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# The High Frequency Effects of Dollar Swap Lines*

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**Abstract**

We study the effects of dollar swap lines using high frequency responses in asset prices around policy announcements. News about expanded dollar swap lines causes a reduction in liquidity premia, compression of deviations from covered interest parity (CIP), and depreciation of the dollar. Equity prices rise and the VIX falls, while the response of long-term government bond prices is mixed. The cross-section of high frequency responses implies that swap lines affect the dollar factor or the price of risk. Our findings are qualitatively consistent with models relating the supply of dollar liquidity to the broader economy.

**JEL codes**: E44, F31, G15
**Keywords**: dollar swap lines, liquidity premium, exchange rates

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# 1 Introduction

In recent crises, dollar swap lines between the U.S. Federal Reserve and foreign central banks have emerged as an integral part of the global policy response. In these arrangements, the Federal Reserve lends dollars to foreign central banks in exchange for foreign currency, and foreign central banks in turn lend the dollars to their domestic institutions. For instance, in response to the Covid-19 pandemic, the Federal Reserve lent $450bn via swap lines by May 2020. This accounted for virtually all of the credit extended through liquidity facilities during the crisis, and nearly 20% of the entire increase in its balance sheet by that time.[1]

Assessing the effects of dollar swap lines is challenging for two reasons. First, these tools are deployed precisely when the demand for dollars is high, making it difficult to separate the effects of demand shocks from policy-induced changes in supply. Second, these tools are deployed in concert with an array of other policy responses to crises such as conventional policy easing and quantitative easing programs, making it difficult to identify the effects of dollar swap lines alone.

In this paper, we provide high frequency estimates of the effects of dollar swap lines which can overcome these challenges. By focusing on tight intraday windows around dollar swap line announcements, we plausibly identify shocks to the future supply of dollar liquidity alone. We find that news about expanded dollar swap lines causes a reduction in liquidity premia, compression of deviations from covered interest parity (CIP), and depreciation of the dollar. Equity prices rise and the VIX falls, while the response of long-term government bond prices is mixed. Across currencies, the cross-section of high frequency responses implies that swap lines affect the dollar factor or the price of risk in currency markets. We focus on announcements during March 2020 but find that our results are robust to announcements during the September-October 2008 period as well. Our findings are qualitatively consistent with models relating the supply of dollar liquidity to other asset prices and the macroeconomy. Our results provide identified moments which can quantitatively discipline these models, and suggest that these models be broadened to relate the supply of dollar liquidity to CIP deviations, the dollar factor, and the price of risk.

Our empirical methodology focuses on the intraday responses to selected dollar swap line announcements in a broad range of asset classes. We first assemble a list

[1] See `https://www.federalreserve.gov/monetarypolicy/bst_recenttrends.htm`.

of all announcements pertaining to dollar swap lines by the Federal Reserve over the 2007-2010 and 2020-2021 periods. From these, we identify eight announcements which were not accompanied by simultaneous Federal Reserve news regarding other policies such as other crisis policies or FOMC statements. We then estimate the change in spot, futures, and forward prices of interest rates, exchange rates, equities, and bonds in tight windows around these eight announcements, using minute-by-minute data. Since this intraday data is more complete for the 2020-2021 announcements, we focus in the main text on these two announcements: on March 19, 2020 the Federal Reserve announced it would create temporary swap lines with nine central banks beyond the five central banks with which it already had standing facilities; and on March 20, 2020, the Federal Reserve announced it would increase the frequency of standing swap line operations from weekly to daily. Within two weeks from these announcements, swap line usage rose by more than $200bn.

We find that these swap line announcements compressed liquidity premia. We obtain close to zero responses of the Fed funds rate from futures prices, the three-month OIS rate, and the three-month Treasury bill rate. By contrast, we estimate sharp declines in three-month Libor rates from Eurodollar futures prices. The nearest three-month Libor rate fell by a cumulative $11bp$ and the four-quarter ahead rate fell by a cumulative $4bp$ (both annualized), with monotonically declining responses in between. All of these are statistically significantly different from zero at conventional levels. While these may reflect a decline in counterparty risk among financial institutions, our preferred interpretation is that they reflect a decline in the liquidity premium, given the comovement between the three-month Libor/OIS and Libor/Treasury bill spreads and other commonly used measures of liquidity premia such as the Treasury basis (Du, Im, and Schreger (2018a), Jiang, Krishnamurthy, and Lustig (2021)), which we are not able to measure intraday.

The swap line announcements also implied a dollar depreciation and compression of CIP deviations. In spot markets, we estimate a statistically significant depreciation of $72bp$ versus G7 currencies and $117bp$ versus emerging market currencies.[2] The three-month forward premium, the log difference in the three-month forward rate less the spot rate with both expressed in foreign currency per dollar, rose by a statistically

[2]The G7 currencies are the Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), Euro (EUR), British pound (GBP), Japanese yen (JPY), and New Zealand dollar (NZD). The emerging market currencies for which we have intraday data are the Brazilian real (BRL), Mexican peso (MXN), Russian ruble (RUB), and South African rand (ZAR).

significant 21*bp* versus G7 currencies (again annualized). This in turn compressed the synthetic cost of borrowing in dollars for foreigners, the foreign interbank rate less the forward premium, relative to the actual dollar interbank rate — i.e., the deviation from CIP. Indeed, for currencies with sufficiently frequent intraday quotes in three-month OIS rates, we estimate very close responses of the forward premium and CIP deviation, reflecting a negligible response of the OIS rate differential. Given an average annualized three-month CIP deviation of 82*bp* on March 18 prior to the announcements, a 21*bp* compression is economically meaningful.

Finally, the swap line announcements raised equity prices and lowered the VIX, while having mixed effects on long-term government bond prices. We estimate a 151*bp* increase in the S&P 500 futures price and broad increase in foreign equity futures prices, and 415*bp* decline in the VIX futures price. The latter effect is statistically significantly different from zero at all conventional levels. By contrast, long-term government bond futures prices rose on March 19 but fell on March 20, and the cumulative response was an order of magnitude smaller than for equities. We further note that our use of intraday data is essential to identify these effects: using the cumulative two-day change in these asset prices instead, the S&P 500 futures price fell by 486*bp*, the 30-year Treasury bond futures price rose by 488*bp*, and the dollar appreciated by 66*bp*, consistent with the flight to safety during this period.

The cross-section of responses to swap line announcements implies that these policies affect the dollar factor or lower the price of risk in currency markets. We project daily changes in spot exchange rates and CIP deviations on daily changes in the broad dollar index over January 2007 through April 2020. The resulting dollar betas have been shown to price the cross-section of average currency returns and CIP deviations (Verdelhan (2018), Avdjiev, Du, Koch, and Shin (2019)). We find that these dollar betas also line up with the high frequency responses of spot exchange rates and forward premiums to swap line announcements. The explanatory power of dollar betas in fact drives out other potential variables such as the average CIP deviation in each country in the month prior to the announcements, or the usage of the swap lines by each foreign central bank subsequent to the announcements. One interpretation is that news of more generous swap lines affects the dollar factor itself, generating cross-sectional effects which line up with unconditional exposures to the factor. Another is that news of more generous swap lines reduces investors' required compensation to bear exposure to the dollar factor (the price of risk), generating

cross-sectional effects which again line up with exposures to the factor.

Our results have implications for existing empirical studies and for models relating the supply of dollar liquidity to other asset prices and the macroeconomy. On the empirical side, our results imply that studies of dollar swap lines which exploit cross-sectional differences across countries in usage of swap lines may be misspecified, to the extent that usage is not the relevant dimension generating heterogeneity in the effects of swap lines (and instead, exposures to risk factors such as the dollar factor are). This is particularly problematic in the case of exchange rates, because countries with more usage tend to be those with *smaller* dollar betas and thus smaller appreciations. With a differences-in-differences design based on usage, one might erroneously conclude swap lines weaken foreign currencies. On the theoretical side, our findings are qualitatively consistent with the predictions of existing models that an increase in the supply of dollar liquidity is associated with lower liquidity premia, a weaker dollar, and an increase in equity prices. Our estimates imply that these models should be broadened to relate the supply of dollar liquidity to CIP deviations, the dollar factor, and the price of risk in currency markets. More broadly, our estimates can be used as empirical targets in the quantitative development of these models.

**Related literature** Our analysis of dollar swap lines sits between rapidly growing literatures estimating the liquidity premium of safe, dollar-denominated assets and deviations from CIP. Our contribution to these literatures is to identify the effects of a particular structural shock of interest on liquidity premia, CIP deviations, exchange rates, and other asset prices. Jiang et al. (2021) and Engel and Wu (2023) document that a lower Treasury liquidity premium is associated with a depreciation and expected appreciation of the dollar. Avdjiev et al. (2019) document that a weaker dollar is associated with a compressed CIP deviation. All three papers identify important unconditional comovements between these variables. Our analysis identifies a specific shock to the supply of dollar liquidity and thus liquidity premia, and traces out the resulting effects on other asset prices including exchange rates and CIP deviations. In this respect it builds on Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), Krishnamurthy and Li (2022), and other papers which estimate the demand for money and near-money assets using shocks to supply. The innovation relative to these papers is to focus on dollar swap lines as opposed to Treasury supply, and to study the effects on asset prices beyond liquidity premia.

Our paper is of course not the first to study dollar swap lines. Among other recent important contributions, Baba and Packer (2009a,b) demonstrate that swap line operations reduced CIP deviations in 2008; Bahaj and Reis (2022) demonstrate both theoretically and empirically that swap lines put a ceiling on CIP deviations and raised the price of corporate bonds disproportionately held by banks with access to the swap lines in 2011; and Bahaj and Reis (2020), Cetorelli, Goldberg, and Ravazzolo (2020a,b), and Goldberg and Ravazzolo (2022) demonstrate that swap lines reduced CIP deviations and supported the U.S. corporate credit market in 2020. Relative to this work, we look beyond CIP deviations and corporate bonds to also estimate the effects of these policies on liquidity premia, exchange rates, aggregate stock markets, and the yield curve. Relatedly, we use intraday data, whereas these studies have used daily or lower frequency data, and variation across banks or countries to identify their effects of interest.[3,4] This allows us to estimate effects on asset prices which are not amenable to a differences-in-differences design (such as dollar Libor, U.S. equities and Treasury bonds, and the VIX), and to ask whether such a design appropriately identifies effects on asset prices such as exchange rates and CIP deviations.

# 2 Empirical approach

We begin by outlining our empirical approach.

## 2.1 Dollar swap line announcements

We first identify the subset of swap line announcements by the Federal Reserve for our analysis. Over the 2007-2010 period, we begin with the set of 15 swap line announcements reported in Table 1 of Goldberg, Kennedy, and Miu (2011). Over the 2020-2021

[3]In doing so, our paper complements large literatures on the high frequency effects of other central bank policies including conventional monetary policy (Cook and Hahn (1989), Kuttner (2001), Cochrane and Piazzesi (2002), Gurkaynak, Sack, and Swanson (2005a,b), among others) and quantitative easing (Gagnon, Raskin, Remache, and Sack (2011), Krishnamurthy and Vissing-Jorgensen (2011), Swanson (2011), among others).

[4]We are aware of two other papers using intraday data in studies of dollar swap lines. Bevilacqua, Danielsson, Ergun, Uthemann, and Zigrand (2023) use intraday data to characterize policy surprises around macroeconomic announcements, including of swap lines. The outcome variables of interest are daily changes in the risk of large price drops from options prices. Cesa-Bianchi, Eguren-Martin, and Ferrero (2022) use intraday exchange rate data to quantify the surprise in swap line announcements. The outcome variables of interest are the daily responses of other asset prices.

period, we survey all press releases on the Federal Reserve website and identify six announcements pertaining to swap lines. From this list of 21 announcements, there are eight which are not accompanied by a simultaneous Federal Reserve announcement regarding other policies, and for which the timestamp is provided on the Federal Reserve website. Appendix A summarizes the initial sample of 21 announcements and the final sample of eight which we study.

In the main text, we focus on the effects of the two announcements in our final sample from the 2020-2021 period. These are the March 19, 2020 announcement that the Federal Reserve would create temporary swap lines with nine central banks beyond the five central banks with which it already had standing facilities,[5] and the March 20, 2020 announcement that the Federal Reserve would increase the frequency of standing swap line operations from weekly to daily. Appendix C depicts the total usage of swap lines at the end of each day in March and April 2020. Within two weeks from these announcements, swap line usage rose by more than $200bn.

## 2.2 Data

We conduct our high frequency analysis of the effects of these swap line announcements using asset price data from FirstRate Data and Refinitiv. We obtain transaction prices at the start of each minute ("opening prices"), transaction prices at the end of each minute ("closing prices"), and trading volume over the minute for futures contracts and spot exchange rates from FirstRate Data. We analogously obtain bid and ask quotes at the start of each minute, bid and ask quotes at the end of each minute, and the number of bid and ask quotes over the minute for forwards, OIS, and Treasury bills from Refinitiv. We average the data for bids and asks.

We primarily focus on futures contracts for interest rates, equities, and bonds because several of the announcements we study occur outside of regular market hours for the underlying assets on the relevant exchanges. Where spot prices for these underlying assets are available (from Refinitiv), we have verified that the responses of spot prices and the nearest futures prices are very similar. Because trading is more thin around several of the announcements in the 2007-2010 period even using futures

[5]Temporary swap lines were created with the Reserve Bank of Australia, Banco Central do Brasil, Danmarks NationalBank, Bank of Korea, Banco de Mexico, Norges Bank, Reserve Bank of New Zealand, Monetary Authority of Singapore, and Sveriges Riksbank. Standing facilities exist with the Bank of Canada, Bank of England, Bank of Japan, European Central Bank, and Swiss National Bank.

prices, we focus on the March 2020 announcements in the main text.

## 2.3 Methodology

We follow the literature on the high frequency analysis of conventional monetary policy shocks in focusing on asset price responses in a tight window around each swap line announcement. In particular, for asset $i$ around an announcement at $t$, let $p_{it}^-$ denote the last price 10 minutes prior to the announcement time.[6] Let $p_{it}^+$ denote the first price 20 minutes after the announcement time. We define the response of asset $i$ around the announcement (in basis points) as

$$\text{response}_{it} \equiv 10000(\log p_{it}^+ - \log p_{it}^-).$$

The response is set to missing if there is no trading volume in the 10-20 minutes prior to or 20-40 minutes after the announcement.[7] For interest rate futures, we multiply this response by minus one to report the change in the implied interest rate. For forward premiums, $\log p_{it}$ is the forward premium, and for CIP deviations it is the log dollar rate less log synthetic dollar rate. For averages across assets (such as the average exchange rate response), we compute simple averages.

We build on Krishnamurthy and Vissing-Jorgensen (2011) in assessing the statistical significance of these responses as follows. For concreteness, consider the March 19, 2020 and March 20, 2020 announcements at 9:00 EDT and 10:00 EDT, respectively, studied in the next section. For every hour on every trading day in March 2020 (denoted $t$), we follow the above approach in defining the response of each asset $i$ around $t$. For each asset $i$, we run the OLS regression

$$\text{response}_{it} = \delta_{0i} + \delta_{1i} 1\{\text{announcement at } t\} + \epsilon_{it}.$$

We then use the delta method to report the standard error of the estimate $2\left(\hat{\delta}_{0i} + \hat{\delta}_{1i}\right)$, which equals the cumulative response to the announcements of interest. Since the average hourly change outside swap line announcements ($\hat{\delta}_{0i}$) is close to zero for all asset prices, we can interpret asset prices with significantly different responses from

[6] We define the announcement time as the press release time on the Federal Reserve website. In all cases we have verified that the first articles referencing these announcements on Factiva occur within a few minutes of the press release time.

[7] Thus, the maximal event window in our analysis is one hour around the announcement.

zero as also significantly different from other hours in March 2020.

# 3 Results

We now present our results on the high frequency responses to dollar swap line announcements.

**Main results** Table 1 reports our main results for the March 2020 announcements. In the last column of each panel we report the standard error of the cumulative response, which is computed as described in the prior section. Figure 1 depicts selected asset prices in the two hours around each announcement. Appendix C summarizes the responses of additional asset prices, and provides additional figures of asset prices and trading volumes around each announcement. For all assets and announcements emphasized in the main text, there is non-zero trading volume in the minutes before and after each announcement.

Panel A of Table 1 summarizes the response of interest rates from futures contracts. There is neither an economically nor statistically significant response of the expected Fed funds rate in the current month or three months ahead,[8] indicating that the expansion of dollar swap lines was not expected to affect the path of policy rates at least in the short term. By contrast, there are economically and statistically significant declines in expected three-month Libor rates, of $11bp$ cumulatively for the current Eurodollar contract and $4bp$ cumulatively for the four-quarter ahead contract, with declining responses in between. The sharp declines in the nearest Libor rate around each announcement are evident from the first row of Figure 1. While the decline in Libor rates may reflect a decline in counterparty risk among financial institutions, our preferred interpretation is that they reflect a decline in the liquidity premium, given the absence of any meaningful change in the three-month OIS rate or Treasury bill rate reported in appendix C.[9] Appendix B demonstrates in lower frequency data that the three-month Libor/OIS and Libor/Treasury bill spreads comove with other

[8] We multiply the response of the current Fed funds rate by $\frac{T}{T-t-1}$, where $T$ denotes the number of days in the month and $t$ denotes the announcement day, to account for the days already elapsed.

[9] To be clear, a decline in counterparty risk and in the liquidity premium are not mutually exclusive, and might be reinforcing. Credit default swap (CDS) spreads suggest that counterparty risk among financial institutions indeed fell around the swap line announcements. For instance, the iTraxx Europe Senior Financials 5-year CDS spread fell by $28bp$ from March 18 to March 20. See also Forbes, Friedrich, and Reinhardt (2023).

| | 3/19 | 3/20 | Sum | (SE) | | 3/19 | 3/20 | Sum | (SE) |
|---|---|---|---|---|---|---|---|---|---|
| *A. Interest rate futures* | | | | | *C. Forward premiums* | | | | |
| Fed funds, current | 1 | -1 | 1 | (4) | AUD, 3 mo | 0 | 3 | 4 | (3) |
| Fed funds, 3 mo ahead | 0 | 0 | 0 | (2) | CAD, 3 mo | -0 | 8 | 7 | (2) |
| Eurodollar, current | -7 | -4 | -11 | (2) | CHF, 3 mo | 5 | 28 | 34 | (7) |
| Eurodollar, 1 qtr ahead | -6 | -3 | -9 | (2) | EUR, 3 mo | 6 | 43 | 49 | (8) |
| Eurodollar, 2 qtr ahead | -4 | -3 | -7 | (2) | GBP, 3 mo | -2 | 19 | 17 | (5) |
| Eurodollar, 3 qtr ahead | -3 | -2 | -5 | (2) | JPY, 3 mo | -2 | 40 | 38 | (8) |
| Eurodollar, 4 qtr ahead | -3 | -1 | -4 | (2) | NZD, 3 mo | -1 | 0 | -1 | (3) |
| *B. Spot exchange rates* | | | | | Average, 3 mo | 1 | 20 | 21 | (3) |
| AUD | -82 | -35 | -117 | (44) | *D. Equity index futures* | | | | |
| CAD | -65 | -19 | -84 | (23) | S&P 500 | 40 | 112 | 151 | (110) |
| CHF | -28 | -31 | -59 | (20) | Euro Stoxx 50 | 30 | 102 | 132 | (137) |
| EUR | -30 | -40 | -70 | (21) | FTSE 100 | -6 | -24 | -30 | (113) |
| GBP | -6 | -81 | -87 | (30) | Nikkei 225 | 97 | 108 | 205 | (118) |
| JPY | 7 | -4 | 3 | (25) | VIX | -33 | -382 | -415 | (138) |
| NZD | -73 | -21 | -94 | (40) | *E. Bond futures* | | | | |
| Average | -40 | -33 | -72 | (22) | Treasury, 10 yr | 23 | -9 | 13 | (19) |
| | | | | | Treasury, 30 yr | 49 | -30 | 20 | (50) |

Table 1: high frequency responses

Notes: responses are defined as the log open price of the first one-minute bar with positive trading volume beginning 20 minutes after the press release time, less the log close price of the last one-minute bar with positive trading volume ending 10 minutes before the press release time, multiplied by 10000 (thus reported in *bp*). Interest rate responses multiplied by minus one, so these correspond to responses of yields. Response is missing (denoted .) if there is no trading volume in 10-20 minutes prior to the press release time or 20-40 minutes after the press release time. Standard errors of cumulative response reported under null of no difference in responses versus other hours in March 2020.

measures of liquidity premia which we are unable to measure intraday, such as the Treasury basis studied in Du et al. (2018a) and Jiang et al. (2021).

Panel B of Table 1 summarizes the response of spot exchange rates. Throughout the paper, we write all exchange rates as foreign currency per dollar. The dollar depreciates by an economically and statistically significant amount versus all currencies except the Japanese yen. Taking the simple average across these seven currencies, the dollar depreciates by $72bp$ cumulatively. The second row of Figure 1 depicts these average responses: the dollar depreciation is sharp around both announcements. Appendix C demonstrates that similar results are obtained for the four emerging market currencies in our data, though trading volume is more thin than for the G7 currencies. The dollar depreciates by $117bp$ cumulatively against these currencies, also statistically significant at conventional levels.

Panel C of Table 1 summarizes the response of three-month forward premiums, defined as the log forward rate less log spot rate, annualized. The forward premiums rise by an economically and statistically significant amount for all currencies except the Australian dollar and New Zealand dollar, driven in particular by the March 20 announcement of an increased frequency of standing swap line operations. On average, the forward premium rises by $21bp$ across both announcements. The third row of Figure 1 depicts these average responses. Appendix C reports the responses of three-month CIP deviations using OIS rates, defined as the dollar OIS rate less the foreign OIS rate plus the forward premium. For the four currencies with sufficiently frequent intraday quotes for OIS rates to obtain estimates, the response of the three-month CIP deviation is very close to the response of the forward premium, as the response of the OIS rate differential is small. We conclude that our estimated $21bp$ rise in the average forward premium across all seven currencies corresponds to a roughly $21bp$ compression in the average CIP deviation across these currencies.[10]

Panel D of Table 1 summarizes the response of equities. The S&P 500 rises by a cumulative $151bp$. Two of the three foreign stock markets also rise in their local currencies, but all of them would rise in dollars given the dollar depreciation discussed above. The VIX falls by an economically and statistically significant $415bp$ cumulatively. While the (local currency) stock market responses are otherwise insignificantly

[10]Appendix C also reports the responses of one-year CIP deviations using Libor rates, based on the prices of cross-currency basis swaps. The swap line announcements compress these one-year CIP deviations statistically and economically significantly as well.

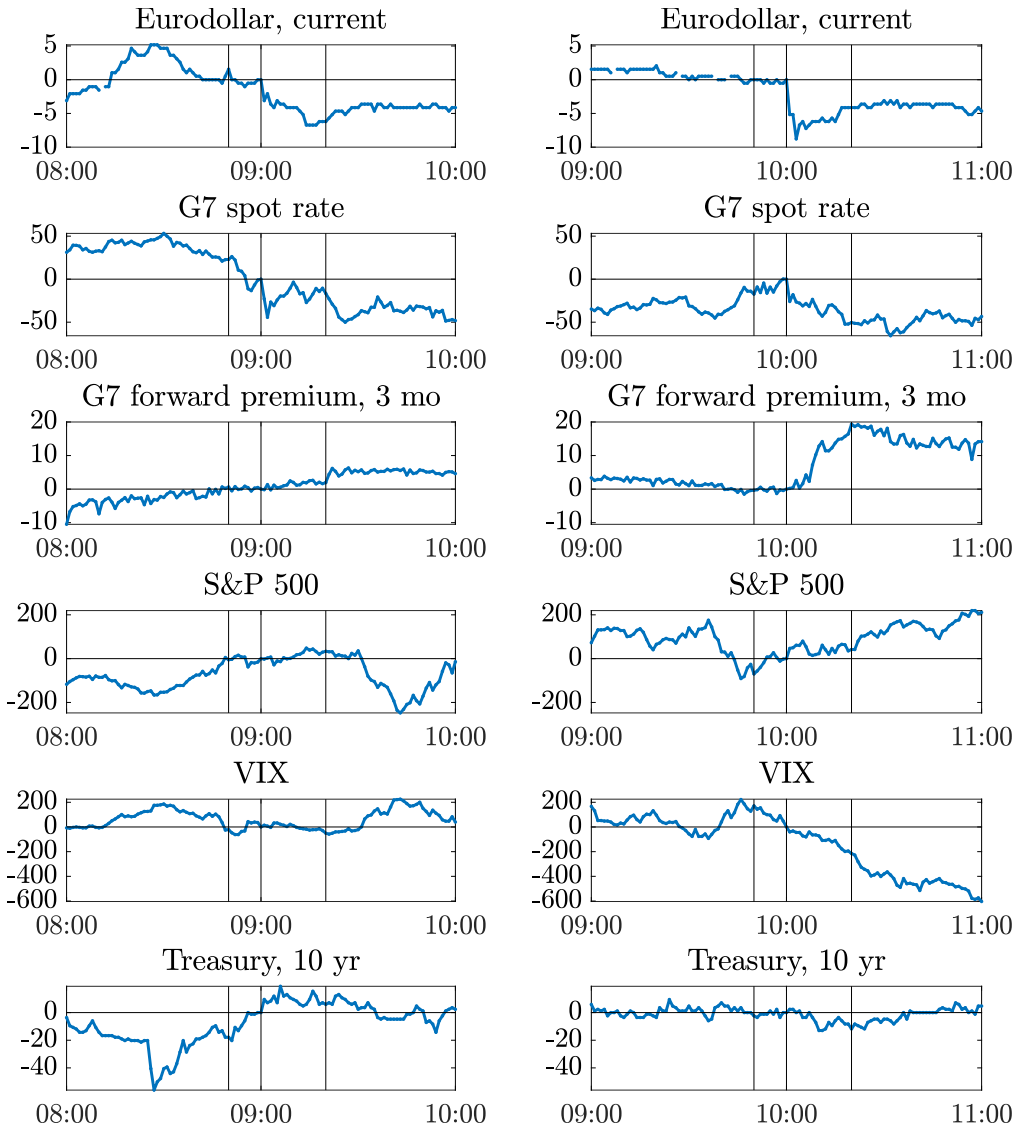


Figure 1: selected asset prices on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict log open prices by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. In first row, Eurodollar responses multiplied by minus one to depict response of three-month Libor yields. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

or marginally different from zero, the fourth and fifth rows of Figure 1 demonstrate sharp responses in these asset prices around the March 20, 2020 announcement in particular. Appendix C demonstrates similar results for the MSCI EM Equity Index. Overall, we view this as reasonably compelling evidence that equity markets rise and the VIX falls around news of expanded dollar swap lines.

