following the swap line for all currencies and maturities. In particular, the magnitude of CIP deviations with the swap line is lower than implied by the counterfactual. The results for the 1 week maturity are strongest for the EUR/USD with a narrowing of deviations within 4 days, however the JPY/USD deviation narrows over a longer horizon of 2-3 weeks. Across all pairs, we find the largest effects for the 1 month maturities, with a peak difference between observed and counterfactual estimates of 90 basis points for the EUR/USD, 70 basis points for the GBP/USD and 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.

[11] 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 A1: CIP Deviations: Counterfactual vs Actual Using Synthetic Controls



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

Table A5: Synthetic Control; Estimates of Difference between Actual and Counterfactual

	4	7	14	21	28	35	43
EUR-1W	86.07**	67.94	79.97**	78.31***	75.36***	76.34***	72.62***
GBP-1W	35.58*	33.24	52.15**	55.24	55.06	55.81	53.64
JPY-1W	-152.18**	-134.49**	-23.28	11.81	27.00	37.31	41.95
EUR-1M	77.86***	62.61**	79.74***	86.75***	88.8***	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 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 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.[12]

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

Table A6 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 the settlement day itself.

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

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 A6: 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. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Appendix C: FX Dealer/Client Pricing

Table A1: Median Forward Premium and CIP Wedge (bps) Before and After Auction (24h window around 2020-03-18 08:47 UTC) – Buy/Sell

Panel A: 1 Week	**Forward Premium (bps)**			**CIP Wedge (bps)**		
	Before	After	Δ	Before	After	Δ
Dealer/Client Buy$						
EUR-USD	329.5	139.9	-189.6	-261.2	-70.2	190.9
GBP-USD	246.3	-32.8	-279.1	-244.5	36.9	281.4
JPY-USD	92.4	111.4	19.0	-66.4	-82.6	-16.2
Dealer/Client Sell$						
EUR-USD	395.8	236.8	-158.9	-327.4	-167.1	160.3
GBP-USD	1331.0	796.1	-534.9	-1329.2	-792.0	537.2
JPY-USD	773.2	-88.7	-861.9	-747.2	117.5	864.7
Panel B: 1 Month	**Forward Premium (bps)**			**CIP Wedge (bps)**		
	Before	After	Δ	Before	After	Δ
Dealer/Client Buy$						
EUR-USD	261.3	179.0	-82.3	-198.2	-117.4	80.8
GBP-USD	109.2	122.5	13.3	-108.1	-121.6	-13.5
JPY-USD	336.7	393.8	57.1	-315.1	-372.8	-57.7
Dealer/Client Sell$						
EUR-USD	343.9	241.1	-102.8	-280.8	-179.5	101.3
GBP-USD	208.1	196.4	-11.7	-207.0	-195.5	11.5
JPY-USD	368.6	433.2	64.6	-347.0	-412.3	-65.2
Panel C: 3 Months	**Forward Premium (bps)**			**CIP Wedge (bps)**		
	Before	After	Δ	Before	After	Δ
Dealer/Client Buy$						
EUR-USD	212.0	193.6	-18.4	-148.3	-133.6	14.7
GBP-USD	138.7	95.2	-43.4	-138.2	-95.1	43.0
JPY-USD	200.6	222.5	22.0	-180.2	-203.7	-23.5
Dealer/Client Sell$						
EUR-USD	216.3	181.8	-34.5	-152.6	-121.8	30.8
GBP-USD	128.6	82.6	-46.0	-128.1	-82.5	45.6
JPY-USD	216.2	196.9	-19.4	-195.9	-178.1	17.8

Note: This table reports median forward premiums and CIP wedges, in basis points, by currency pair, tenor, and market segment, using transaction-level data in a symmetric 24-hour window around the BOE USD auction timestamp (18 March 2020, 08:47:00 UTC). Market segments distinguish between trades where the dealer buys USD at the forward leg ("Dealer/Client Buy$") and trades where the dealer sells USD at the forward leg ("Dealer/Client Sell$"). "Before" refers to the 24 hours preceding the timestamp (evaluated with OIS closing rates as of 17 March 2020); "After" refers to the 24 hours following (OIS closing rates as of 18 March 2020). Forward premiums are annualized and reported in basis points. The CIP deviation is defined as in equation (1). Δ denotes After minus Before.