Finally, panel E of Table 1 and the last row of Figure 1 summarize the response of long-term Treasury bonds from futures contracts. These responses are more mixed, with fairly sharp rises on the first announcement, but declines on the second. The cumulative effect is a mild increase in long-term Treasury bond prices, notably smaller than most of the equity market responses, and in no case statistically different from zero. Appendix C demonstrates similar results for Treasury bonds of other maturities as well as Gilts and euro bonds. We conclude that the response of government bond prices is more muted than for the other asset prices we study.

**One-day changes** Appendix C presents the one-day change in each asset price, rather than the high frequency response. Using the cumulative two-day change in these asset prices, the dollar appreciates by $66bp$, the S&P 500 futures price falls by $486bp$, and 30-year Treasury bond futures price rises by $488bp$, consistent with the flight to safety during this period. The interest rate responses are now inconsistent across announcements, some foreign currencies appreciate versus the dollar while others depreciate, and the CIP deviations widen on average on March 19. Overall, this underscores the importance of focusing on intraday windows to identify the effects of swap lines on our asset prices of interest. At daily or lower frequencies, the multitude of shocks affecting financial markets during this volatile period makes it difficult to infer the effects of (news about) changes in dollar supply alone.

**2007-2010 announcements** Appendix D also reports the high frequency response of asset prices around the six announcements during the 2007-2010 period. In many cases we do not observe responses within our windows, in part because several of these announcements occurred in the very early morning. However, where we have available data, we broadly find that our conclusions from the March 2020 announcements are robust: these announcements caused a reduction in Libor rates, a depreciation of the dollar, a rise in forward premiums, an increase in the S&P 500, and a mixed and muted response of Treasury bond prices.

# 4 Exploring the cross-section

We now further explore the heterogeneity in high frequency responses to swap line announcements across currencies.

We compare the responses to swap line announcements with the unconditional exposures of spot exchange rates and CIP deviations to the dollar factor in currency markets ("dollar betas"). We estimate these betas by running regressions of the form

$$\Delta \log (\text{spot exchange rate})_{it} = \alpha_i + \beta_i \Delta \log (\text{broad dollar index})_{it} + \varepsilon_{it}$$

on daily data over January 1, 2007 through April 30, 2020, and analogously for daily changes in CIP deviations on the left-hand side.[11] The dollar factor is here measured as the strength of the dollar against its major trading partners, as reported by the Federal Reserve Board. Betas with respect to this factor or similarly related measures have been shown to price the cross-section of currency returns and CIP deviations (Verdelhan (2018), Avdjiev et al. (2019)). The betas are summarized by our estimated loadings $\hat{\beta}_i$ for spot exchange rates, and analogously for CIP deviations.

Figure 2 demonstrates that the high frequency responses of exchange rates and forward premiums to the March 2020 announcements line up with the unconditional dollar betas of exchange rates and CIP deviations. Appendix E demonstrates that these results are robust to including the high frequency response of emerging market exchange rates or using alternative estimates of dollar betas which exclude crisis periods, which exclude the currency in question from the definition of the broad dollar index, or which include additional factors as in Verdelhan (2018). The appendix further demonstrates that the cross-section of currency responses during the 2007-2010 announcements are again correlated with dollar betas.[12]

Dollar betas in fact drive out other potential explanations for the cross-section of exchange rate and forward premium responses. In appendix E, we compare these high frequency responses to the 30-day moving average of CIP deviations in each currency

[11] Following Avdjiev et al. (2019), we further multiply the daily change in the CIP deviation by 100 (i.e, expressed in basis points) before running the regression. We obtain bilateral spot exchange rates and the broad dollar index from the Federal Reserve Board, and three-month (Libor-based) CIP deviations from Du et al. (2018a), updated through 2020 and shared with us by Wenxin Du.

[12] Appendix E also replaces the dollar with the euro, pound, or yen as our base currency. We find that the high frequency response of currencies and CIP deviations similarly line up with betas in the case of the yen; line up with betas in the case of the pound, but with the opposite sign; and exhibit a much weaker relation with betas in the case of the euro.

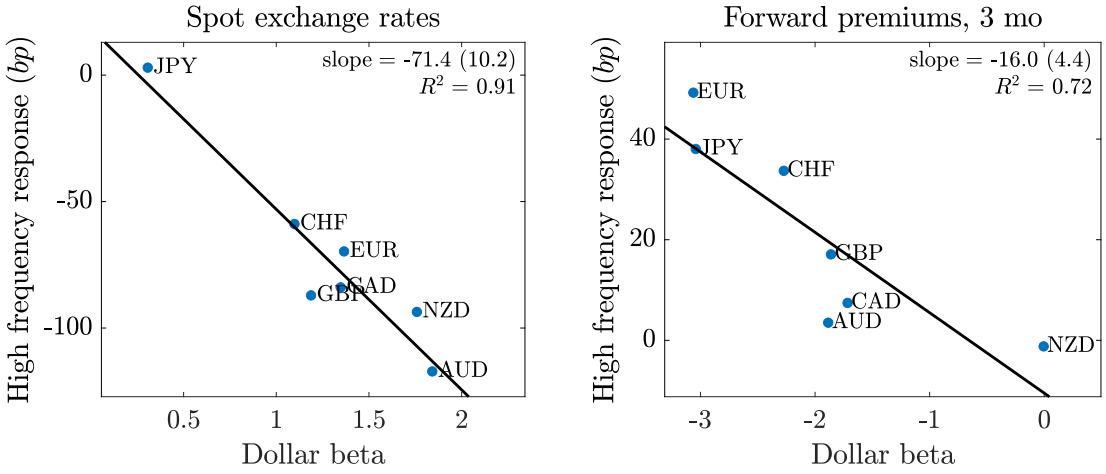


Figure 2: high frequency responses and dollar betas

Notes: dollar betas are regression coefficients of daily change in log bilateral exchange rate on daily change in log broad dollar index (left panel), and daily change in bilateral CIP deviation on daily change in log broad dollar index (right panel), estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

as of March 18, 2020 (prior to the announcements), as well as to the peak usage of swap lines by each foreign central bank from March 21, 2020 (after the announcements) through the end of the year. The former measure is a natural candidate to explain take-up of swap lines, as there is a greater incentive to bid for dollars via swap lines if CIP deviations are high; the latter measure is a direct measure of take-up itself. Appendix E demonstrates that in univariate specifications, both measures are statistically and economically significant explanatory variables for the cross-section of exchange rate and forward premium responses to swap line announcements. However, once the dollar betas are also included as potential explanatory variables, the significance of these other variables is lost.

One case study which helps to make sense of this result is the response of the Japanese yen. The yen had among the widest CIP deviations vis-à-vis the dollar prior to the swap line announcements, and the Bank of Japan was the counterparty with the largest usage of swap lines in 2020. However, in spot markets, the yen appreciated the least versus the dollar upon the swap line announcements, even though the forward premium rose substantially. The smaller dollar beta of the yen but sizable dollar beta of yen CIP deviations is able to account for these responses in a way that the moving

average of CIP deviations or swap line usage cannot.

The explanatory power of dollar betas for the high frequency responses to swap lines is consistent with two mechanisms. One is that news of more generous swap lines affects the dollar factor itself, generating cross-sectional effects across spot exchange rates and forward premiums which line up with unconditional exposures to the factor. Another is that news of more generous swap lines reduces the price of risk — that is, investors' required compensation to bear a unit of exposure to the dollar factor. This would affect spot exchange rates and forward premiums differentially according to their degree of exposure to the factor.

# 5 Implications of our findings

We finally discuss the implications of our findings in the context of the broader literatures on dollar swap lines, liquidity premia, and CIP deviations.

**Effects of dollar swap lines** Our high frequency identification approach is distinct from the existing literature which estimates the effects of dollar swap lines using a differences-in-differences design across countries with differing access to or take-up of swap lines. Our results on the explanatory power of dollar betas suggests that such empirical designs may not in fact capture the causal effects of swap lines, to the extent that access or take-up are not the relevant dimensions generating heterogeneity in the effects of swap lines (and instead, exposures to aggregate risk factors such as the dollar factor are).

This is particularly problematic in the case of exchange rates, because countries with more usage tend to be those with *smaller* dollar betas (such as the yen, as previously described). Hence, in appendix E we show that a univariate specification would find that more usage of swap lines is associated with a relatively *weaker* foreign currency. This is less obviously a problem for estimates of the effects on CIP deviations, where countries with more usage tend to have larger (more negative) CIP dollar betas. Hence, a univariate specification would find that more usage of swap lines is associated with a more compressed CIP deviation.

**Liquidity premia, CIP deviations, and exchange rates** It is useful to compare the causal effects of swap line announcements which we estimate to the relationships

between liquidity premia, CIP deviations, and exchange rates estimated in the prior literature without conditioning on identified shocks.

The swap line-induced effects on liquidity premia and exchange rates are comparable to the unconditional relationship between these variables previously estimated. Jiang et al. (2021) estimate that a fall in the annualized Treasury basis by $1pp$ is associated with a $10pp$ depreciation in the dollar (their Table III). Engel and Wu (2023) estimate with a slightly different specification and sample period that a fall in the annualized Treasury basis by $1pp$ results in a $6pp$ depreciation of the dollar (their Table 1 or 2). We estimate a $11bp$ decline in the nearest annualized three-month Libor rate and $72bp$ depreciation of the dollar (our Table 1). Linearly extrapolating, it follows that a $1pp$ decline in the annualized three-month Libor rate is associated with a $0.72 \times (1/0.11) = 7pp$ depreciation, comparable to these papers.[13] In other words, the relationship between liquidity premia and exchange rates conditional on our swap line announcements is consistent with the unconditional relationship between these variables uncovered in the prior literature.

The swap line-induced effects on CIP deviations and exchange rates are an order of magnitude larger than the unconditional relationship between these variables previously estimated. Avdjiev et al. (2019) estimate that a broad dollar depreciation by $1pp$ is associated with a $2bp$ compression of the average three-month CIP deviation (their Table 1). We estimate that a $0.7pp$ dollar depreciation is associated with a $21bp$ increase in the average three-month forward premium and thus compression of the CIP deviation (again our Table 1). One reason for the larger responsiveness of CIP deviations to the dollar exchange rate in our estimates may be that markets are more segmented in crises, generating a larger response of CIP deviations than in normal times. Relatedly, it may be that the elasticity of the CIP deviation is comparable over time, but the semi-elasticity varies with the level of the CIP deviation. It may also be that the structural shocks generating the unconditional comovements in Avdjiev et al. (2019) are of a different nature than the changes in dollar supply which we study. These are all interesting questions for future study.

[13] Recall that we estimate very small changes in the three-month dollar OIS rate and Treasury bill rate. Our estimates are thus comparable to Jiang et al. (2021) and Engel and Wu (2023) because the unconditional volatilities of the three-month Libor/OIS and Libor/Treasury bill spreads are of the same order of magnitude as the Treasury basis, as shown in appendix B.

**Models of dollar liquidity and broader economy** Our findings finally relate to a growing body of structural models studying the special demand for liquid, dollar assets and its macroeconomic consequences.[14]

Our estimates are at least qualitatively consistent with the predictions of these models. These models predict that an increase in the supply of dollar liquidity should be associated with a compression of the liquidity premium, a dollar depreciation, and a rise in the price of dollar-denominated assets which do not provide liquidity, in the latter two cases conditional on an unchanged path of nominal interest rates. These predictions are qualitatively consistent with the decline in the liquidity premium, dollar depreciation, and rise in equity prices which we estimate. Quantitatively, confronting these models' predicted effects of an increase in dollar supply against our estimates would put discipline on their underlying structural parameters governing the relative demand for assets of varying liquidity, currency, and riskiness. Such models can in turn be useful in quantifying the effects of swap lines on outcomes which cannot be measured at high frequencies directly in the data, such as output.

Our estimates also suggest that these models should be enriched to study the link between liquidity premia and deviations from CIP, the dollar factor in currency markets, and the price of risk. One natural mechanism linking liquidity premia and CIP deviations is that the foreign demand for safe dollar assets may be accompanied by a demand to hedge dollar exposure, consistent with patterns documented in Du and Huber (2023), together with balance sheet constraints on banks in providing such hedging services, consistent with the findings of Du, Tepper, and Verdelhan (2018b).[15] In such an environment, the provision of dollar liquidity via swap lines would ease the demand for safe dollar assets in the rest of the world, in turn easing the demand for hedging services and thus reducing CIP deviations. A structural account of the link between liquidity premia, the dollar factor, and the price of risk remains an open question and fruitful direction for future work.[16] For instance, greater dollar liquidity may endogenously reduce the price of risk by relaxing financial constraints facing intermediaries in currency markets.

[14] In the open economy see, for instance, Engel (2016), Bianchi, Bigio, and Engel (2022), Devereux, Engel, and Wu (2023), Jiang, Krishnamurthy, and Lustig (2023), and Kekre and Lenel (2024).

[15] This is related to the link between Libor-based CIP deviations and the Treasury basis proposed in Jiang et al. (2021), and adds a demand for safe dollar assets to the hedging channel of exchange rate determination in Liao and Zhang (2021).

[16] See Bacchetta, Davis, and van Wincoop (2023) for recent progress along this dimension.

Bahaj and Reis (2022) argue that swap lines enable the Federal Reserve to serve as a lender of last resort to foreign banks with access. Our emphasis on liquidity premia, the dollar factor, and the price of risk is complementary with this view but is especially useful to make sense of three sets of our findings. First, as previously noted, a reduction in liquidity premia can explain why the dollar exchange rate depreciates upon swap line announcements. Second, a reduction in liquidity premia can explain why the price of dollar assets which do not provide liquidity (such as equities) rise by more than those which do (such as Treasuries). Third, a decline in the dollar factor or price of risk accounts for the cross-section of responses to swap line announcements. An important implication is that the effects of swap lines are not simply concentrated among those countries with access to these facilities.

# 6 Conclusion

In this paper we have studied the effects of dollar swap lines using the high frequency responses of asset prices around policy announcements. We find that news about expanded dollar swap lines causes a reduction in liquidity premia, compression of deviations from CIP, and depreciation of the dollar. Equity prices rise and the VIX falls, while the response of long-term government bond prices is mixed. The cross-section of high frequency responses across currencies implies that swap lines affect the dollar factor or price of risk in currency markets. Our findings are qualitatively consistent with models relating the supply of dollar liquidity to asset prices and the macroeconomy. Our estimates can be used to quantitatively discipline these models, and suggest that they be broadened to relate the supply of dollar liquidity to CIP deviations, the dollar factor, and the price of risk.

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# Appendix for Online Publication

## A Swap line announcements

In this section we outline the set of 21 swap line announcements from which we obtain our sample of eight announcements studied in the main text and in this appendix.

Table 2 summarizes the 15 announcements over the 2007-2010 period from Table 1 of Goldberg et al. (2011). We obtain the press release time from the Federal Reserve's website.[17] We also characterize simultaneous Federal Reserve news by reading the press releases and searching the Federal Reserve website for other press releases at the same time as the ones of interest. We highlight the six announcements without simultaneous news from the Federal Reserve, and with a posted press release time.

Table 3 summarizes six announcements from the 2020-2021 period.[18] We obtain these by manually reading the titles of all Federal Reserve press releases over these two years and identifying those referencing the swap lines, and we characterize the associated press release times and simultaneous Federal Reserve news as above. We highlight the two announcements without simultaneous news from the Federal Reserve, and with a posted press release time.

The resulting eight announcements form our sample of analysis in the main text and in this appendix.

## B Measures of liquidity premia

In this section we relate the three-month Libor/OIS and Libor/Treasury bill spreads (which we can measure intraday) to the swapped G10 government bond/Treasury bill spread (which we cannot measure intraday).[19] The latter is one commonly used

[17] In four cases, no press release time is provided.

[18] There is one announcement on March 31, 2020 pertaining to the Foreign and International Monetary Authorities (FIMA) repo facility which could have been added to this list. While this is not the same as the dollar swap lines, it is similar. However, the aggregate usage of the FIMA repo facility was negligible relative to the swap lines, so we exclude this announcement from the paper. We have conducted an intraday analysis for this announcement and find directionally similar, but smaller, effects on asset prices from this announcement versus the ones studied in the paper.

[19] To be more precise, in intraday data, we measure the nearest three-month Libor rate from the current Eurodollar *futures* market, and the three-month OIS and Treasury bill rates from the *cash* markets. This is because the cash Libor rate is set once a day. The Libor/OIS and Libor/Treasury bill spreads plotted later in this section are using daily data in which all rates refer to the cash rates.

measure of the liquidity premium on safe, liquid dollar-denominated assets and has been studied by Du et al. (2018a) and Jiang et al. (2021), among others.

Figure 3 depicts these measures from January 2002 through June 2020. For readability, we plot the average values over each month for each series. There is a striking comovement across these measures, suggesting they all capture the liquidity or safety of money-like dollar assets. The relative liquidity/safety provided by Treasury bills versus Libor deposits is straightforward to understand. The relative liquidity/safety provided by the OIS rate versus Libor deposits may reflect that the fixed leg of an OIS contract is like a term deposit at the Federal Reserve, as the floating leg of the contract pays the Federal funds rate.

# C Additional evidence on 2020 announcements

In this section we present additional evidence on the effects of the March 2020 swap line announcements studied in the main text.

Figure 4 depicts the total usage of swap lines at the end of each day in March and April 2020. Within two weeks from these announcements, swap line usage rose by more than $200bn.

Figures 5-12 present asset prices and trading volume (for futures) and number of quotes (for forwards) by one-minute bar for the assets summarized in Table 1 in the main text. Trading in Fed funds futures is more sporadic than the others, but in all cases there is non-zero volume around the announcements.

Table 4 provides additional high frequency responses supplementing those in Table 1 in the main text. Panel A of Table 4 reports the responses of three-month CIP deviations using OIS rates. There are only sufficiently frequent intraday quotes of OIS rates for four currencies to estimate these, and of these it is evident from Figures 13 and 14 which follow that quotes in Canadian dollar and New Zealand dollar OIS rates are quite thin around the announcements. For the euro and British pound, however, the responses of the three-month CIP deviations are essentially identical to those of the three-month forward premiums in Table 1. Even for the Canadian dollar and New Zealand dollar, the response of forward premiums and CIP deviations are within a few basis points of each other. The average compression of the CIP deviation is economically meaningful relative to the $82bp$ average CIP deviation among the G7

currencies on March 18, prior to the announcements.[20]

Panel B of Table 4 reports the responses of one-year CIP deviations using Libor rates, based on the prices of cross-currency basis swaps. Again there are only sufficiently frequent intraday quotes for four currencies to estimate these. Averaging across the Swiss franc, euro, British pound, and Japanese yen, the swap line announcements compress the one-year CIP deviation by a statistically significant $6bp$. This is again economically significant relative to the average one-year CIP deviation of $26bp$ among these currencies on March 18, prior to the announcements. Figures 15 and 16 depict the responses and volume of cross-currency basis swap quotes.

Panel C of Table 4 reports the responses of the three-month OIS and Treasury bill rates. There is essentially no change in these rates, in contrast to the Libor rates discussed in the main text. Figures 17 and 18 depict the responses and volume of quotes for these assets.

Panel D of Table 4 reports the responses of emerging market currencies and equities. These responses are consistent with the G7 currency and equity responses in Table 1: the dollar depreciates and equities rise, in the former case by a statistically significant amount. Figures 19 and 20 depict the associated responses and trading volume; as is evident, trading in the emerging market contracts is more thin than for the G7 countries.

Finally, panel E of Table 4 reports additional responses of bond prices. As in the case of the bonds studied in Table 1, some bond prices rise, some fall, and the overall responses are muted. Figures 21 and 22 depict the responses and volume.

Tables 5 and 6 are analogs to Tables 1 and 4 except using one day changes in each asset price. In particular, we define the one day change as the log closing price on the announcement day less the log closing price on the prior trading day, multiplied by 10000. Using the cumulative two-day change in these asset prices, the dollar appreciates by $66bp$, the S&P 500 futures price falls by $486bp$, and 30-year Treasury bond futures price rises by $488bp$, consistent with the flight to safety during this period. We further see that the interest rate responses are inconsistent across announcements, some foreign currencies appreciate versus the dollar while others

[20]The large standard error for the average response in the CIP deviation ($28bp$) is because of very large movements in the Australian OIS rate in the Refinitiv data on March 30. While this was not associated with a swap line announcement, it increases the standard error of our estimated response to swap line announcements given the approach to calculating standard errors described in section 2.3 (by increasing the standard error of $\hat{\delta}_{0i}$ as described therein).

depreciate, and the CIP deviations widen on average on March 19. Overall, this underscores the importance of focusing on intraday windows to identify the effects from shocks to dollar supply alone on our asset prices of interest.

# D Additional evidence on 2008 announcements

In this section we present additional evidence on the effects of the September-October 2008 swap line announcements identified in section A of this appendix.

Figure 23 is the analog of Figure 4 over the September-November 2008 period. Unlike the March 2020 announcements studied in the main text, three of the six announcements during this period occurred when more than half of the peak usage of swap lines during this crisis had already occurred.

Tables 7-10 report the high frequency responses to these six announcements.[21] Relative to Tables 1 and 4, there are many more missing observations. This reflects the absence of sufficient trading/quote volume around these announcements, in part because several of these occurred overnight in the U.S. Where data does exist, the results are broadly in line with those for the March 2020 announcements. In particular, these announcements generally caused a reduction in Libor rates consistent with a reduction in liquidity premia; a depreciation of the dollar (except against the yen); a rise in forward premiums; an increase in the S&P 500; and a mixed and muted response of Treasury bonds. The dollar interestingly appreciated versus other currencies around the September 18, 2008 announcement, even though forward premiums still rose.

Figures 24-39 depict the prices and associated trading/quote volumes for interest rate futures, spot exchange rates, forward premiums, equities, and Treasury bonds around these announcements. The thinness of volumes is again evident versus the March 2020 announcements. However, where data around the announcements does exist, in many cases we see sharp responses upon the announcement.

[21] Because FirstRate Data only reports intraday spot rates from 2010 onwards, we use Refinitiv as the source for spot exchange rates during this period. As with the other Refinitiv data, this means we define the spot exchange rate as the average of bid and ask quotes.

# E Additional evidence on currency cross-section

In this section we present additional evidence exploring the cross-section of spot exchange rate and forward premium responses to swap line announcements.

**Including emerging markets** Figure 40 adds emerging market spot exchange rates to the left panel of Figure 2. The high frequency responses are reported in Table 4 earlier in this appendix, and the dollar betas are estimated for these currencies using the approach described in the main text.[22] Including the emerging markets does not change the conclusion that the appreciation of foreign currencies vis-à-vis the dollar is highly correlated with unconditional dollar betas.

**Other measures of dollar betas** We next present the robustness of our findings to other measures of dollar betas.

Figure 41 is the analog of Figure 2 except that the dollar betas are estimated over January 1, 2010 through December 31, 2019; that is, they exclude the acute periods of the Global Financial Crisis and Covid-19 pandemic. The high frequency responses remain highly correlated with the dollar betas, indicating that the correlation is not mechanically driven by the effects of swap line announcements being reflected in the dollar betas themselves.

Figure 42 replaces the dollar betas from Figure 2 with those estimated on end-of-month data using the currency factors proposed by Verdelhan (2018). In particular, on the right-hand side of the regressions estimating dollar betas, we include the lagged interest rate differential, the dollar factor, the carry factor, and the product of the lagged interest rate differential and the current carry factor ("conditional carry"). This measure of the dollar factor is furthermore currency-specific as it excludes the currency in question when computing the change in the dollar index against other currencies. We obtain the data from Adrien Verdelhan's website and estimate these specifications over January 2007 through April 2020. Figure 42 demonstrates that this measure of dollar betas remains quite correlated with the high frequency response of spot exchange rates and forward premiums to the swap line announcements.

[22] Russia is excluded because the Federal Reserve Board does not provide its bilateral exchange rate vis-à-vis the dollar.

**High frequency responses in 2008** Figure 43 compares the (baseline) dollar betas to the high frequency responses of spot exchange rates and forward premiums to the 2008 announcements studied in Table 7 and 8 of appendix D. There remains a tight correlation between the dollar betas and high frequency response of spot exchange rates to these announcements. However, the correlation for forward premiums is more tenuous, perhaps reflecting the smaller sample of forward premium responses we are able to estimate over this period.

**Other explanatory variables** We now consider alternative explanations for the cross-section of responses to swap line announcements. We return to focus on the March 2020 announcements, though the conclusions which follow would again hold for the September-October 2008 announcements at least for spot exchange rates. We also continue focusing on G7 currencies, though including the emerging markets would only strengthen the conclusions which follow, since the average CIP deviations and swap line usage of these currencies is unable to explain the responses of their spot exchange rates to swap line announcements.

We first consider the 30-day moving average of CIP deviations as of March 18, 2020, prior to the swap line announcements under study. Figure 44 demonstrates that there are strong univariate relationships in which currencies with wider CIP deviations prior to the announcements experience a smaller appreciation and larger increase in forward premiums upon the swap line announcements. These results are reproduced in the first and third columns of Table 11. However, the second and fourth columns demonstrate that once the dollar betas are included as an additional explanatory variable, they drive out the economic and statistical significance of moving average CIP deviations in explaining the cross-section of high frequency responses.

We next consider the peak usage of swap lines by counterparty from March 21, 2020 (after the swap line announcements under study) through the end of the year. For ease of interpretation, we scale usage by annual U.S. GDP as of Q4 2019. Figure 45 and the first and third columns of Table 12 again demonstrate that there are strong univariate relationships in which central banks with more usage of the swap lines experience a smaller appreciation and larger increase in forward premiums for their currencies upon the swap line announcements. However, the second and fourth columns of Table 12 again demonstrate that once the dollar betas are included as an additional explanatory variable, they drive out the economic and statistical signifi-

cance of swap line usage in explaining the cross-section of high frequency responses.

**Implications for differences-in-differences design** The results described in the prior paragraph indicate the limitation of a differences-in-difference research design to capture the causal effects of swap lines, at least for the response of exchange rates. In such a design, prevalent in the existing literature using daily or lower frequency data, researchers have compared outcomes across currencies or countries with differing access to or take-up of swap lines around swap line announcements. The first panel of Figure 45 and first column of Table 12 imply that, with such a design, a researcher may erroneously conclude that swap lines cause a foreign currency *depreciation*. This is because countries with more usage tend to be those with smaller dollar betas and thus smaller appreciations. This is less of a problem for estimates of the effects on CIP deviations, where the second panel of Figure 45 and third column of Table 12 indicate that countries with more usage feature a larger increase in forward premiums. This is because countries with more usage tend to have larger (more negative) CIP dollar betas.

**Alternative base currencies** One way of interpreting our cross-sectional findings is that the currencies and CIP deviations that respond more to global shocks outside swap line announcements, as reflected in dollar betas of greater magnitude, respond more to swap line announcements. Global shocks are measured using returns from the perspective of a U.S. investor. Here, we instead measure sensitivity to global shocks from the perspective of a European, U.K., or Japanese investor by replacing the dollar with the euro, pound, or yen as our base currency, respectively.[23]

For instance, we first estimate euro betas by regressing

$$\Delta \log \left(\text{spot exchange rate}\right)_{it} = \alpha_i + \beta_i \Delta \log \left(\text{euro index}\right)_{it} + \varepsilon_{it},$$

where both the spot exchange rate and euro index are expressed as foreign currency per euro.[24] We similarly estimate euro betas of CIP deviations relative to the euro.

[23]We thank an anonymous referee for suggesting this interpretation of our cross-sectional results and suggesting this analysis of alternative base currencies.

[24]We compute the daily change in the log euro index as the simple average of the change in log bilateral exchange rates between 22 currencies and the euro. These currencies are those of Australia, Brazil, Canada, China, Denmark, Hong Kong, India, Japan, Malaysia, Mexico, New Zealand, Norway, Singapore, South Africa, South Korea, Sri Lanka, Sweden, Switzerland, Taiwan,

We then compare these euro betas to the high frequency responses of spot exchange rates and CIP deviations again expressed relative to the euro.

Figure 46-48 depict the results. For the responses of currencies, we obtain the same results from the perspective of a Japanese investor: currencies which appreciate by more when the yen depreciates were the ones which indeed appreciated the most relative to the yen upon the announcements. From the perspective of a U.K. investor, we also obtain similar results, except with the opposite sign: currencies which appreciate by more when the pound depreciates were the ones which indeed *depreciated* the most relative to the pound upon the announcements. From the perspective of a European investor, we do not obtain a systematic relation between euro betas and the high frequency response of currencies relative to the euro.

The responses of CIP deviations exhibit a similar pattern. We obtain the same results from the perspective of a Japanese investor: CIP deviations which have a more positive loading on the yen were the ones which indeed widened the most relative to the yen upon the announcements. From the perspective of a U.K. investor, we again obtain similar results, except with the opposite sign: CIP deviations which have a more positive (less negative) loading on the pound were the ones which *compressed* the most relative the pound upon the announcements. From the perspective of a European investor, we again obtain a much weaker relation between euro CIP betas and the high frequency responses of CIP deviations relative to the euro.

We conclude from this analysis that dollar betas and yen betas similarly capture exposure to a global shock relevant for the responses of exchange rates and CIP deviations to swap line announcements. Pound betas also capture this exposure, though with the opposite sign. Euro betas do not well capture this exposure.

Thailand, the U.K., and the U.S., where the euro exchange rates are constructed from the bilateral exchange rates versus the dollar reported by the Federal Reserve Board. We note that when an analogous simple average of log bilateral exchange rates between 22 currencies (now including the euro, and excluding the dollar) and the dollar is used in place of the broad dollar index to compute dollar betas, we obtain virtually identical results as in Figure 2. This is because daily changes in the broad dollar index have a correlation of 0.97 with daily changes in this simple index.

| Date | Press release | Event | Simultaneous Federal Reserve news |
|---|---|---|---|
| 12/12/07 | | Fed establishes 6-month swap lines with ECB and SNB | Establishment of TAF |
| 3/11/08 | | Lines expanded | Establishment of TSLF |
| 5/2/08 | | Lines expanded and agreement extended | Expansion of TAF and TSLF |
| 7/30/08 | 8:45 | Lines expanded | Expansions of PDCF, TAF, and TSLF |
| **9/18/08** | **3:00** | **Lines expanded and lines established with BOC, BOE, and BOJ** | |
| **9/24/08** | **1:00** | **Lines established with RBA, Danmarks NationalBank, Sveriges Riksbank, and Norges Bank** | |
| **9/26/08** | **2:00** | **Lines expanded** | |
| 9/29/08 | 10:00 | Lines expanded and agreements extended | Expansion of TAF |
| **10/13/08** | **2:00** | **Lines expanded** | |
| 10/14/08 | | Lines expanded | |
| **10/28/08** | **17:00** | **Lines established with RBNZ** | |
| **10/29/08** | **15:30** | **Lines established with Banco Central do Brasil, Bank of Korea, Banco de Mexico, and Monetary Authority of Singapore** | |
| 2/3/09 | 10:00 | Agreements extended | Extension of AMLF, CPFF, MMIFF, PDCF, and TSLF |
| 4/6/09 | 10:00 | Arrangement to provide foreign currency liquidity to U.S. institutions | TAF auction |
| 6/25/09 | 12:00 | Agreements extended | Extension of AMLF, CPFF, PDCF, and TSLF |

Table 2: swap line announcements during Great Recession

Notes: press release times in EDT. Bold denotes announcements studied in this appendix.

| Date | Press release | Event | Simultaneous Federal Reserve news |
|---|---|---|---|
| 3/15/20 | 17:00 | Lower pricing and longer maturities on standing swap lines | Releases of FOMC statement and actions to support flow of credit to households and businesses |
| **3/19/20** | **9:00** | **Temporary lines established with RBA, Banco Central do Brasil, Danmarks NationalBank, Bank of Korea, Banco de Mexico, Norges Bank, RBNZ, Monetary Authority of Singapore, and Sveriges Riksbank** | |
| **3/20/20** | **10:00** | **Increased frequency of standing swap lines to daily** | |
| 7/29/20 | 14:00 | Agreements extended | Release of FOMC statement |
| 12/16/20 | 14:00 | Agreements extended | Release of FOMC statement |
| 7/16/21 | 14:00 | Agreements extended | Release of FOMC statement |

Table 3: swap line announcements during pandemic

Notes: press release times in EDT. Bold denotes announcements studied in main text and this appendix.

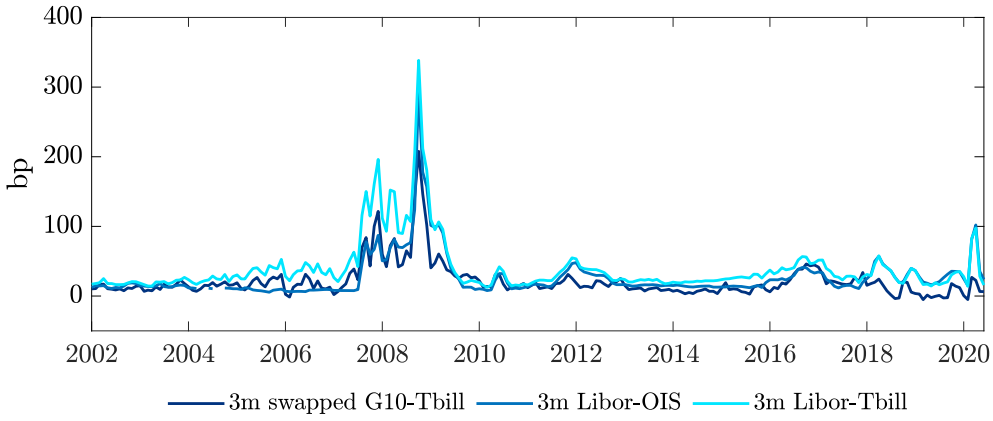


Figure 3: measures of liquidity premia

Notes: three-month swapped G10 government bond/Treasury bill spread from Du et al. (2018a), updated through 2020 and shared with us by Wenxin Du. Each measure averaged within month.

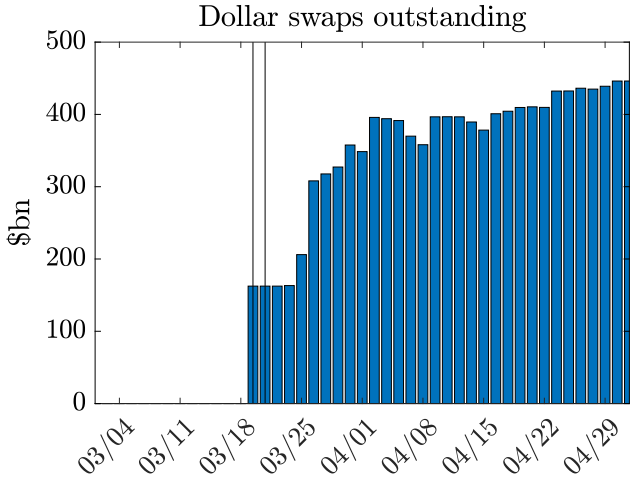


Figure 4: swap line usage in March-April 2020

Notes: vertical lines denote announcement dates. Swap line usage constructed from transaction-level data provided by the Federal Reserve Bank of New York.

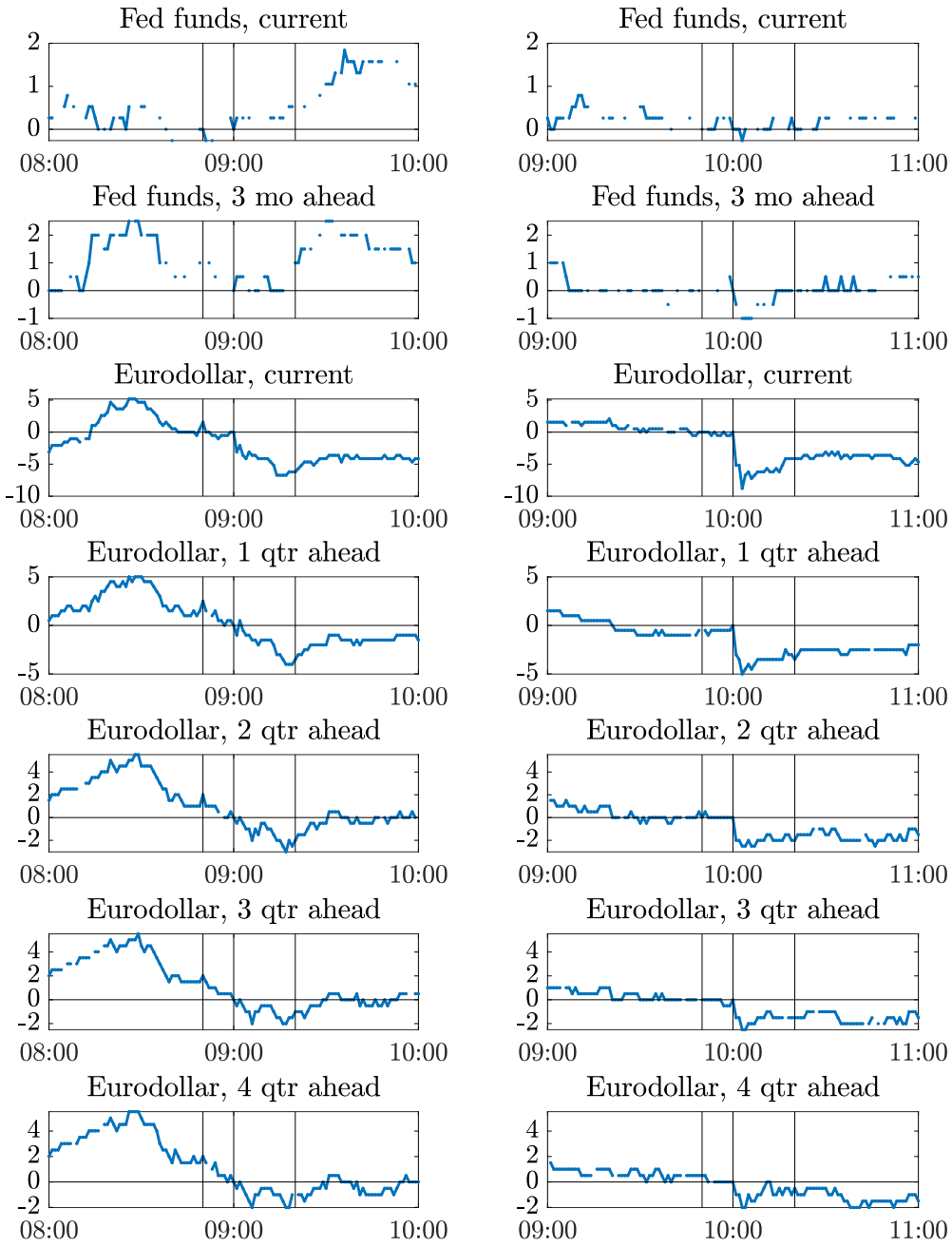


Figure 5: interest rate futures on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict −1 times log open price by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

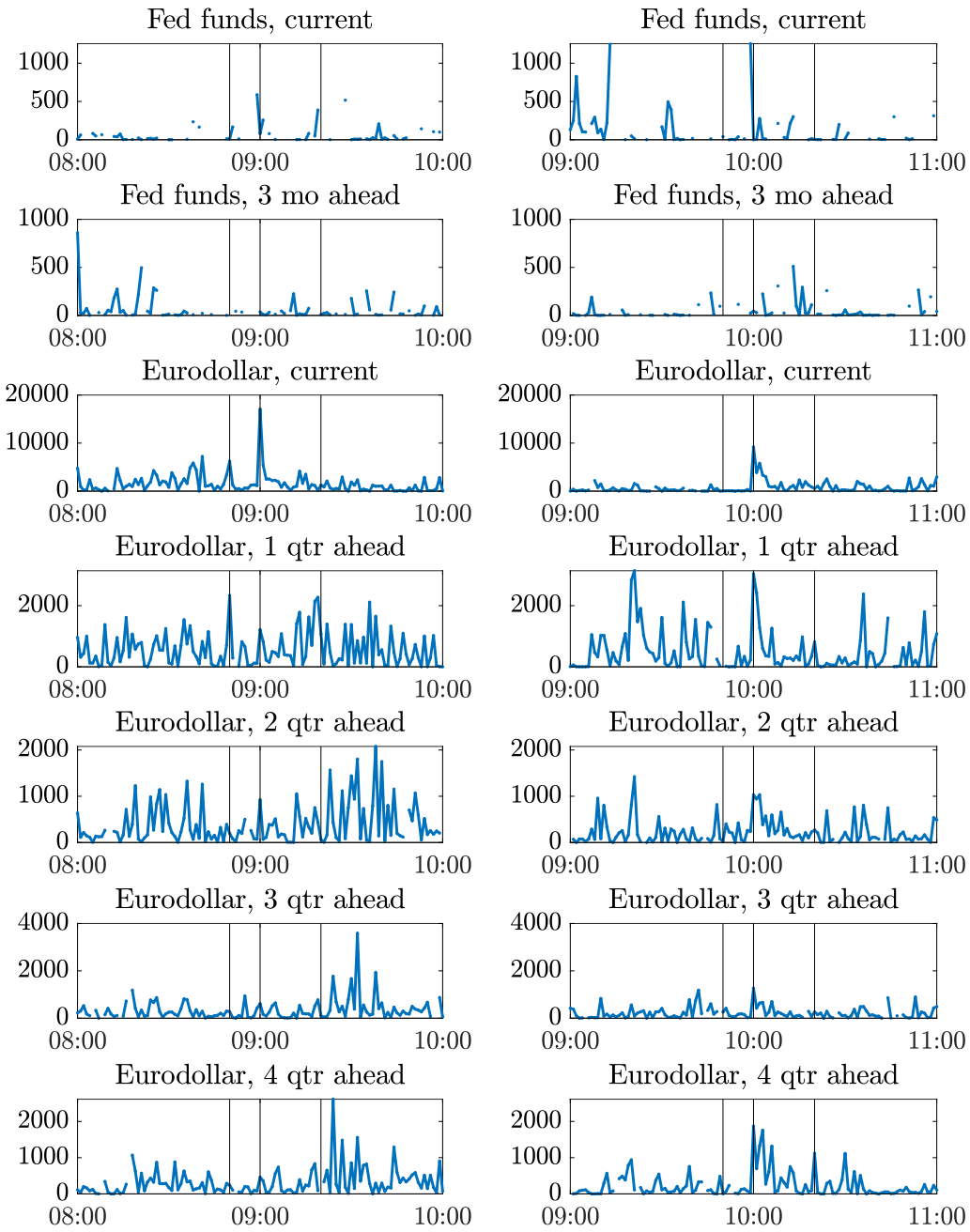


Figure 6: interest rate futures volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

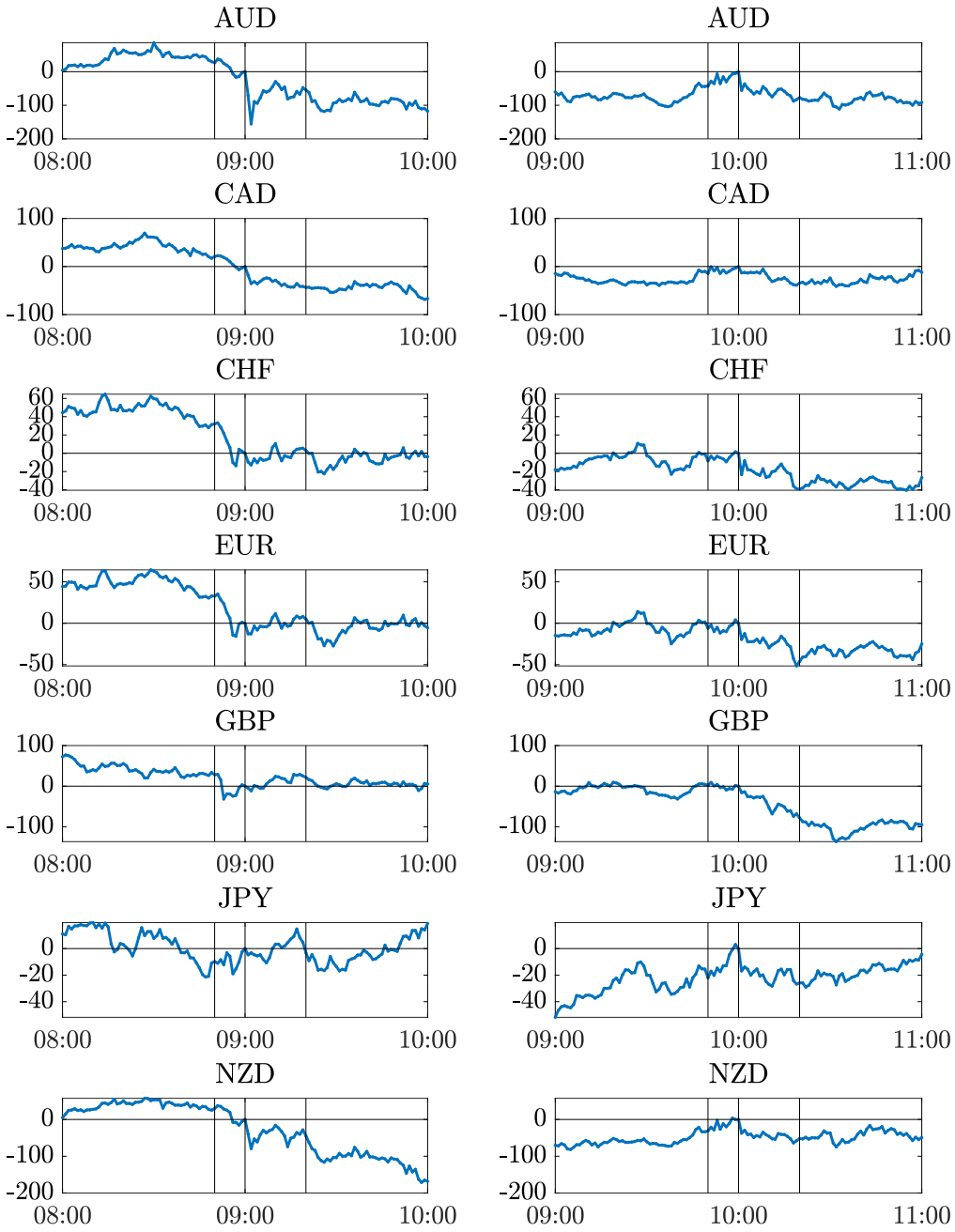


Figure 7: spot exchange rates on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict log open price (foreign per dollar) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

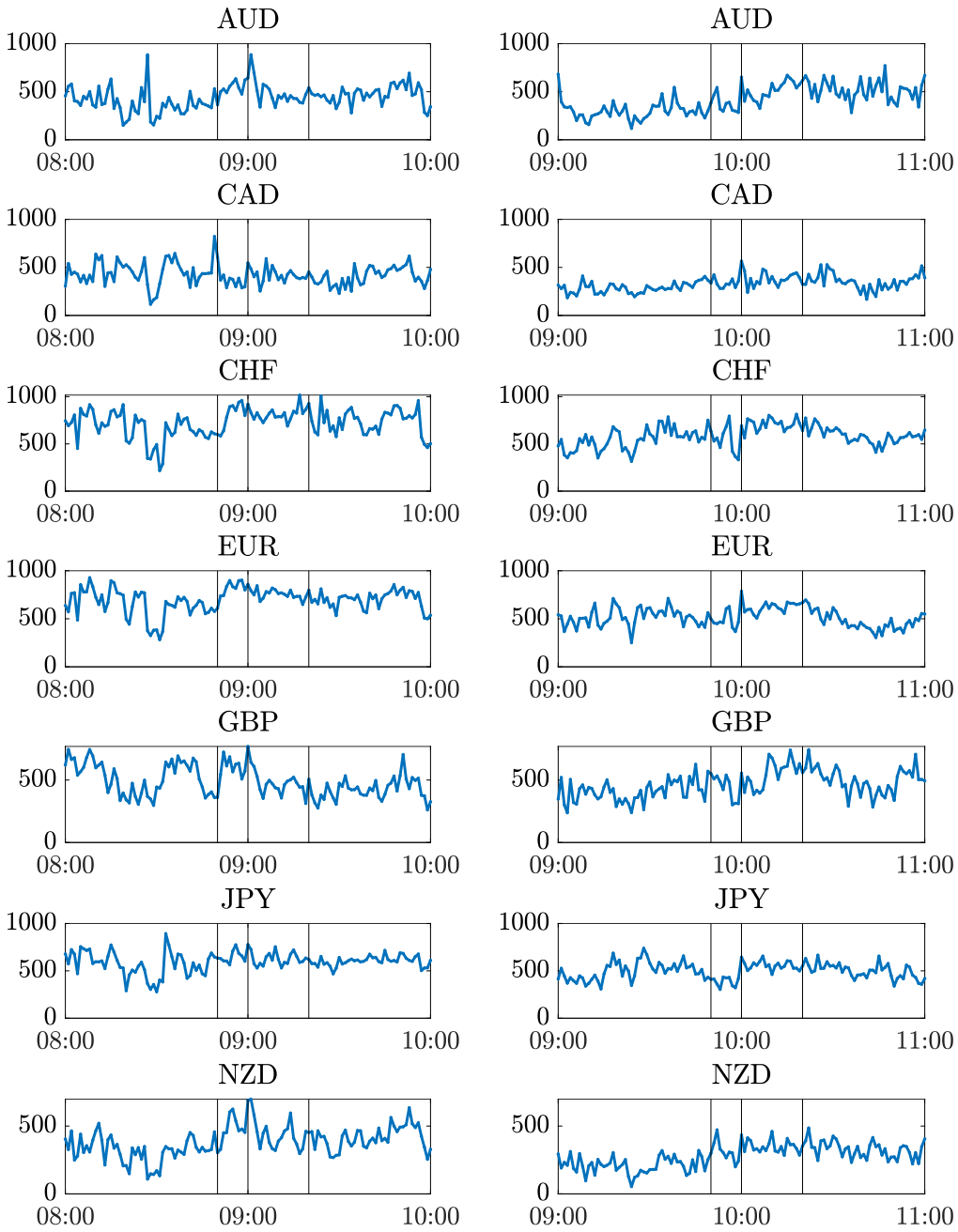


Figure 8: spot exchange rates volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

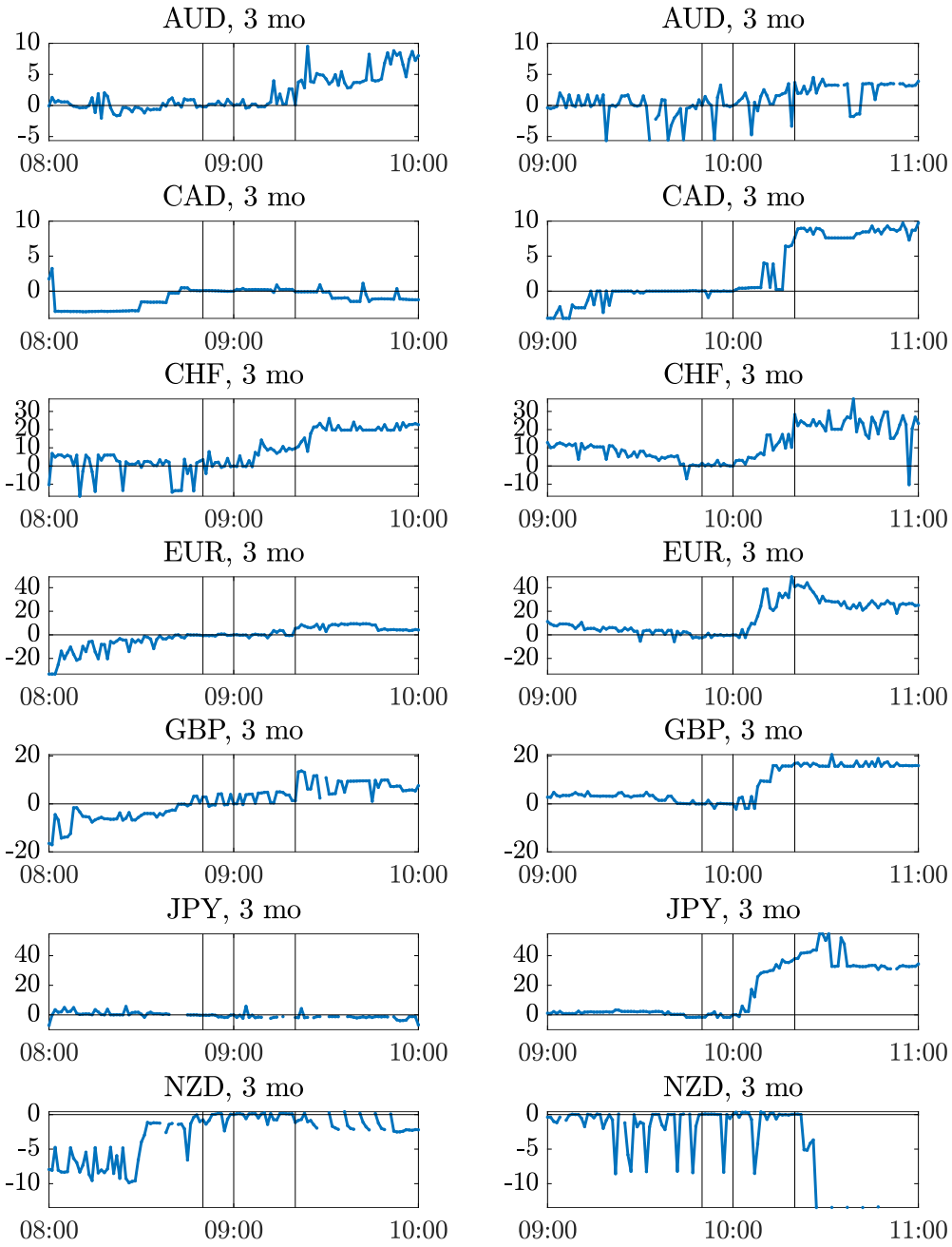


Figure 9: forward premiums on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict forward premium at open by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

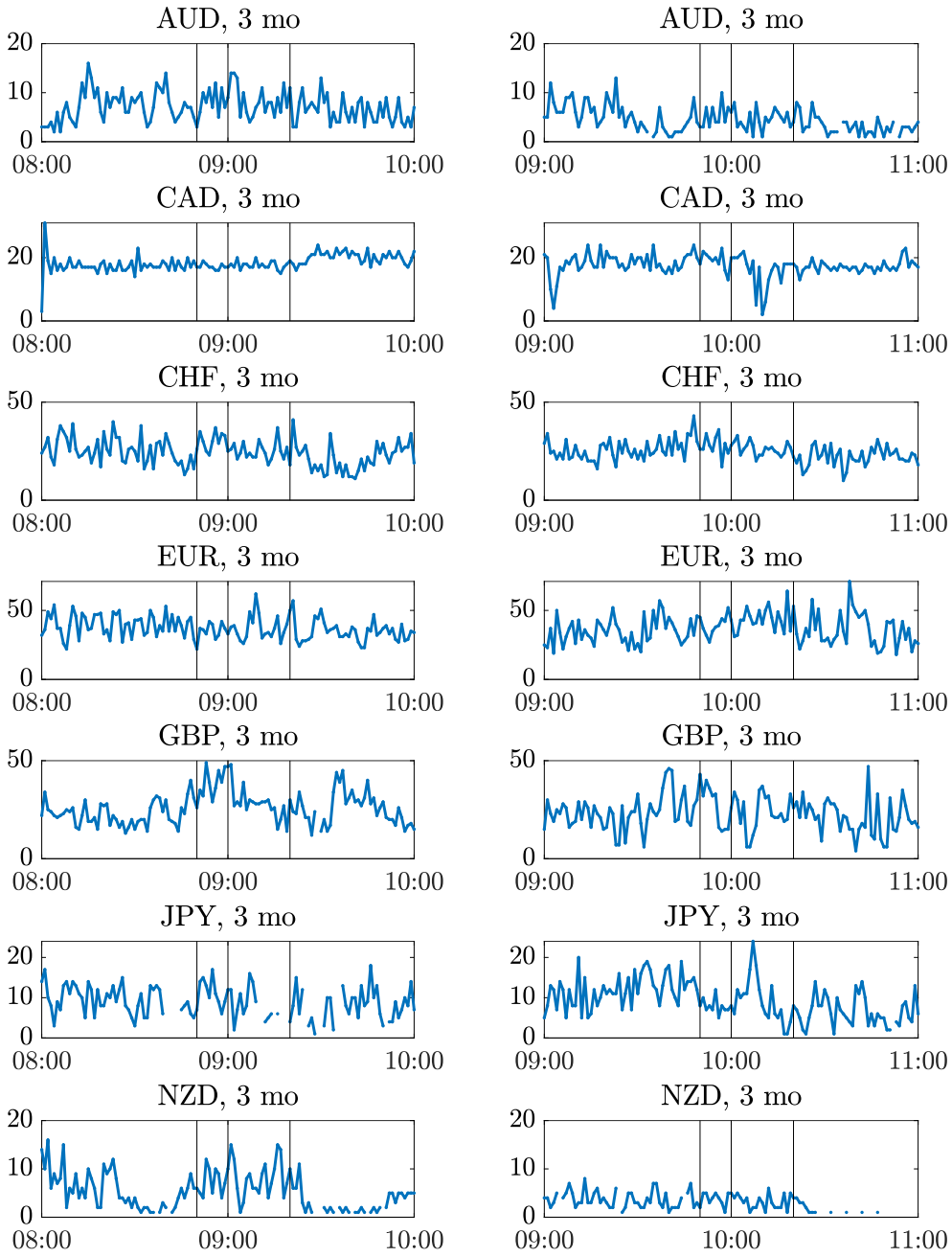


Figure 10: forward volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict average number of bids and asks by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

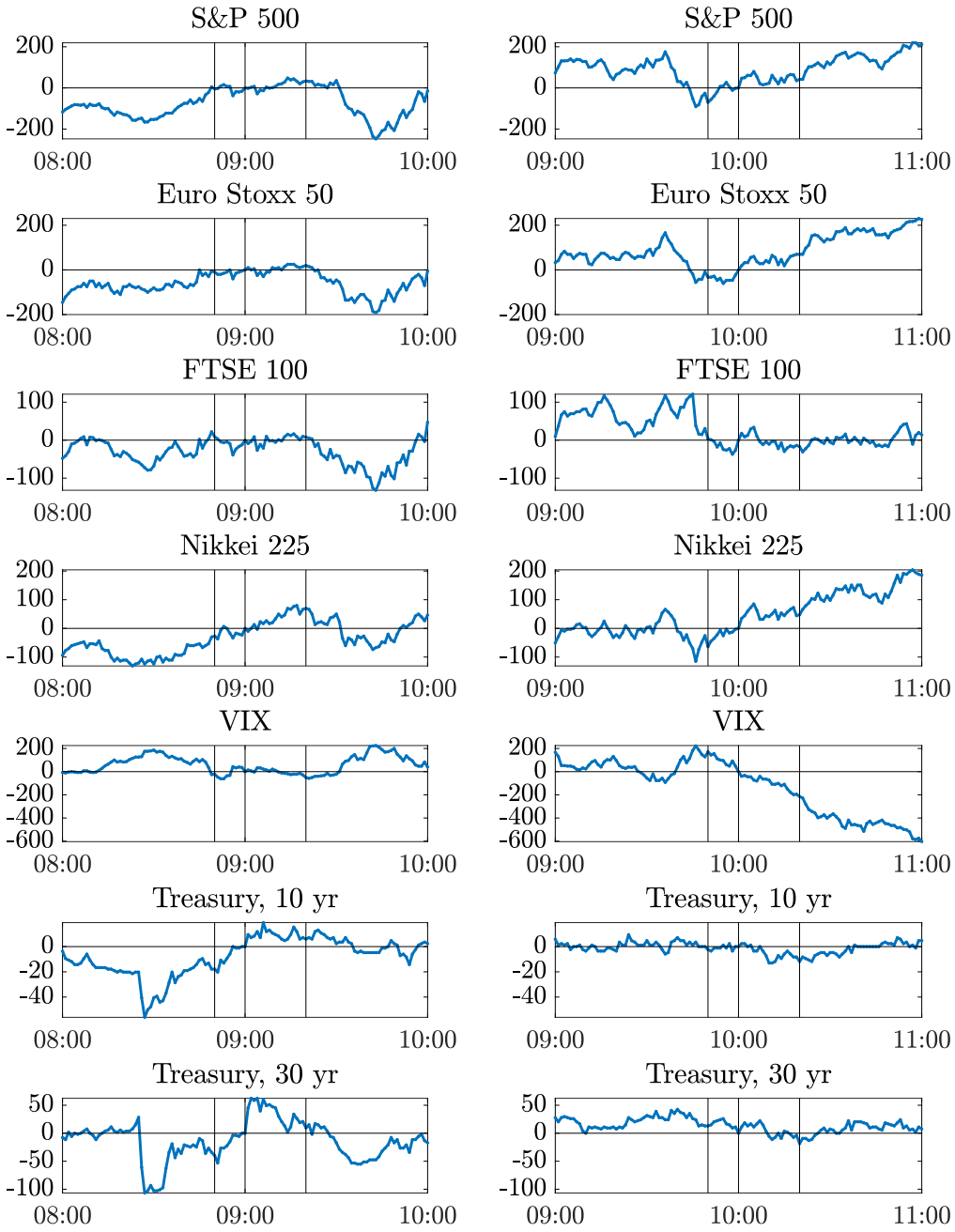


Figure 11: equity and bond futures on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict log open price by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

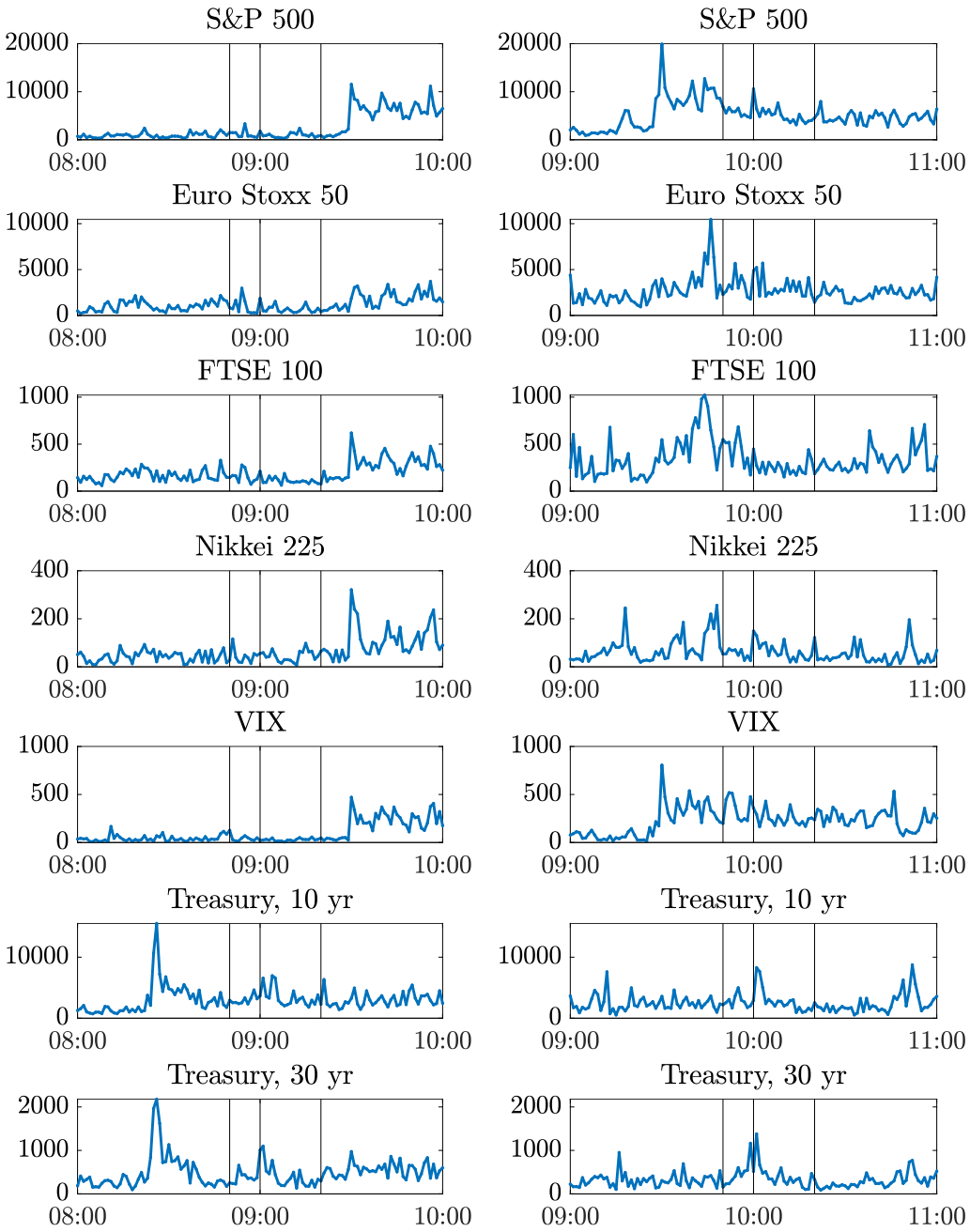


Figure 12: equity and bond futures volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

| | 3/19 | 3/20 | Sum | (SE) | | 3/19 | 3/20 | Sum | (SE) |
|---|---|---|---|---|---|---|---|---|---|
| *A. OIS-based CIP deviations* | | | | | *C. Short-term dollar interest rates* | | | | |
| AUD, 3 mo | . | . | . | . | OIS, 3 mo | 0 | 0 | 0 | (2) |
| CAD, 3 mo | 2 | 8 | 9 | (3) | Treasury, 3 mo | 1 | . | . | . |
| CHF, 3 mo | . | . | . | . | *D. EM currency and equity futures* | | | | |
| EUR, 3 mo | 6 | 43 | 50 | (8) | BRL | -57 | -9 | -66 | (79) |
| GBP, 3 mo | -2 | 19 | 18 | (6) | MXN | -46 | -54 | -100 | (73) |
| JPY, 3 mo | . | . | . | . | RUB | -173 | -47 | -220 | (92) |
| NZD, 3 mo | -1 | -5 | -6 | (4) | ZAR | -31 | -51 | -82 | (53) |
| Average, 3 mo | 1 | 16 | 18 | (28) | Average, EM currencies | -77 | -40 | -117 | (58) |
| *B. Libor-based CIP deviations* | | | | | MSCI EM Equity Index | 109 | 25 | 134 | (94) |
| AUD, 1 yr | . | . | . | . | *E. Additional bond futures* | | | | |
| CAD, 1 yr | . | . | . | . | Treasury, 2 yr | 3 | 3 | 6 | (4) |
| CHF, 1 yr | 2 | 2 | 4 | (2) | Treasury, 5 yr | 13 | 2 | 15 | (10) |
| EUR, 1 yr | 1 | 2 | 3 | (2) | Gilt, 10 yr | 18 | -42 | -23 | (24) |
| GBP, 1 yr | 0 | . | . | . | Euro shatz, 1.75-2.25 yr | -1 | 1 | -0 | (3) |
| JPY, 1 yr | 0 | 11 | 11 | (2) | Euro bobl, 4.5-5.5 yr | -3 | 1 | -2 | (7) |
| NZD, 1 yr | . | . | . | . | Euro bund, 8.5-10.5 yr | -1 | -4 | -6 | (16) |
| Average, 1 yr | 1 | 5 | 6 | (1) | Euro buxl, 24.0-35.0 yr | 15 | 4 | 19 | (54) |

Table 4: additional high frequency responses

Notes: responses are defined as the log open price of the first one-minute bar with positive trading volume beginning 20 minutes after the press release time, less the log close price of the last one-minute bar with positive trading volume ending 10 minutes before the press release time, multiplied by 10000 (thus reported in *bp*). Response is missing (denoted .) if there is no trading volume in 10-20 minutes prior to the press release time or 20-40 minutes after the press release time. Standard errors of cumulative response reported under null of no difference in responses versus other hours in March 2020.

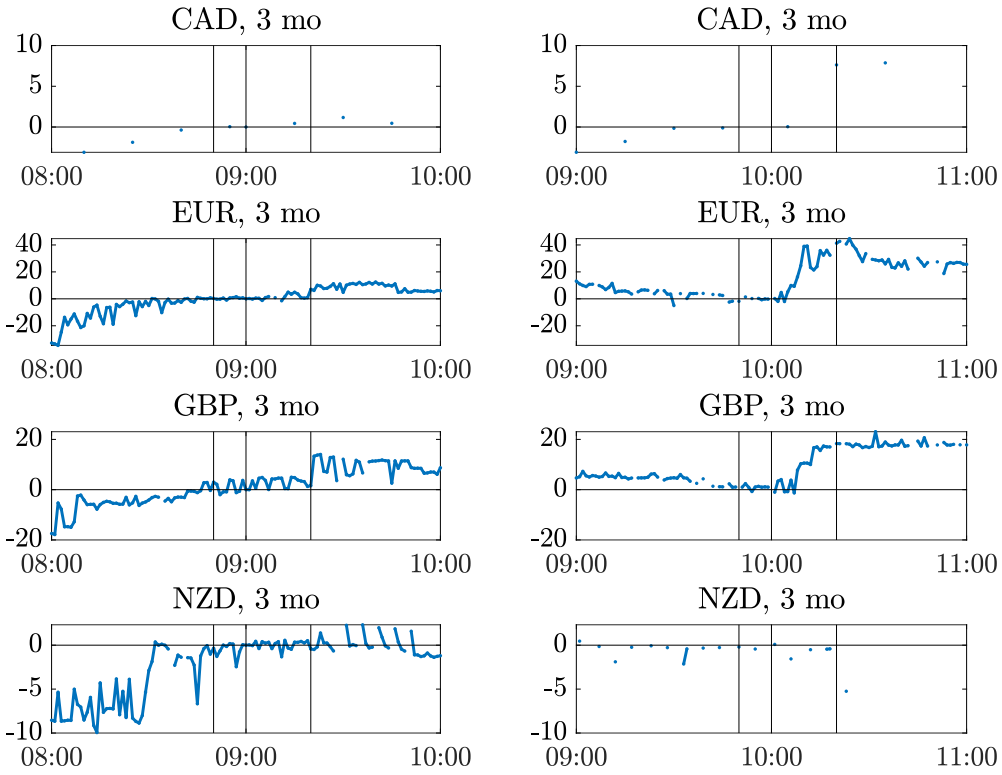


Figure 13: OIS-based CIP deviations on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict CIP deviation at open by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

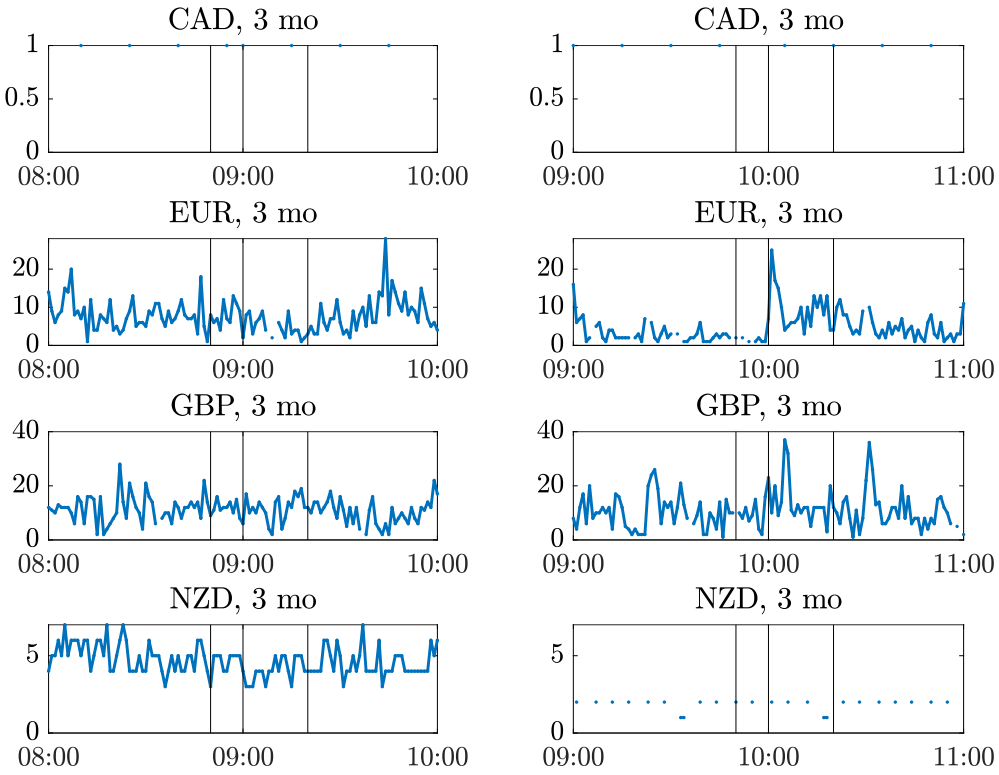


Figure 14: non-dollar OIS volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict average number of bid and ask quotes by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

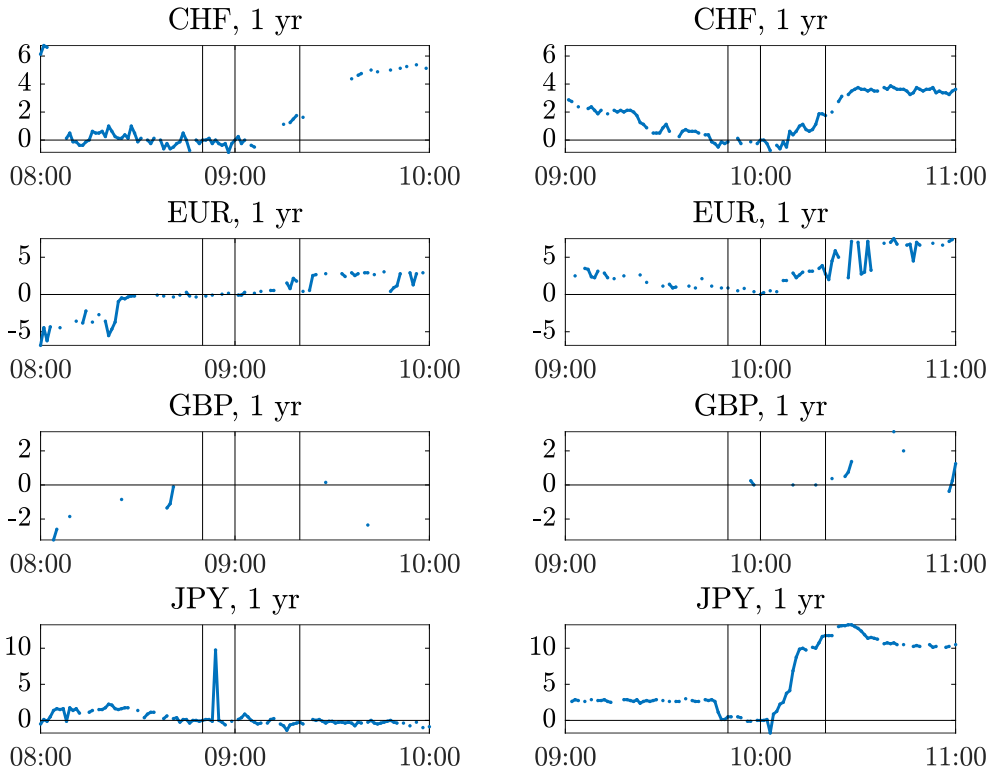


Figure 15: Libor-based CIP deviations on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict CIP deviation at open by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

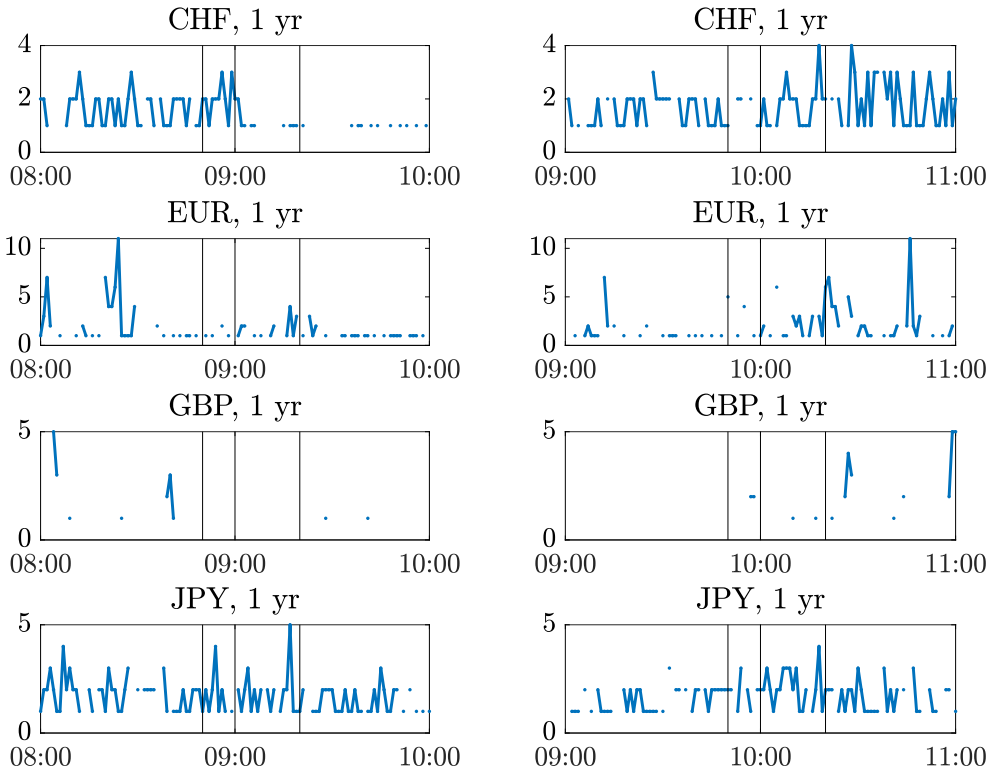


Figure 16: cross-currency basis swap volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict average number of bid and ask quotes by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

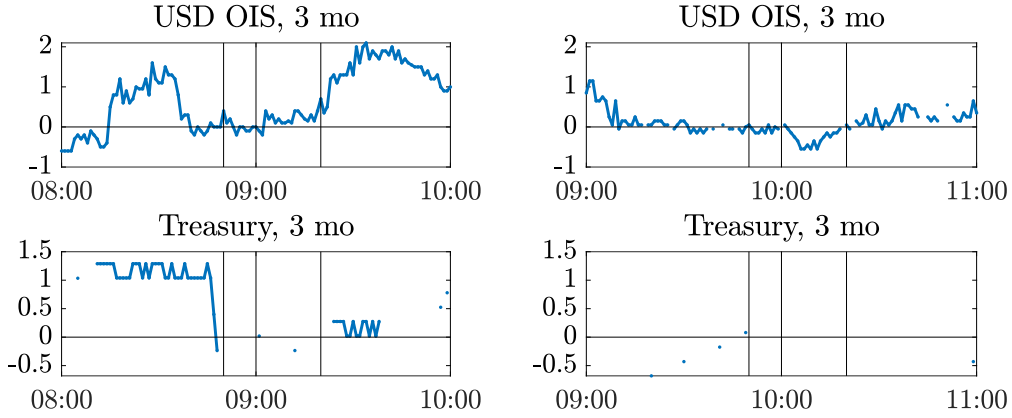


Figure 17: short-term dollar interest rates on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict interest rates at open by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

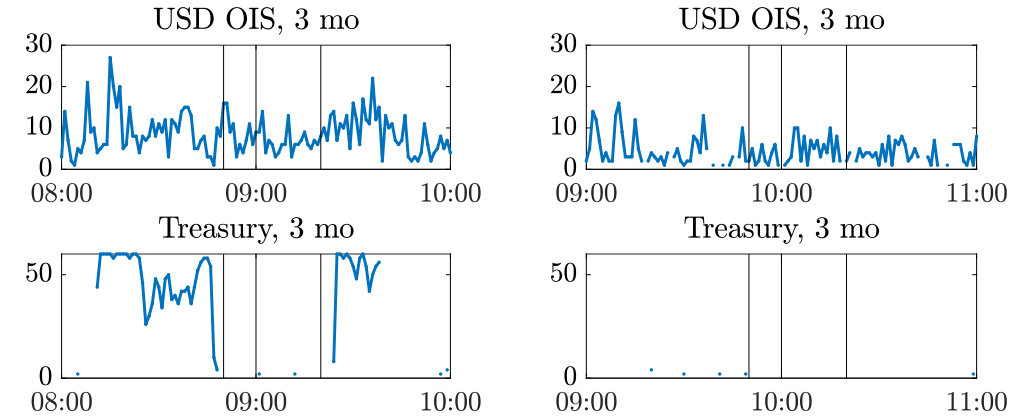


Figure 18: short-term dollar interest rates volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict average number of bid and ask quotes by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

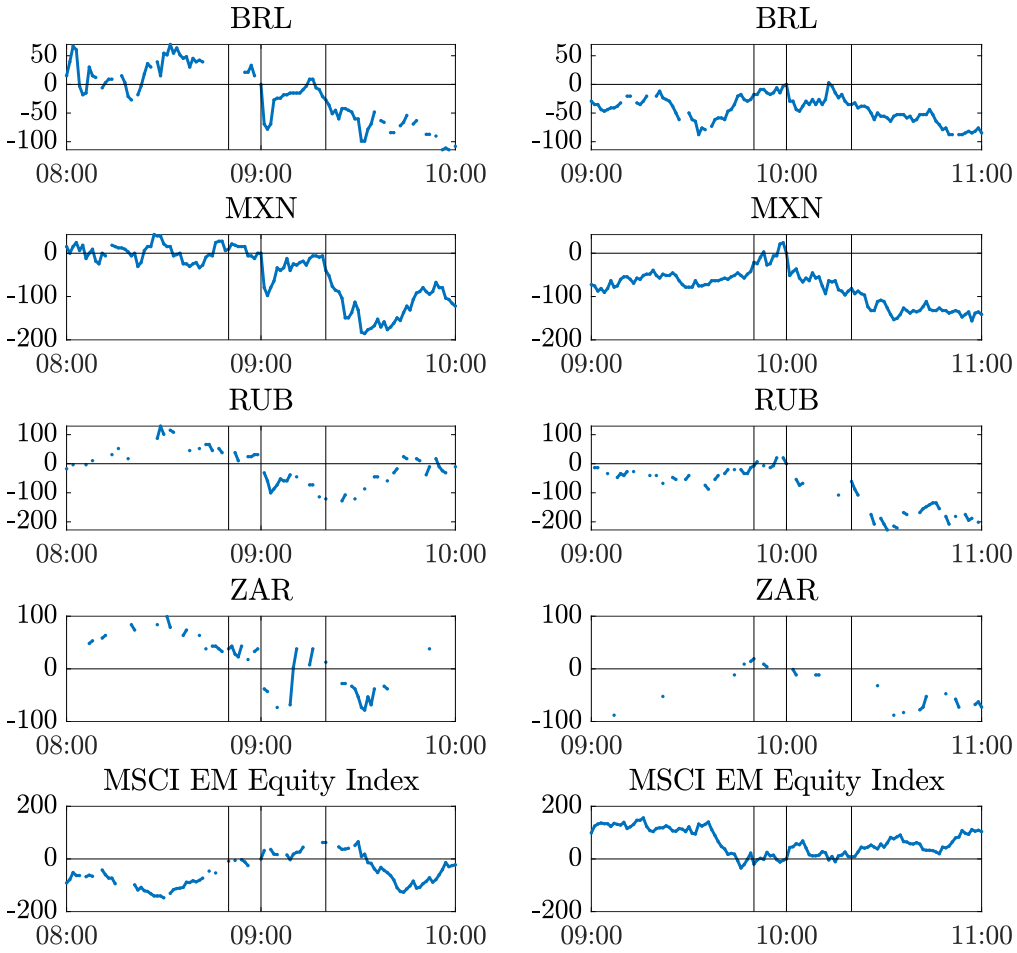


Figure 19: EM currency and equity futures on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict log open price by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

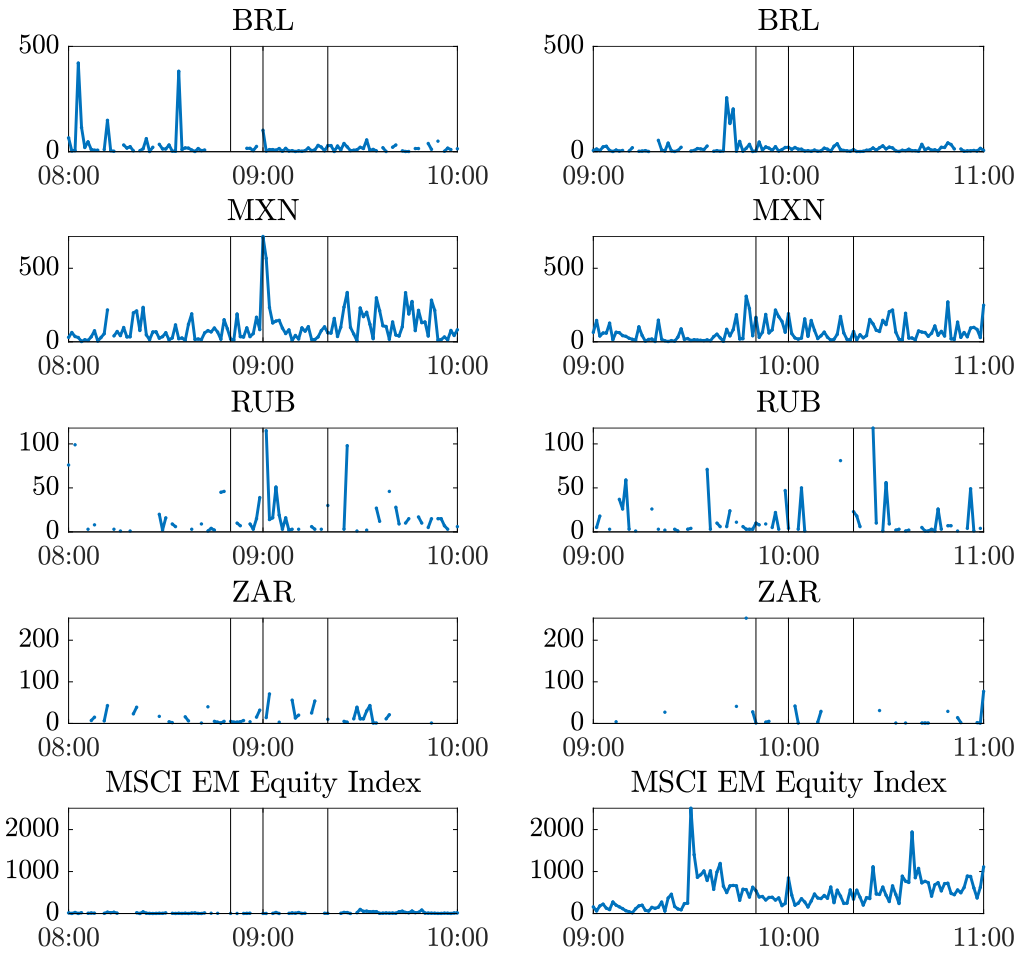


Figure 20: EM currency and equity futures volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

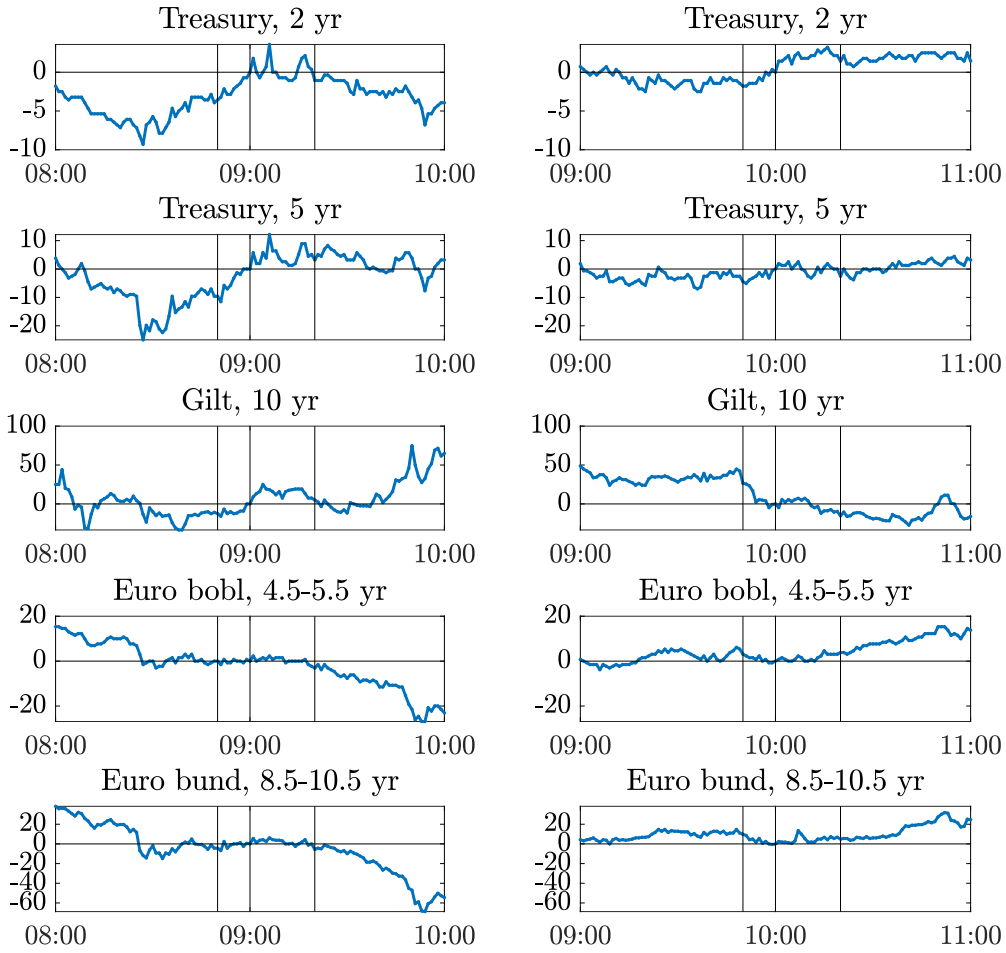


Figure 21: additional bond futures on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict log open price by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

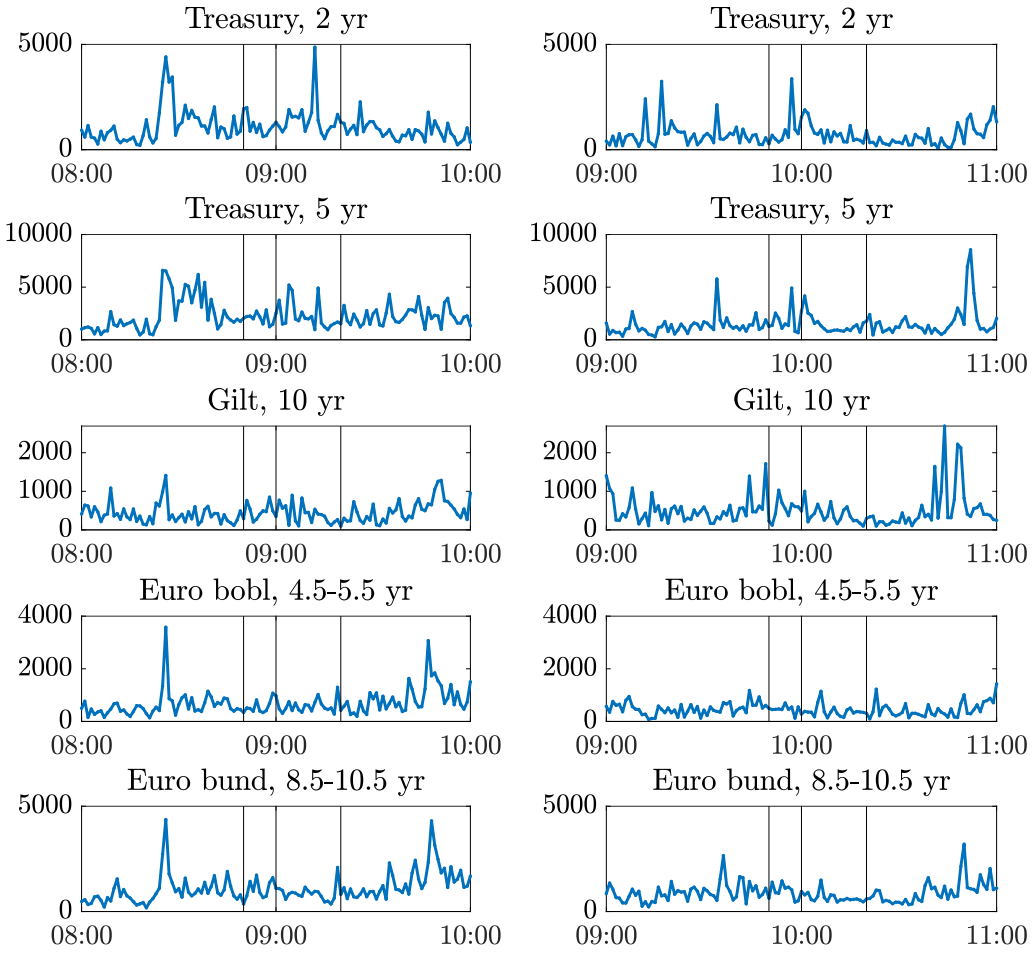


Figure 22: additional bond futures volume on 3/19/20 (L) and 3/20/20 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

| | 3/19 | 3/20 | Sum | | 3/19 | 3/20 | Sum |
|---|---|---|---|---|---|---|---|
| *A. Interest rate futures* | | | | *C. Forward premiums* | | | |
| Fed funds, current | 1 | -6 | -5 | AUD, 3 mo | -7 | 11 | 4 |
| Fed funds, 3 mo ahead | 1 | -1 | 1 | CAD, 3 mo | -2 | 17 | 15 |
| Eurodollar, current | 12 | -11 | 1 | CHF, 3 mo | 1 | 47 | 48 |
| Eurodollar, 1 qtr ahead | 3 | -8 | -5 | EUR, 3 mo | -2 | 46 | 44 |
| Eurodollar, 2 qtr ahead | 1 | -8 | -8 | GBP, 3 mo | -24 | 48 | 24 |
| Eurodollar, 3 qtr ahead | 1 | -10 | -9 | JPY, 3 mo | -60 | 70 | 10 |
| Eurodollar, 4 qtr ahead | -3 | -11 | -13 | NZD, 3 mo | 28 | -37 | -9 |
| *B. Spot exchange rates* | | | | Average, 3 mo | -9 | 29 | 19 |
| AUD | 50 | -109 | -59 | *D. Equity index futures* | | | |
| CAD | -1 | -123 | -123 | S&P 500 | -53 | -434 | -486 |
| CHF | 183 | -5 | 179 | Euro Stoxx 50 | 316 | 366 | 682 |
| EUR | 205 | -8 | 198 | FTSE 100 | 180 | -63 | 117 |
| GBP | 114 | -138 | -24 | Nikkei 225 | 302 | 22 | 324 |
| JPY | 245 | 8 | 252 | VIX | -333 | -396 | -729 |
| NZD | 602 | -565 | 36 | *E. Bond futures* | | | |
| Average | 200 | -134 | 66 | Treasury, 10 yr | 87 | 115 | 203 |
| | | | | Treasury, 30 yr | 287 | 201 | 488 |

Table 5: one day responses

Notes: responses are defined as the log close price as of announcement day, less the log close price as of the trading day prior to announcement, multiplied by 10000 (thus reported in *bp*). Interest rate responses multiplied by minus one, so these correspond to responses of yields.

| | 3/19 | 3/20 | Sum | | 3/19 | 3/20 | Sum |
|---|---|---|---|---|---|---|---|
| *A. OIS-based CIP deviations* | | | | *C. Short-term dollar interest rates* | | | |
| AUD, 3 mo | -8 | 10 | 2 | OIS, 3 mo | 2 | -3 | -0 |
| CAD, 3 mo | -0 | 14 | 14 | Treasury, 3 mo | 1 | -1 | -0 |
| CHF, 3 mo | -15 | 43 | 29 | *D. EM currency and equity futures* | | | |
| EUR, 3 mo | -0 | 44 | 43 | BRL | -212 | -169 | -381 |
| GBP, 3 mo | -16 | 46 | 31 | MXN | 195 | -69 | 127 |
| JPY, 3 mo | -58 | . | . | RUB | -483 | 232 | -251 |
| NZD, 3 mo | 32 | -40 | -8 | ZAR | 197 | -5 | 192 |
| Average, 3 mo | -9 | 20 | 10 | Average, EM currencies | -76 | -3 | -78 |
| *B. Libor-based CIP deviations* | | | | MSCI EM Equity Index | 61 | 109 | 170 |
| AUD, 1 yr | -5 | 3 | -2 | *E. Additional bond futures* | | | |
| CAD, 1 yr | . | . | . | Treasury, 2 yr | 22 | 6 | 28 |
| CHF, 1 yr | -4 | 13 | 9 | Treasury, 5 yr | 62 | 57 | 120 |
| EUR, 1 yr | -6 | 14 | 8 | Gilt, 10 yr | -37 | 258 | 222 |
| GBP, 1 yr | -15 | 11 | -3 | Euro shatz, 1.75-2.25 yr | -26 | 5 | -20 |
| JPY, 1 yr | -13 | 17 | 3 | Euro bobl, 4.5-5.5 yr | -54 | 63 | 9 |
| NZD, 1 yr | 1 | 0 | 1 | Euro bund, 8.5-10.5 yr | -52 | 152 | 99 |
| Average, 1 yr | -7 | 10 | 3 | Euro buxl, 24.0-35.0 yr | -146 | 344 | 198 |

Table 6: additional one day responses

Notes: responses are defined as the log close price as of the announcement day, less the log close price as of the trading day prior to announcement, multiplied by 10000 (thus reported in *bp*).

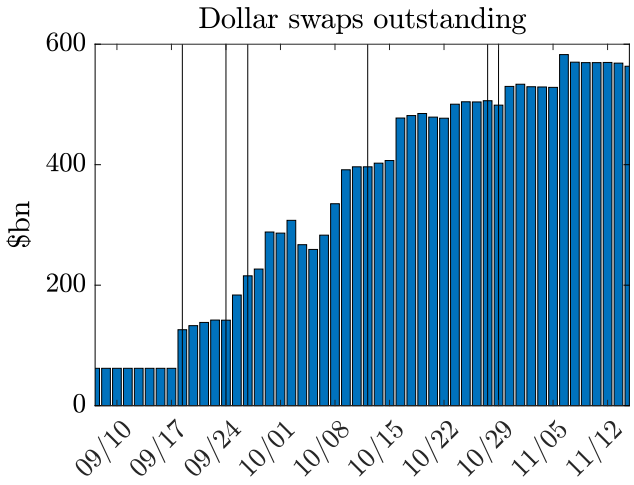


Figure 23: swap line usage in September-November 2008

Notes: vertical lines denote announcement dates.

| | 9/18 | 9/24 | 9/26 | 10/13 | 10/28 | 10/29 |
|---|---|---|---|---|---|---|
| *A. Interest rate futures* | | | | | | |
| Fed funds, current contract | 1 | . | . | . | . | . |
| Fed funds, 3 mo ahead | 3 | . | . | . | . | -1 |
| Eurodollar, current | -18 | -7 | -6 | -4 | . | -2 |
| Eurodollar, 1 qtr ahead | -10 | -3 | -2 | -3 | . | -4 |
| Eurodollar, 2 qtr ahead | -2 | -1 | -1 | -3 | . | -5 |
| Eurodollar, 3 qtr ahead | 3 | 2 | 0 | -2 | . | -5 |
| Eurodollar, 4 qtr ahead | 5 | 1 | 0 | 0 | . | -4 |
| *B. Spot exchange rates* | | | | | | |
| AUD | -3 | -23 | -2 | -148 | -70 | -73 |
| CAD | -4 | -9 | 3 | -28 | 5 | -41 |
| CHF | 49 | -2 | 7 | 18 | -7 | -30 |
| EUR | 27 | -3 | 0 | -52 | -13 | -15 |
| GBP | 31 | -5 | 11 | -60 | -1 | -8 |
| JPY | 64 | -0 | 14 | 21 | 87 | 6 |
| NZD | 10 | -16 | -9 | -113 | -54 | -21 |
| Average | 25 | -8 | 4 | -52 | -8 | -26 |

Table 7: high frequency responses in 2008 (1/2)

Notes: responses are defined as the log open price of the first one-minute bar with positive trading volume beginning 20 minutes after the press release time, less the log close price of the last one-minute bar with positive trading volume ending 10 minutes before the press release time, multiplied by 10000 (thus reported in *bp*). Interest rate responses multiplied by minus one, so these correspond to responses of yields. Response is missing (denoted .) if there is no trading volume in 10-20 minutes prior to the press release time or 20-40 minutes after the press release time.

| | 9/18 | 9/24 | 9/26 | 10/13 | 10/28 | 10/29 |
|---|---|---|---|---|---|---|
| *C. Forward premiums* | | | | | | |
| AUD, 3 mo | -0 | -0 | 0 | 0 | 0 | 0 |
| CAD, 3 mo | . | -1 | 3 | 0 | -3 | -4 |
| CHF, 3 mo | 27 | -0 | -0 | 4 | 7 | 0 |
| EUR, 3 mo | 71 | -5 | -7 | -0 | 2 | -1 |
| GBP, 3 mo | . | 0 | -2 | . | -0 | -5 |
| JPY, 3 mo | 95 | 19 | -2 | 9 | -3 | 1 |
| NZD, 3 mo | 15 | -15 | 2 | -3 | 41 | 14 |
| Average, 3 mo | 42 | -0 | -1 | 2 | 6 | 1 |
| *D. Equity index futures* | | | | | | |
| S&P 500 | 27 | 5 | 15 | 16 | 62 | 79 |
| Euro Stoxx 50 | 40 | . | . | . | . | 238 |
| FTSE 100 | . | . | . | . | . | 228 |
| Nikkei 225 | . | . | . | . | . | 217 |
| VIX | . | . | . | . | . | -37 |
| *E. Bond futures* | | | | | | |
| Treasury, 10 yr | -36 | -8 | -10 | 20 | . | 20 |
| Treasury, 30 yr | -35 | -8 | -14 | 32 | . | 49 |

Table 8: high frequency responses in 2008 (2/2)

Notes: responses are defined as the log open price of the first one-minute bar with positive trading volume beginning 20 minutes after the press release time, less the log close price of the last one-minute bar with positive trading volume ending 10 minutes before the press release time, multiplied by 10000 (thus reported in *bp*). Response is missing (denoted .) if there is no trading volume in 10-20 minutes prior to the press release time or 20-40 minutes after the press release time.

| | 9/18 | 9/24 | 9/26 | 10/13 | 10/28 | 10/29 |
|---|---|---|---|---|---|---|
| *A. OIS-based CIP deviations* | | | | | | |
| AUD, 3 mo | . | . | . | . | . | . |
| CAD, 3 mo | . | . | . | . | . | . |
| CHF, 3 mo | . | . | . | . | . | . |
| EUR, 3 mo | 73 | . | -13 | . | . | . |
| GBP, 3 mo | . | . | -5 | . | . | . |
| JPY, 3 mo | . | . | . | . | . | . |
| NZD, 3 mo | . | . | . | . | . | . |
| Average, 3 mo | 73 | . | -9 | . | . | . |
| *B. Libor-based CIP deviations* | | | | | | |
| AUD, 1 yr | . | . | . | . | . | . |
| CAD, 1 yr | . | . | . | . | . | . |
| CHF, 1 yr | . | . | . | . | . | . |
| EUR, 1 yr | 23 | -2 | . | . | -0 | 0 |
| GBP, 1 yr | 6 | . | -1 | 2 | -1 | -1 |
| JPY, 1 yr | . | . | . | . | . | . |
| NZD, 1 yr | . | . | . | . | . | . |
| Average, 1 yr | 15 | -2 | -1 | 2 | -1 | -0 |

Table 9: additional high frequency responses in 2008 (1/2)

Notes: responses are defined as the log open price of the first one-minute bar with positive trading volume beginning 20 minutes after the press release time, less the log close price of the last one-minute bar with positive trading volume ending 10 minutes before the press release time, multiplied by 10000 (thus reported in *bp*). Response is missing (denoted .) if there is no trading volume in 10-20 minutes prior to the press release time or 20-40 minutes after the press release time.

| | 9/18 | 9/24 | 9/26 | 10/13 | 10/28 | 10/29 |
|---|---|---|---|---|---|---|
| *C. Short-term dollar interest rates* | | | | | | |
| USD OIS, 3 mo | 0 | 1 | -6 | . | . | . |
| Treasury, 3 mo | 2 | 1 | . | . | . | 1 |
| *D. EM currency and equity futures* | | | | | | |
| BRL | . | . | . | . | . | . |
| MXN | . | . | . | . | . | -345 |
| RUB | . | . | . | . | . | . |
| ZAR | . | . | . | . | . | . |
| Average of EM currencies | . | . | . | . | . | -345 |
| MSCI EM Equity Index | . | . | . | . | . | . |
| *E. Additional bond futures* | | | | | | |
| Treasury, 2 yr | -12 | -2 | -3 | 1 | . | 3 |
| Treasury, 5 yr | -27 | -4 | -7 | 7 | . | 17 |
| Gilt, 10 yr | . | . | . | . | . | . |
| Euro shatz, 1.75-2.25 yr | -13 | . | . | . | . | -2 |
| Euro bobl, 4.5-5.5 yr | -18 | . | . | . | . | -2 |
| Euro bund, 8.5-10.5 yr | -14 | . | . | . | . | 1 |
| Euro buxl, 24.0-35.0 yr | 10 | . | . | . | . | . |

Table 10: additional high frequency responses in 2008 (2/2)

Notes: responses are defined as the log open price of the first one-minute bar with positive trading volume beginning 20 minutes after the press release time, less the log close price of the last one-minute bar with positive trading volume ending 10 minutes before the press release time, multiplied by 10000 (thus reported in *bp*). Response is missing (denoted .) if there is no trading volume in 10-20 minutes prior to the press release time or 20-40 minutes after the press release time.

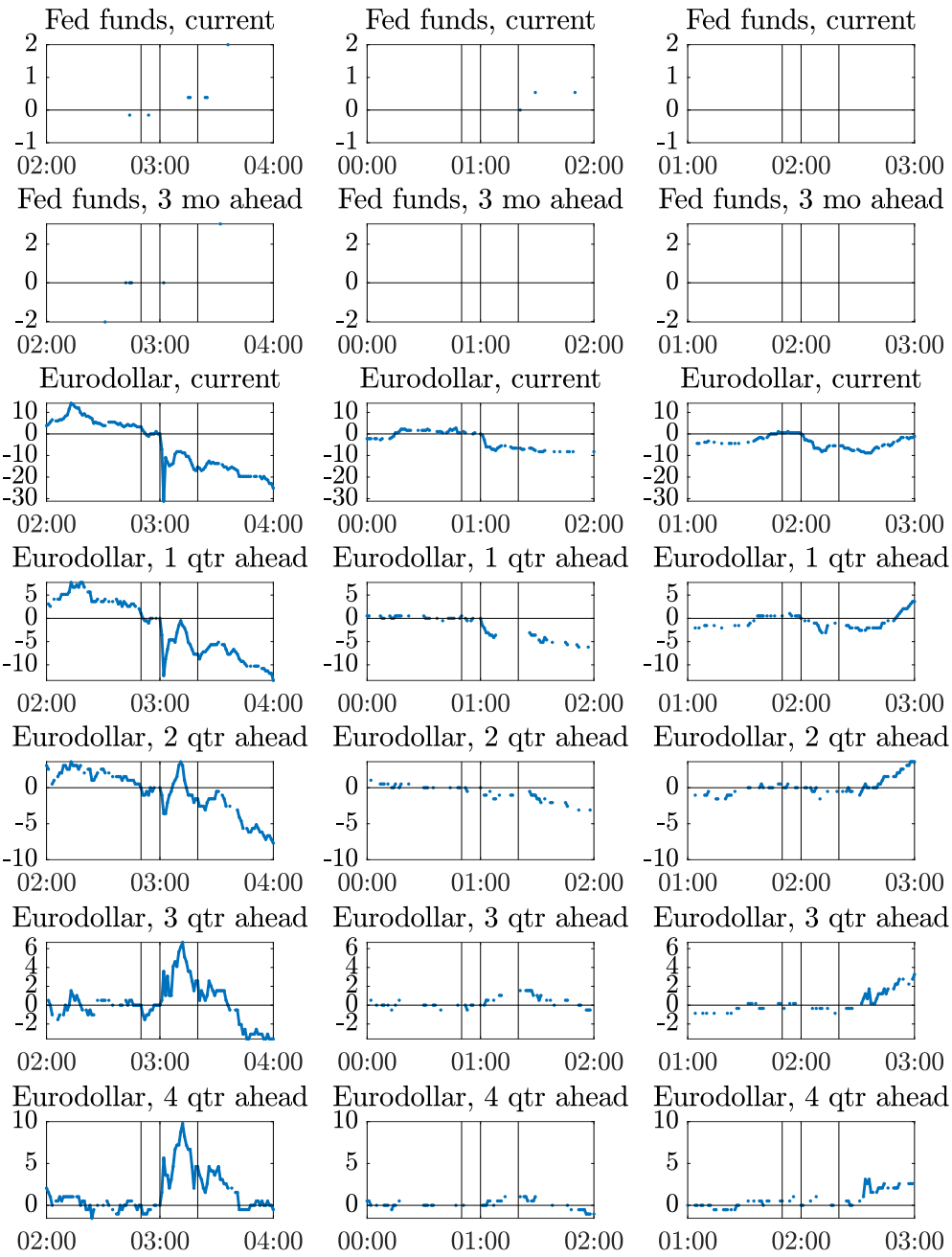


Figure 24: interest rate futures on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict log open price (for S&P 500 future) and −1 times log open price (for bond futures) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

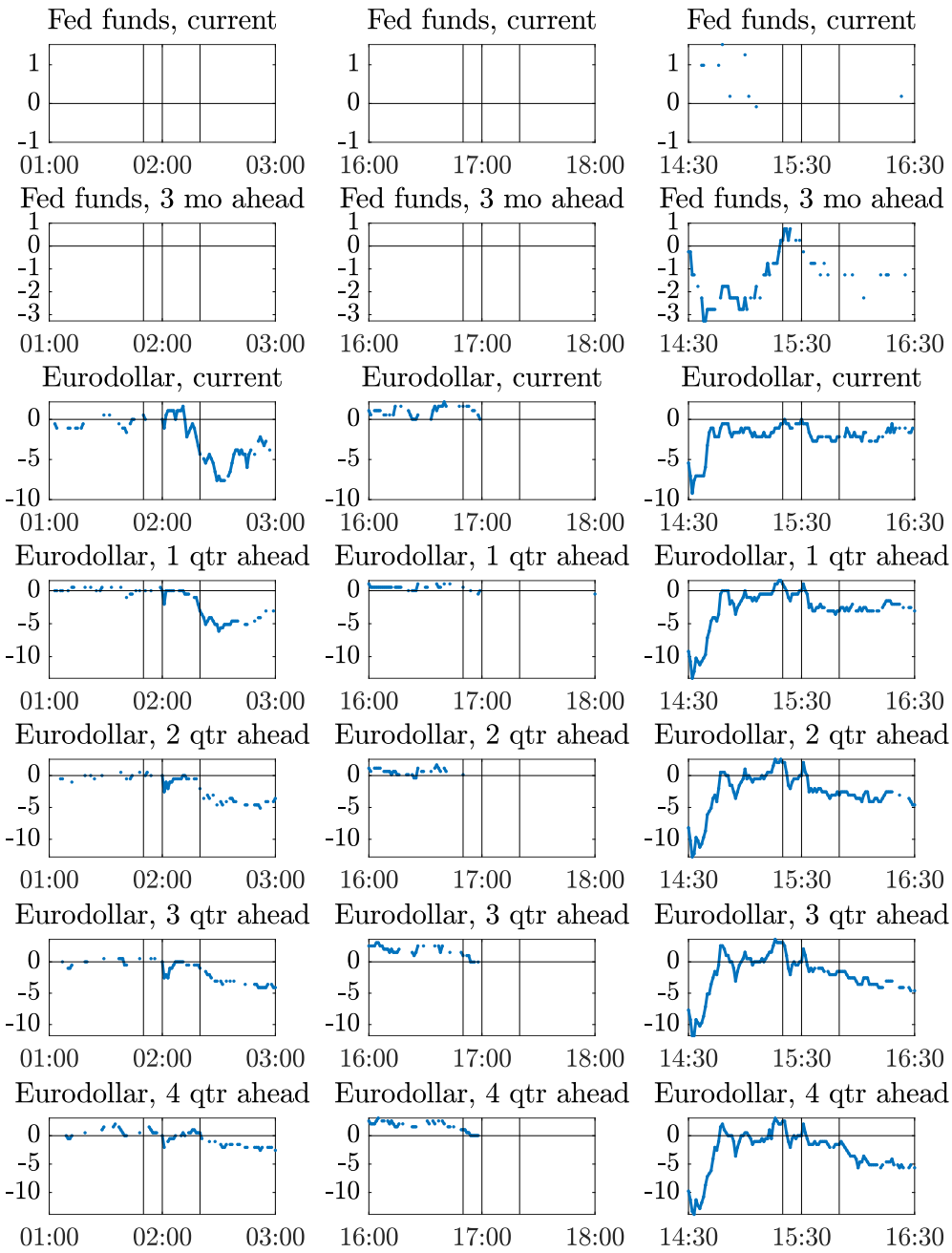


Figure 25: interest rate futures on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict log open price (for S&P 500 future) and −1 times log open price (for bond futures) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

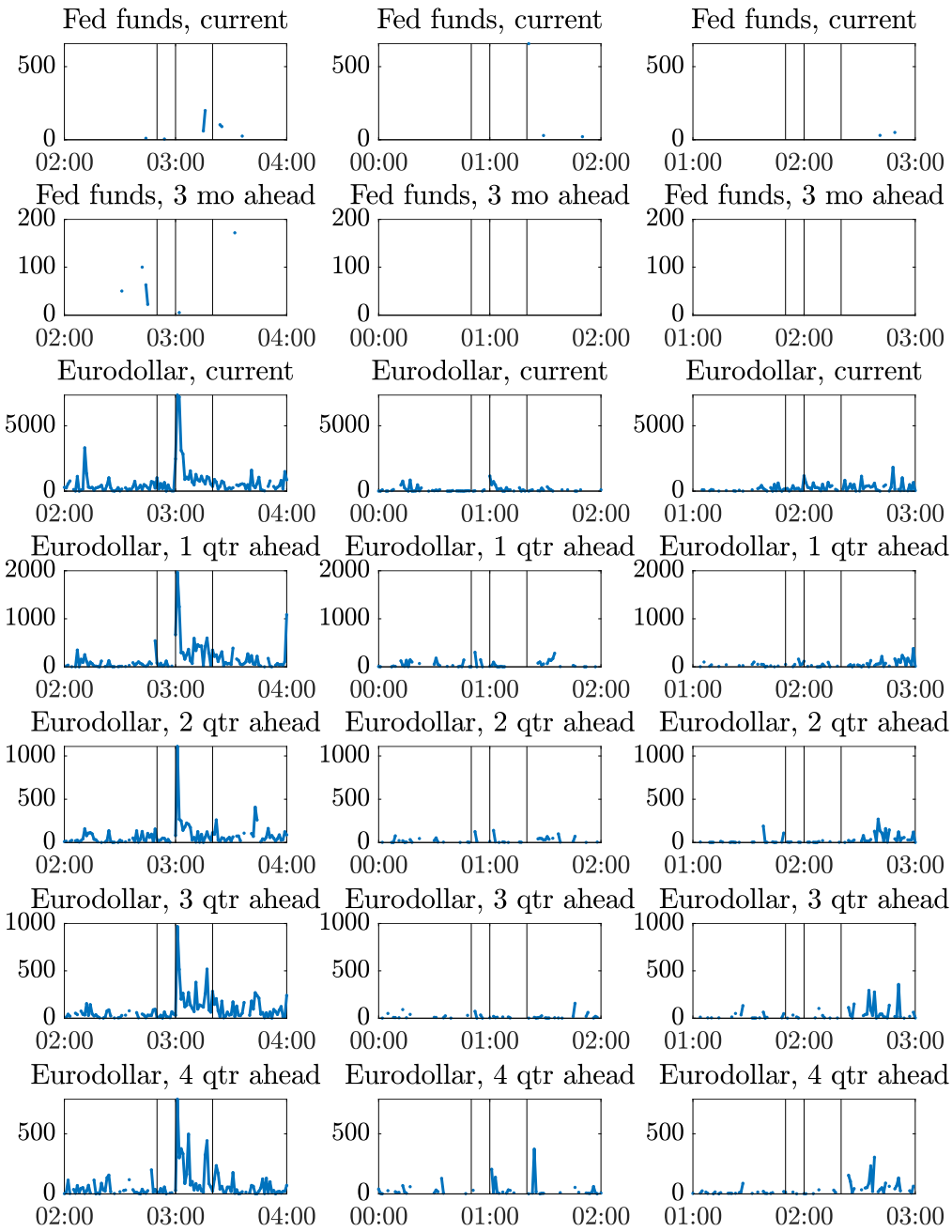


Figure 26: interest rate futures volume on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

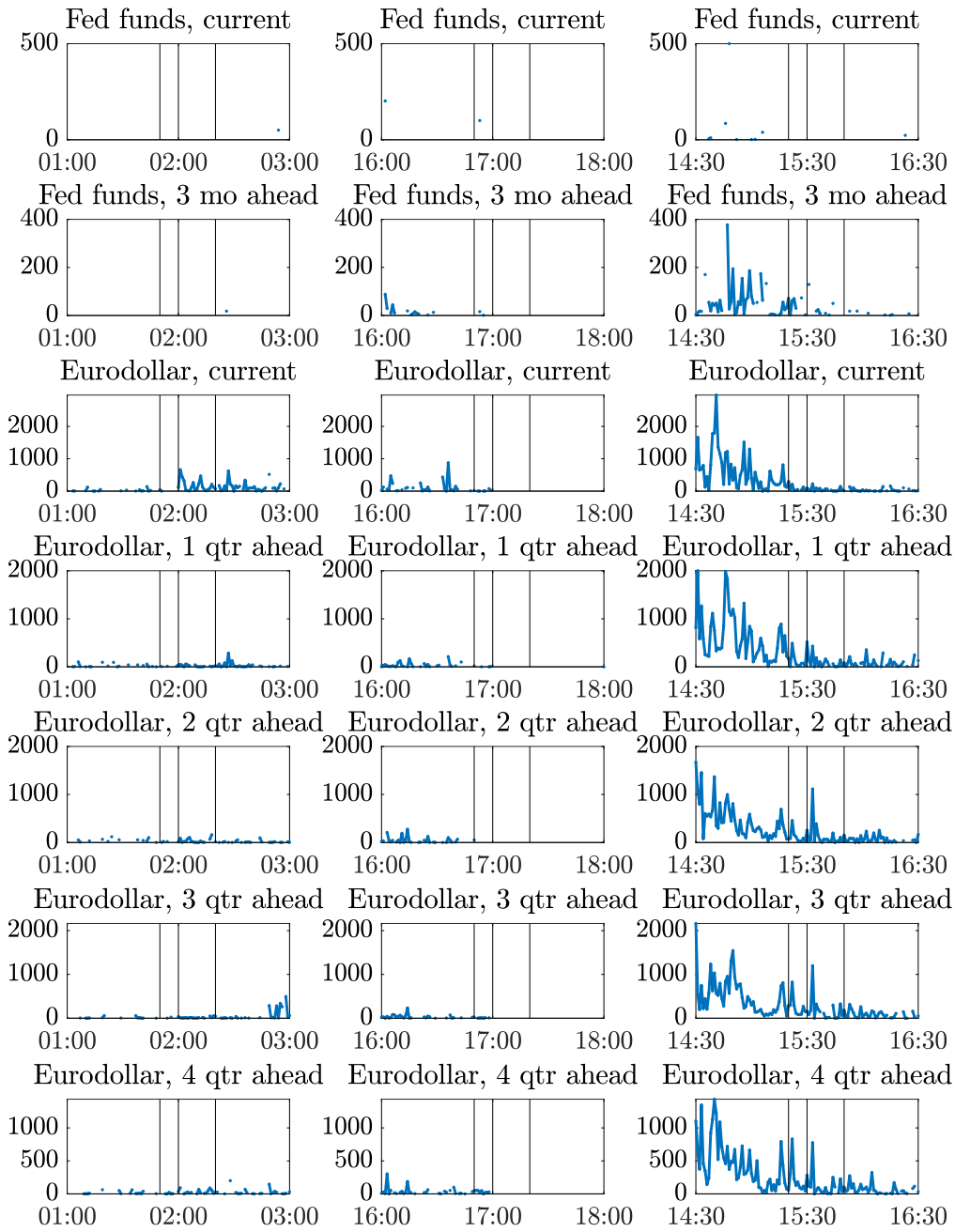


Figure 27: interest rate futures volume on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

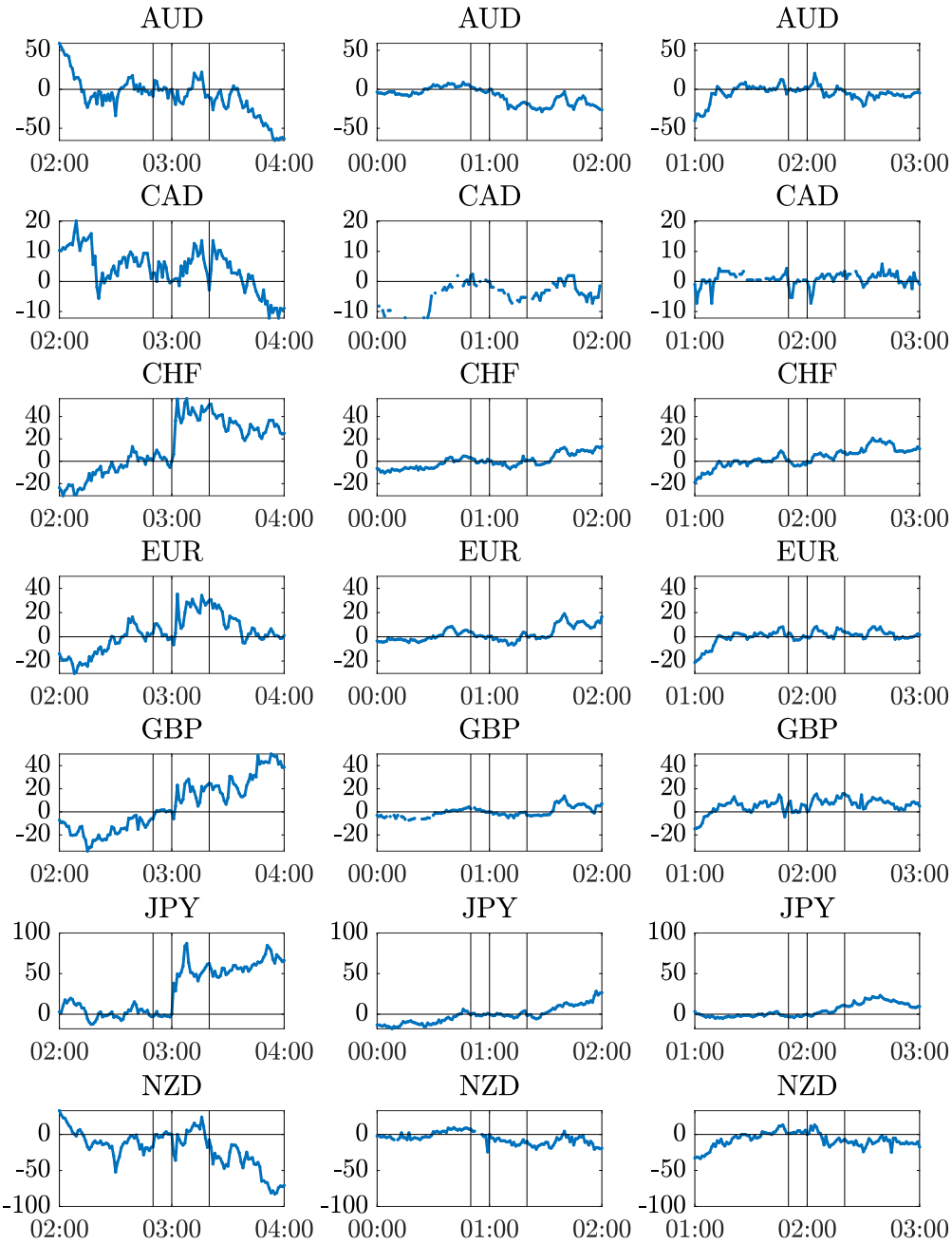


Figure 28: spot exchange rates on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict log open price (foreign per dollar) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

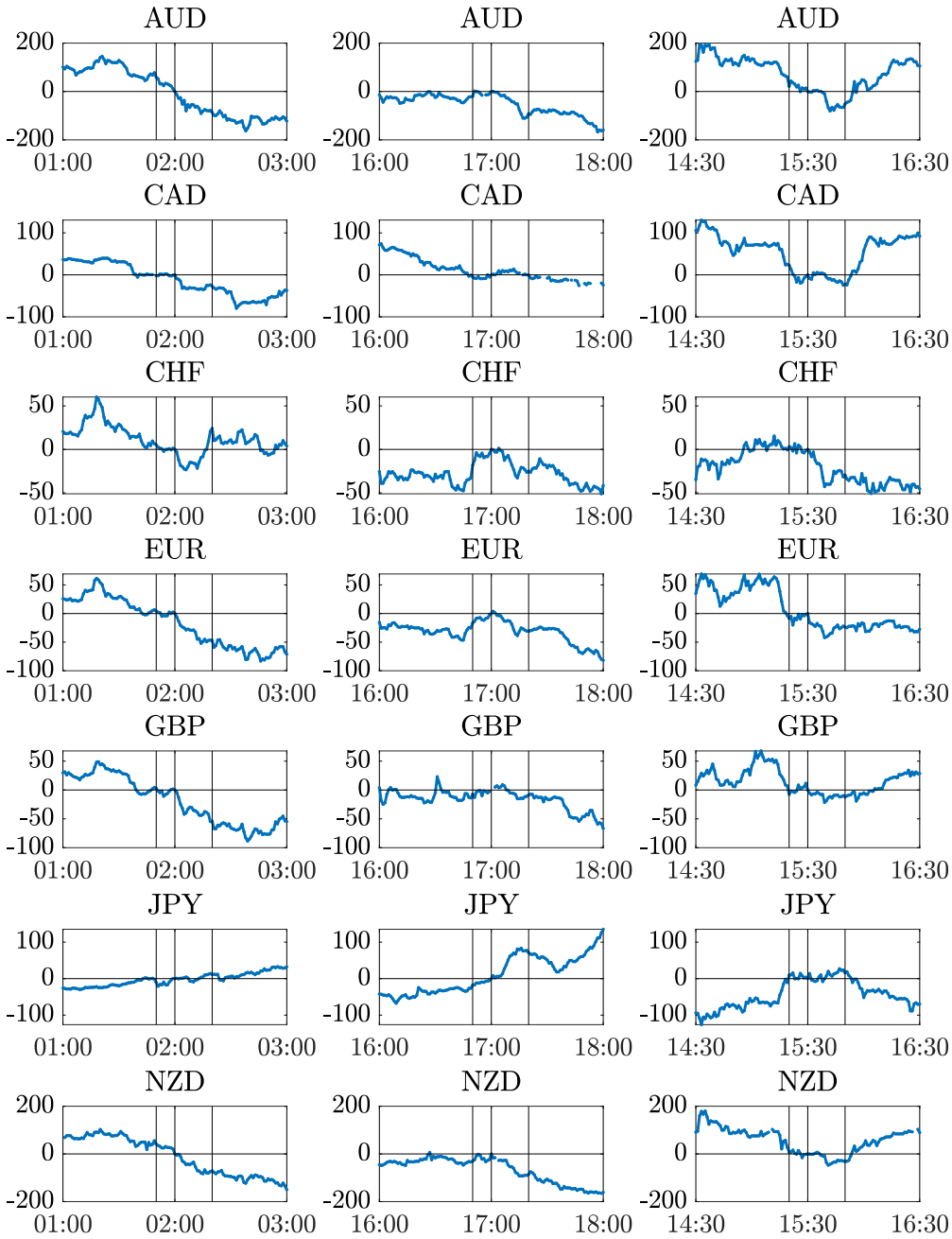


Figure 29: spot exchange rates on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict log open price (foreign per dollar) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

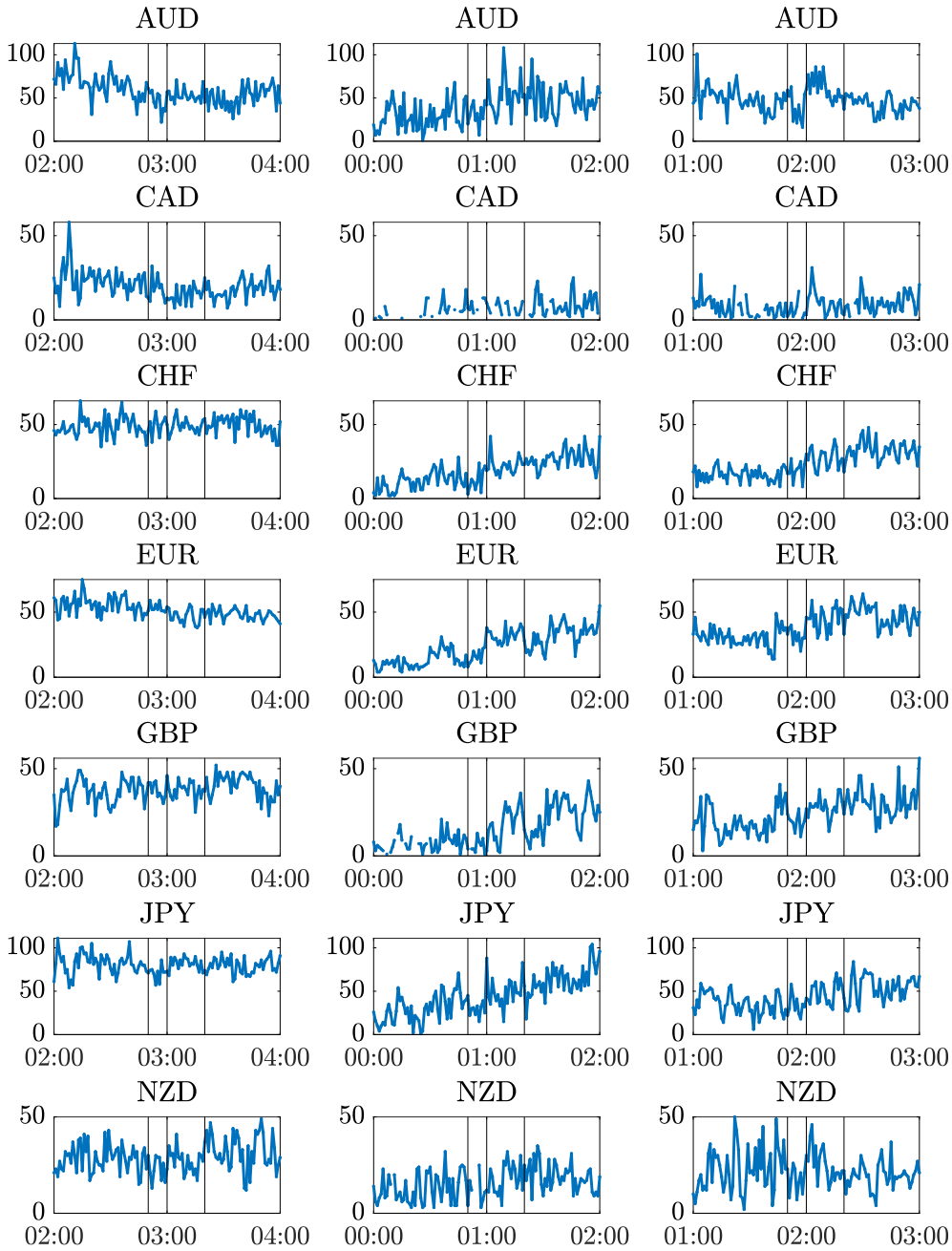


Figure 30: spot exchange rates volume on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict average number of bids and asks by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

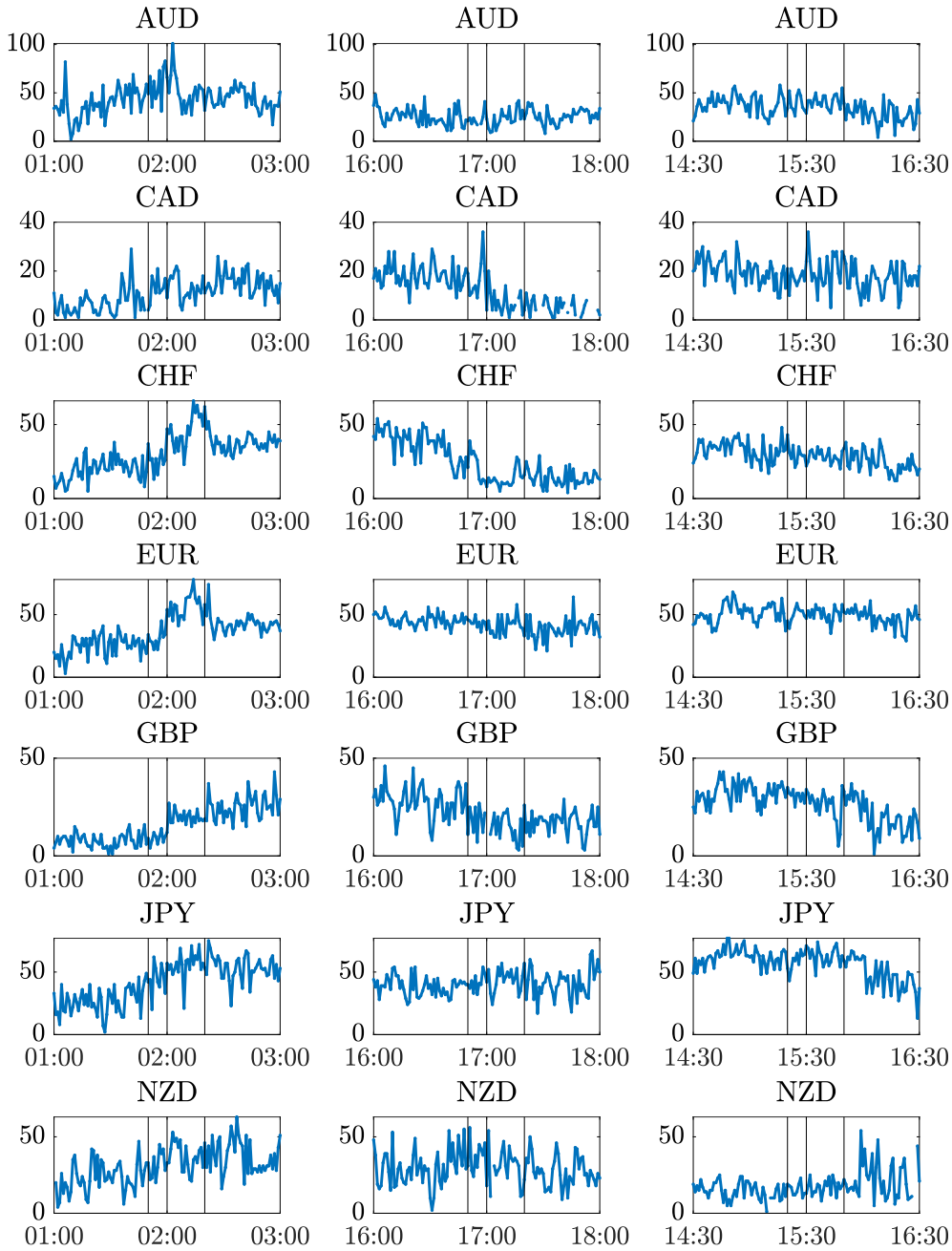


Figure 31: spot exchange rates volume on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict average number of bids and asks by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

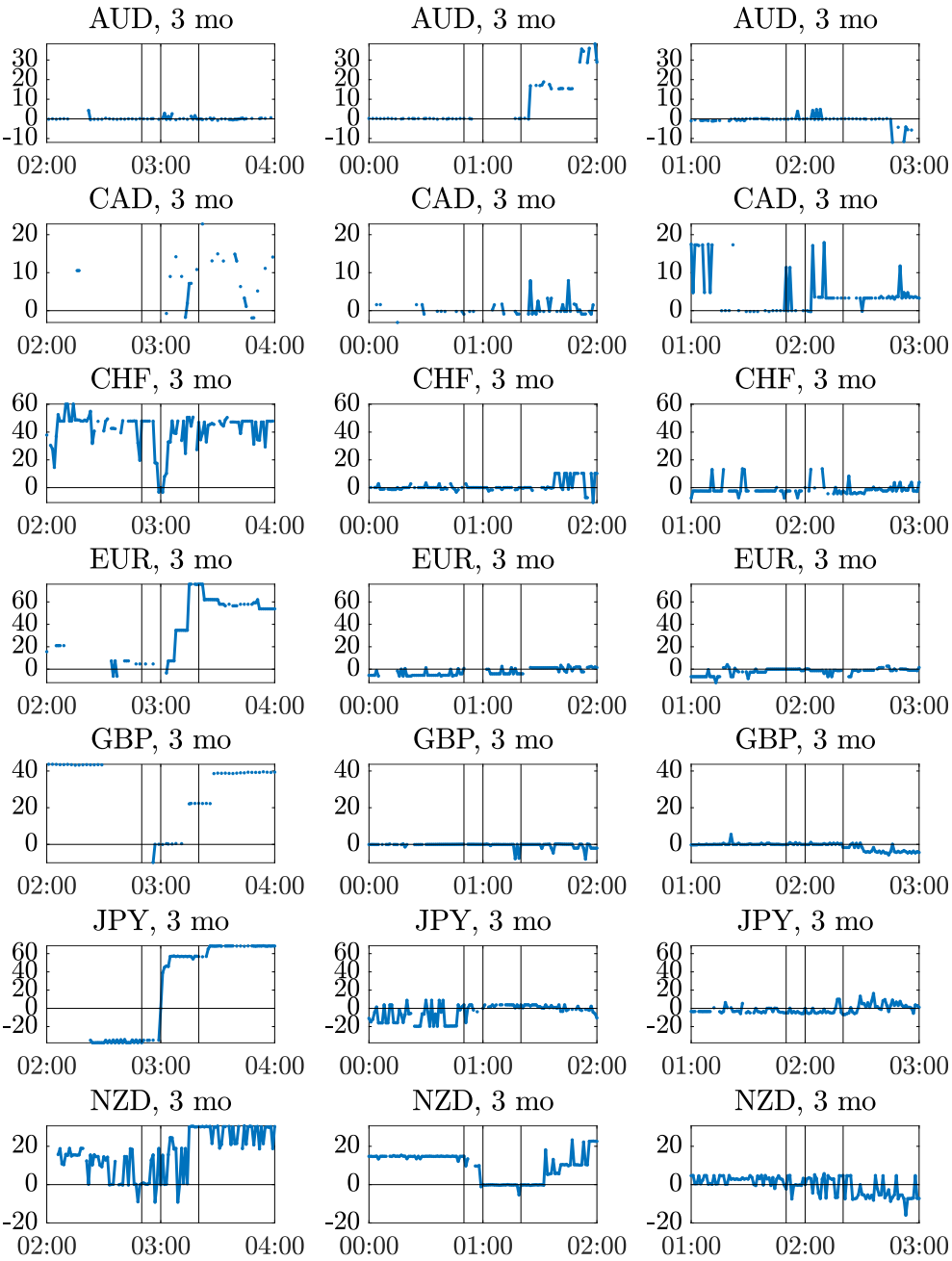


Figure 32: forward premiums on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict forward premiums at open by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

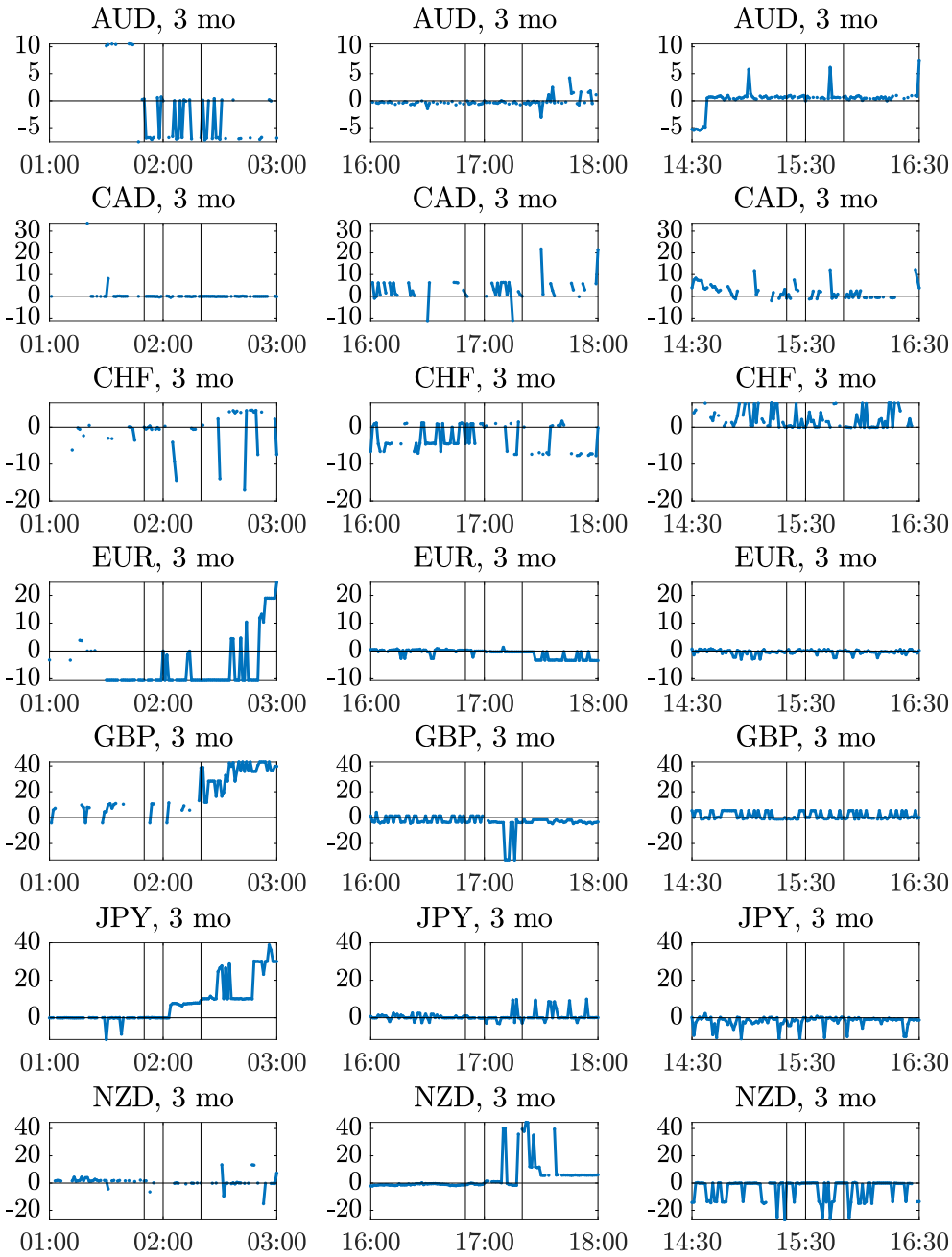


Figure 33: forward premiums on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict forward premiums at open by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

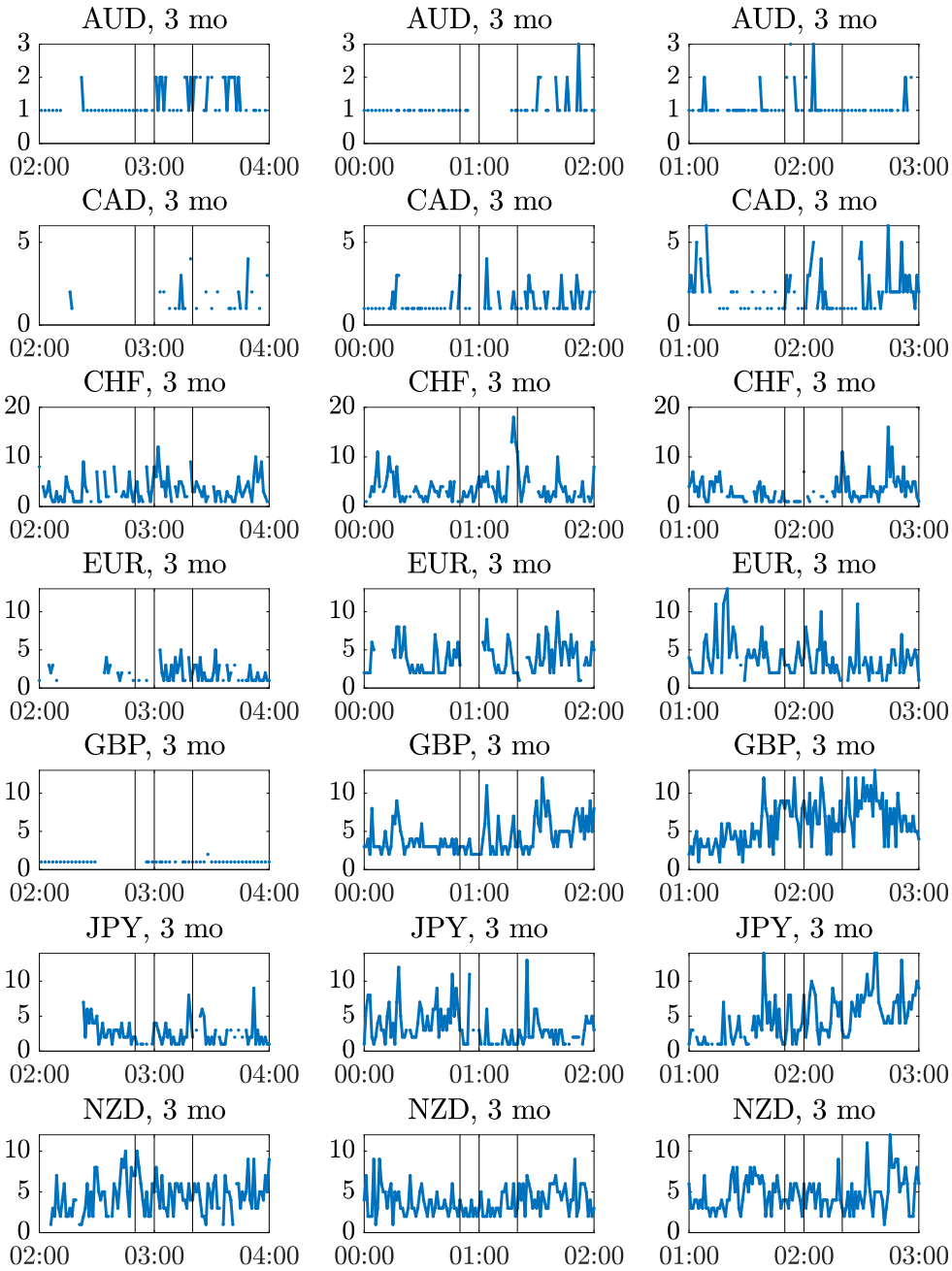


Figure 34: forward volume on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict average number of bid and ask quotes by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

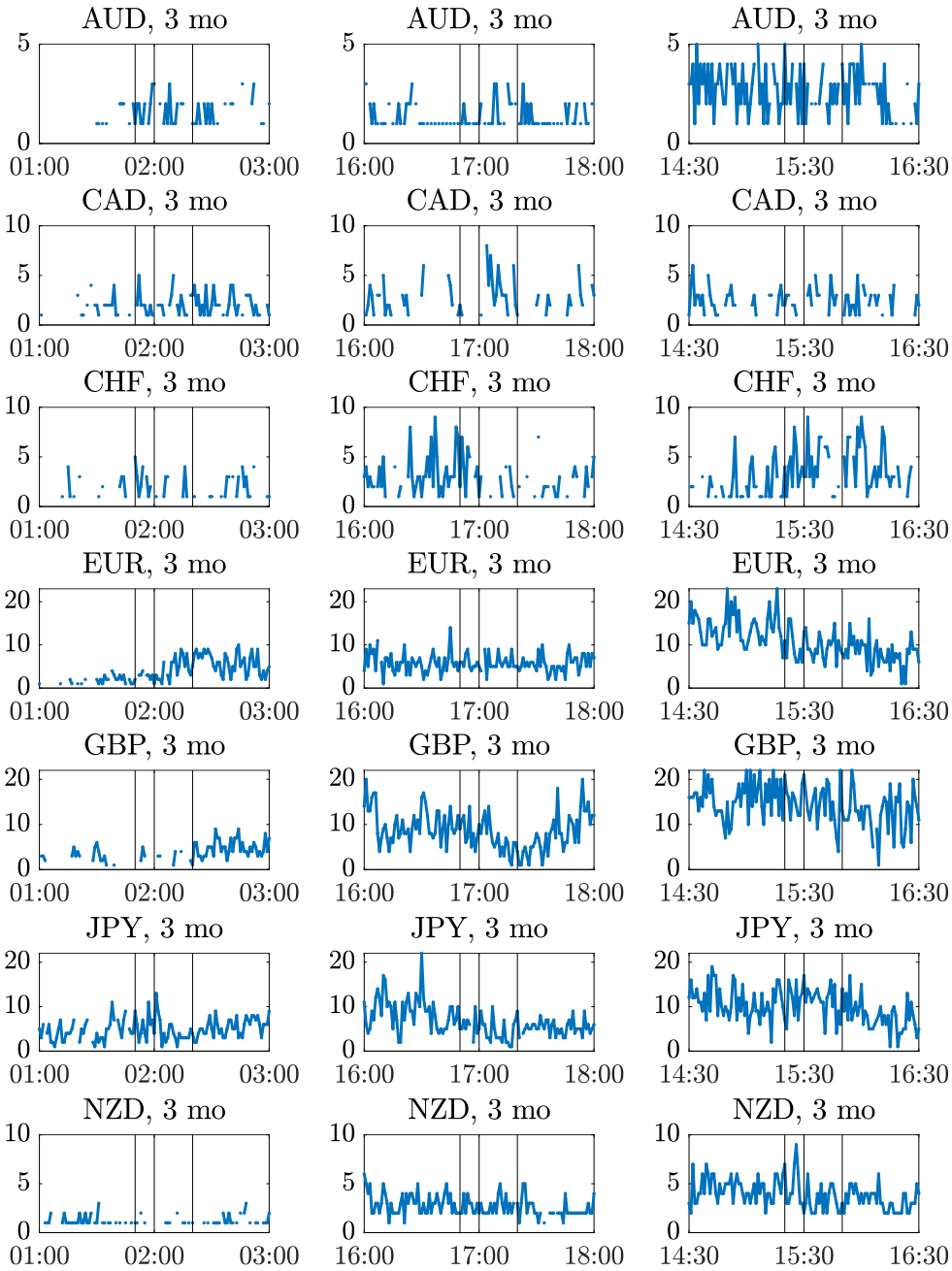


Figure 35: forward volume on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict average number of bid and ask quotes by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

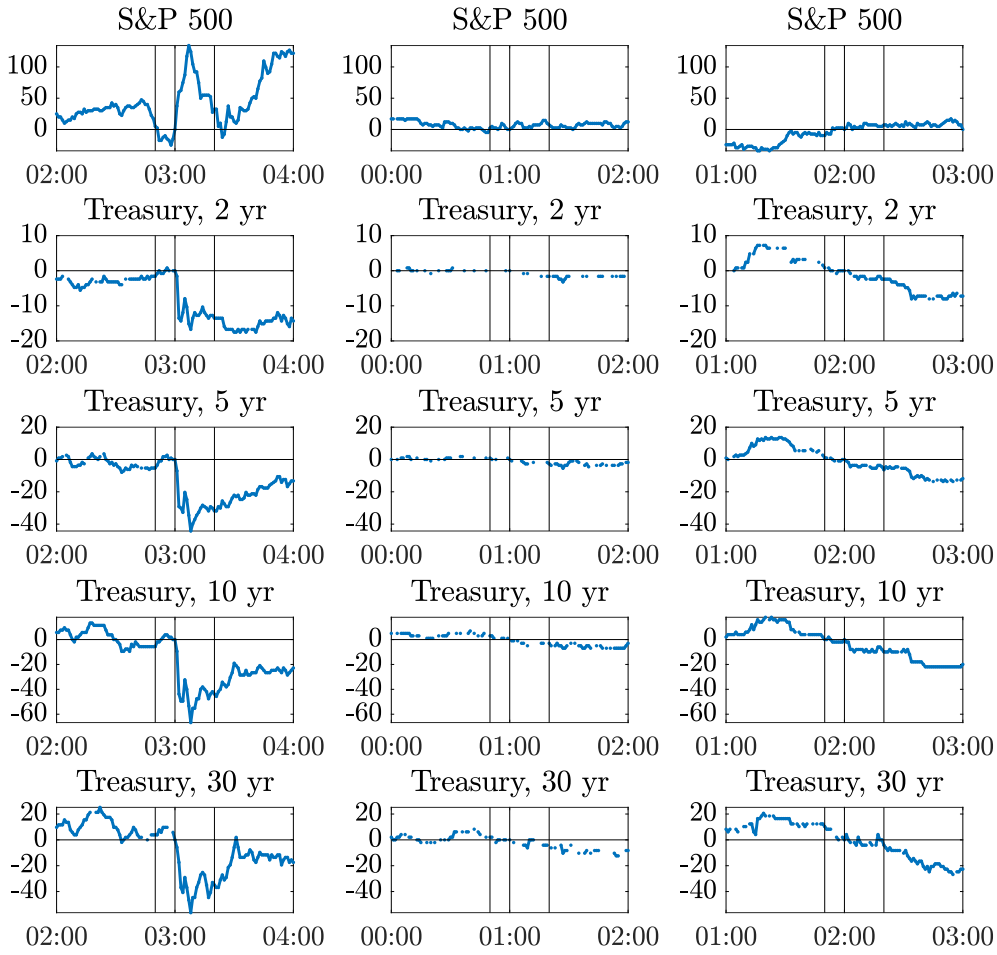


Figure 36: S&P 500 and bond futures on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict log open price (for S&P 500 future) and $-1$ times log open price (for bond futures) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

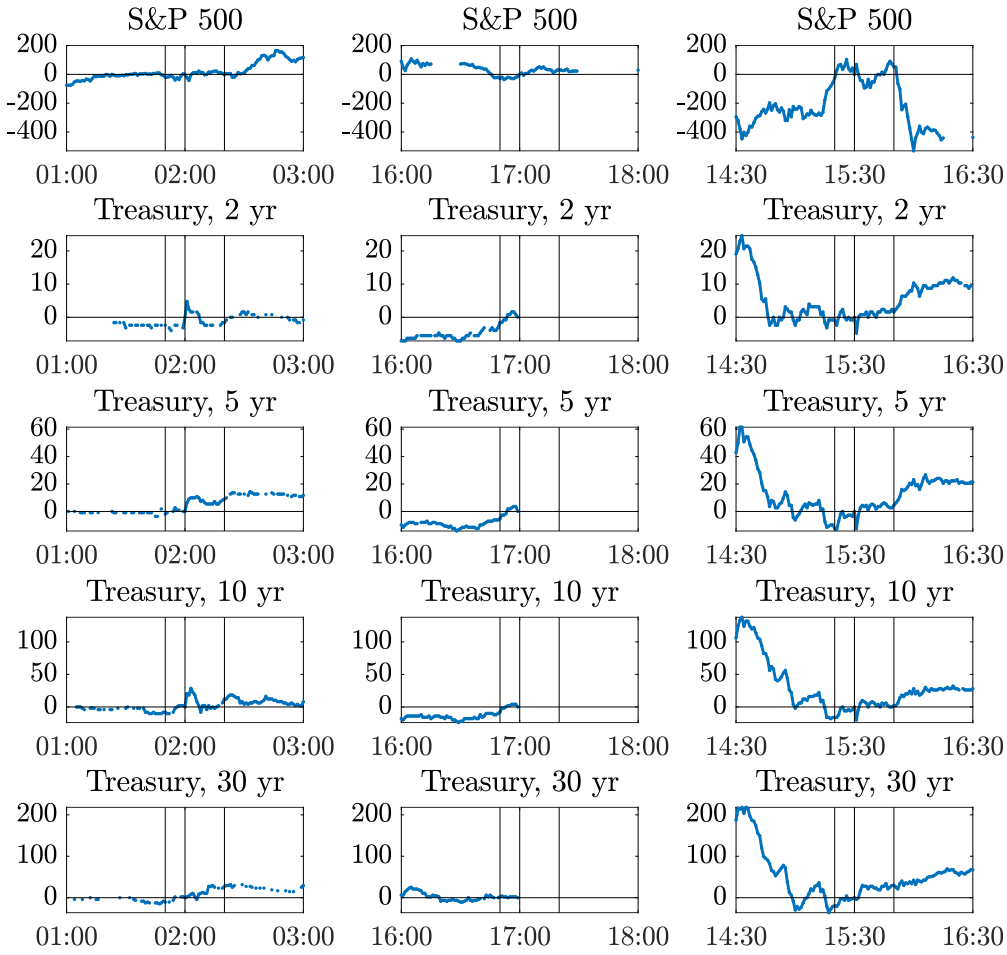


Figure 37: S&P 500 and bond futures on 10/13 (L), 10/28 (M), and 10/29 (R)

Notes: figures depict log open price (for S&P 500 future) and $-1$ times log open price (for bond futures) by one-minute bar, multiplied by 10000 and normalized so that each series equals zero at time of press release. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

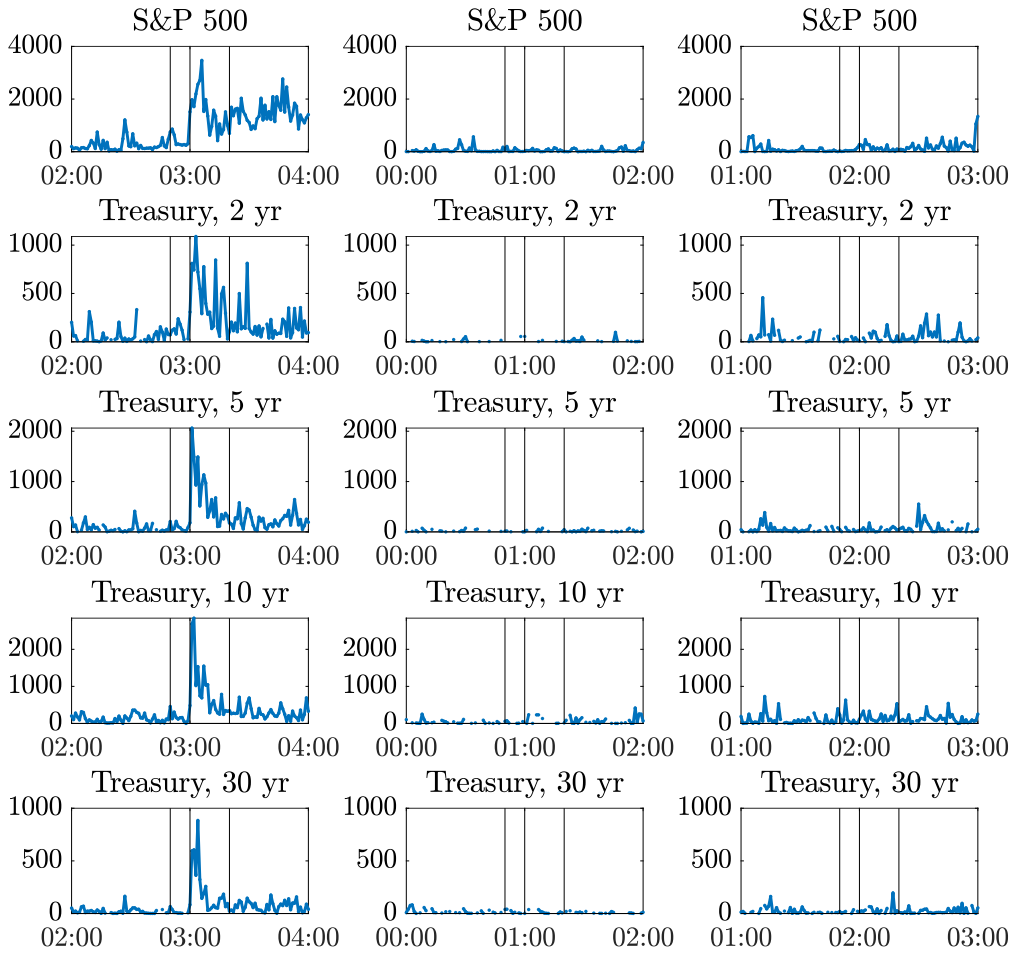


Figure 38: S&P 500 and bond futures volume on 9/18 (L), 9/24 (M), and 9/26 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

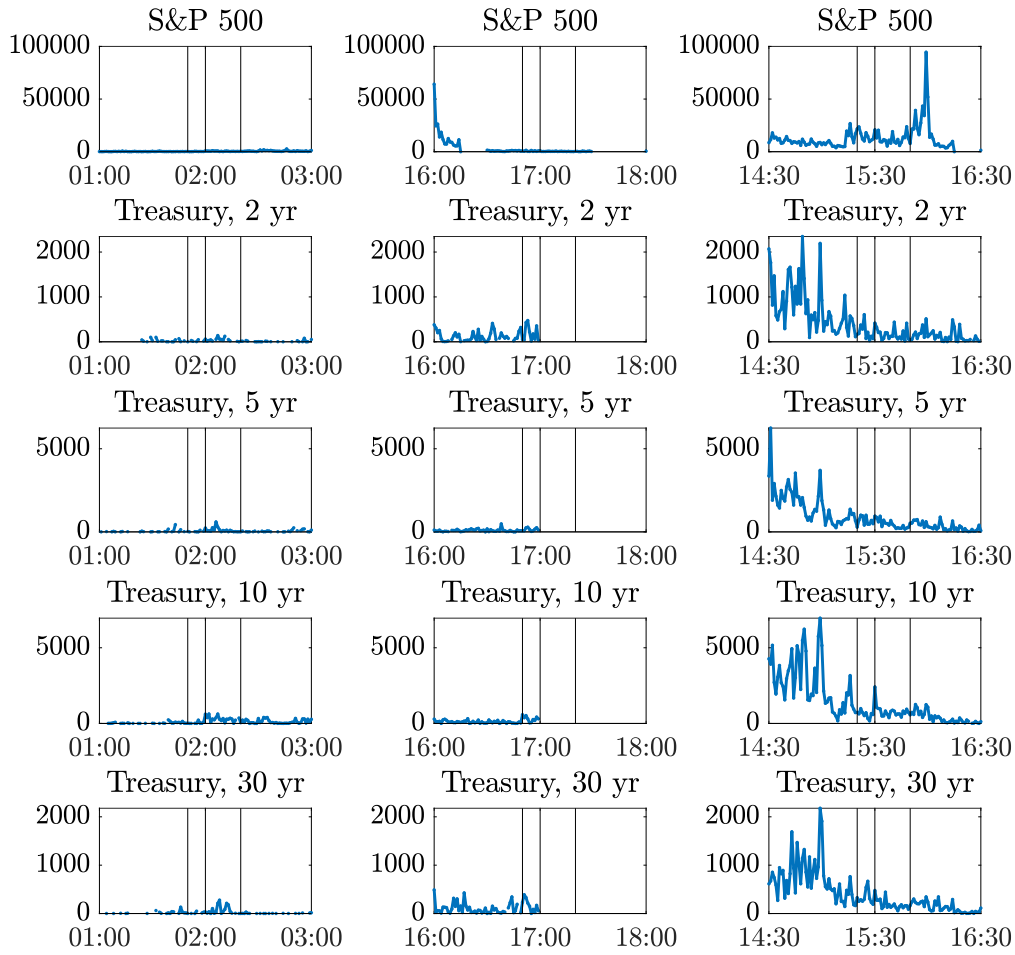


Figure 39: S&P 500 and bond futures volume on 10/13 (L), 10/28 (M), 10/29 (R)

Notes: figures depict trading volume by one-minute bar. Vertical lines depict 10 minutes prior to press release, press release, and 20 minutes after press release. All times are in EDT.

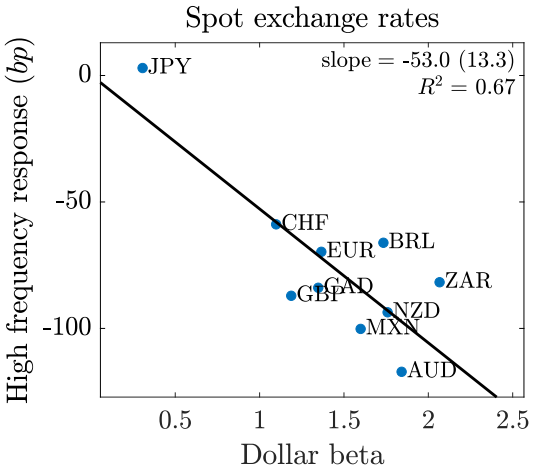


Figure 40: high frequency responses and dollar betas including emerging markets

Notes: dollar betas are regression coefficients of daily change in log bilateral exchange rate on daily change in log broad dollar index, estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1 for G7 and Table 4 for emerging markets. Straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

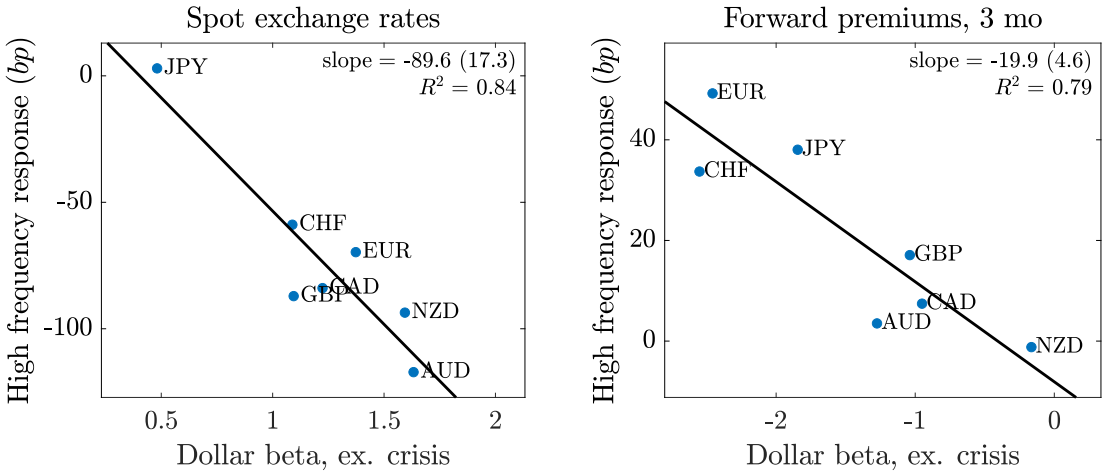


Figure 41: high frequency responses and dollar betas excluding crises

Notes: dollar betas are regression coefficients of daily change in log bilateral exchange rate on daily change in log broad dollar index (left panel), and daily change in bilateral CIP deviation on daily change in log broad dollar index (right panel), estimated over January 1, 2010 through December 31, 2019. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

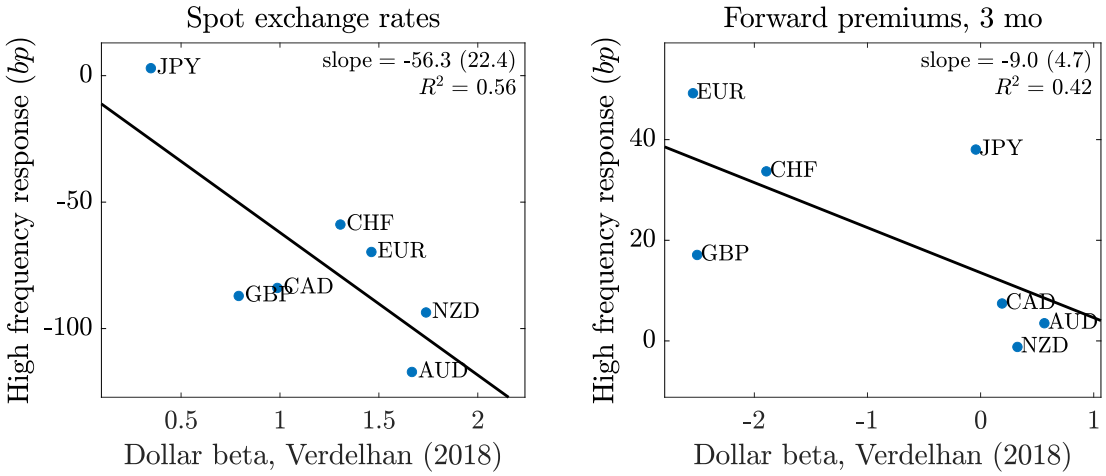


Figure 42: high frequency responses and dollar betas as in Verdelhan (2018)

Notes: dollar betas are obtained from regressions of monthly change in log bilateral exchange rate (left panel) or monthly change in bilateral three-month CIP deviation (right panel) on lagged interest rate differential, dollar factor, carry factor, and product of lagged interest rate differential and carry factor, as in Verdelhan (2018), estimated over January 2007 through April 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

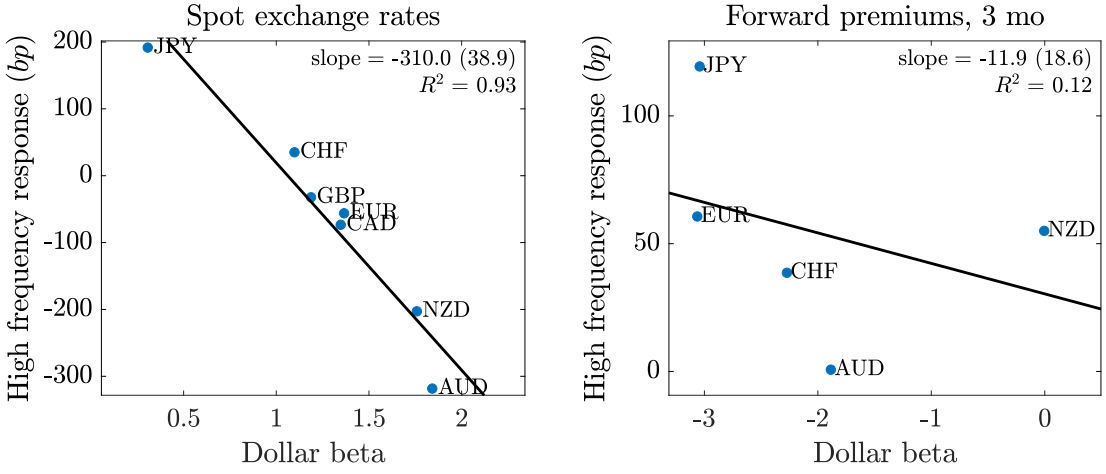


Figure 43: high frequency responses in 2008 and dollar betas

Notes: dollar betas are regression coefficients of daily change in log bilateral exchange rate on daily change in log broad dollar index (left panel), and daily change in bilateral CIP deviation on daily change in log broad dollar index (right panel), estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to September-October 2008 announcements reported in Tables 7 and 8. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

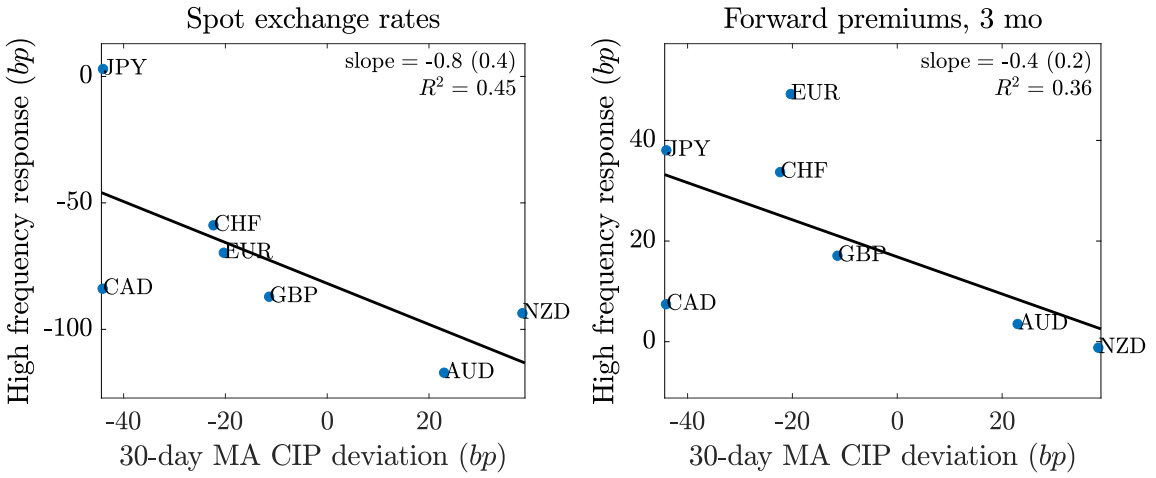


Figure 44: high frequency responses and 30-day moving average of CIP deviations

Notes: 30-day moving average of CIP deviations estimated as of March 18, 2020, prior to announcements under study. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

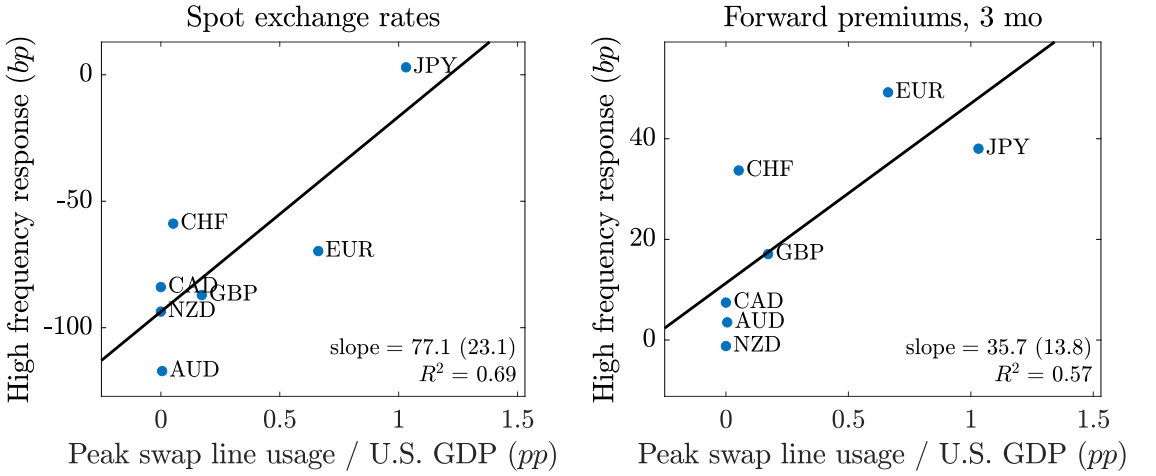


Figure 45: high frequency responses and peak swap line usage

Notes: peak swap lines outstanding by counterparty measured over March 21, 2020 (after announcements under study) through end of year. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in bottom right corner.

| | Spot exchange rates | | Forward premiums, 3 mo | |
|---|---|---|---|---|
| 30-day MA CIP deviation | -0.81 | 0.17 | -0.37 | 0.012 |
| | (0.40) | (0.27) | (0.22) | (0.23) |
| Dollar beta | | -79.7 | | -16.2 |
| | | (16.9) | | (7.07) |
| $N$ | 7 | 7 | 7 | 7 |
| $R^2$ | 0.45 | 0.92 | 0.36 | 0.73 |

Table 11: high frequency responses and 30-day moving average of CIP deviations

Notes: 30-day moving average of CIP deviations estimated as of March 18, 2020, prior to announcements under study. Dollar beta is loading of daily change in spot exchange rate or daily change in 3-month CIP deviation on daily change in broad dollar index, estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. Standard errors in parenthesis.

| | Spot exchange rates | | Forward premiums, 3 mo | |
|---|---|---|---|---|
| Peak usage / U.S. GDP | 77.1 | 22.7 | 35.7 | 14.2 |
| | (23.1) | (18.7) | (13.8) | (16.2) |
| Dollar beta | | -57.3 | | -11.9 |
| | | (15.1) | | (6.44) |
| $N$ | 7 | 7 | 7 | 7 |
| $R^2$ | 0.69 | 0.93 | 0.57 | 0.77 |

Table 12: high frequency responses and peak swap line usage

Notes: peak swap lines outstanding by counterparty measured over March 21, 2020 (after announcements under study) through end of year. Dollar beta is loading of daily change in spot exchange rate or daily change in 3-month CIP deviation on daily change in broad dollar index, estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1. Standard errors in parenthesis.

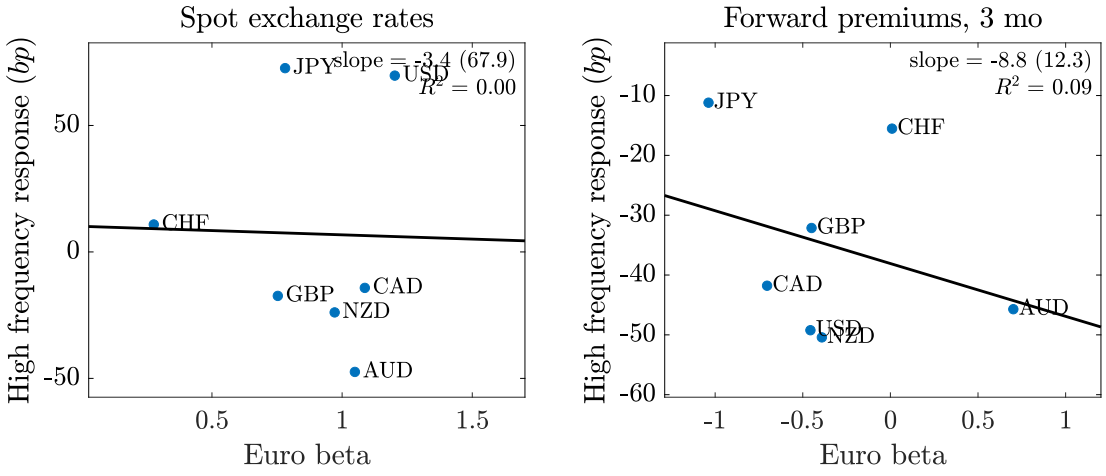


Figure 46: high frequency responses and euro betas

Notes: euro betas are regression coefficients of daily change in log bilateral exchange rate on average daily change in log bilateral exchange rate across 22 currencies (left panel), and daily change in bilateral CIP deviation on average daily change in log bilateral exchange rate across 22 currencies (right panel), all expressed relative to the euro and estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1 and expressed relative to the euro. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

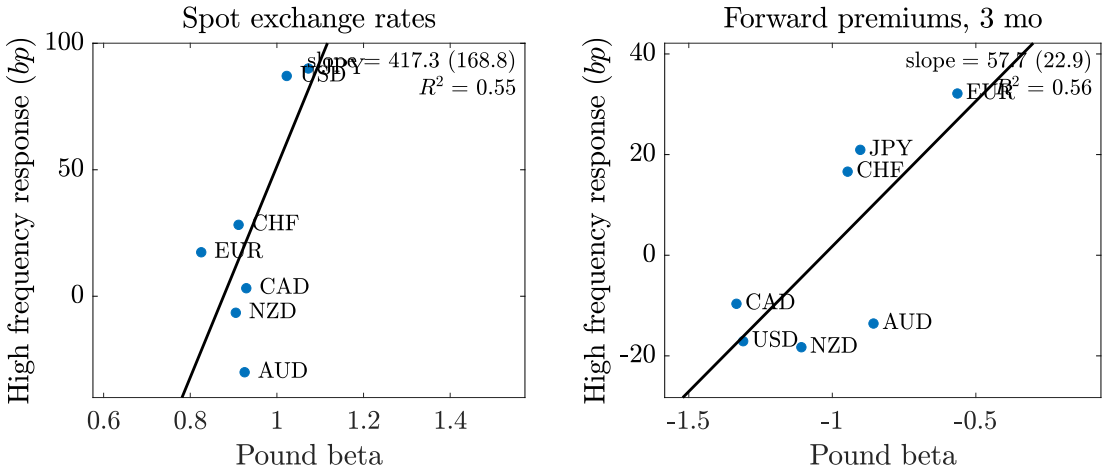


Figure 47: high frequency responses and pound betas

Notes: pound betas are regression coefficients of daily change in log bilateral exchange rate on average daily change in log bilateral exchange rate across 22 currencies (left panel), and daily change in bilateral CIP deviation on average daily change in log bilateral exchange rate across 22 currencies (right panel), all expressed relative to the pound and estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1 and expressed relative to the pound. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.

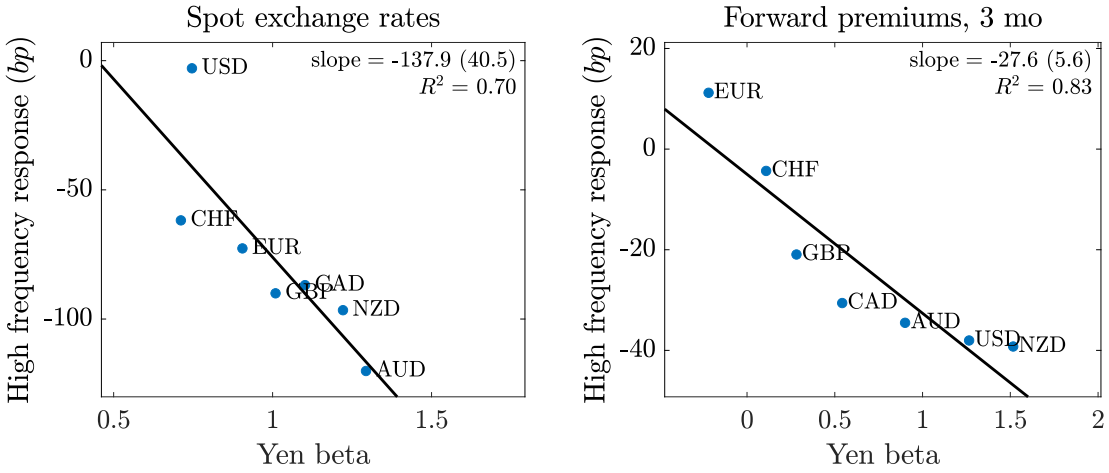


Figure 48: high frequency responses and yen betas

Notes: yen betas are regression coefficients of daily change in log bilateral exchange rate on average daily change in log bilateral exchange rate across 22 currencies (left panel), and daily change in bilateral CIP deviation on average daily change in log bilateral exchange rate across 22 currencies (right panel), all expressed relative to the yen and estimated over January 1, 2007 through April 30, 2020. High frequency responses are cumulative responses to March 2020 announcements reported in Table 1 and expressed relative to the yen. In each panel, straight line is estimated linear regression line, and slope coefficient, standard error of that coefficient, and $R^2$ are reported in top right corner.