U.S. Banks and Global Liquidity*

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Abstract

We document the crucial role of bank reserves in global banks' provision of short-term dollar liquidity post-Global Financial Crisis. Using daily supervisory data, we show that large U.S. banks substitute their excess reserves at the Federal Reserve for short-term lending in the repo and foreign exchange swap markets in response to dollar funding shortages. Intra-firm liquidity sharing between depository institutions and broker-dealer subsidiaries within the same bank holding company are crucial the "reserve-draining intermediation." Our results highlight the importance of a large Federal Reserve balance sheet in the current regulatory environment to ensure the well-functioning of short-term funding markets.

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JEL Classifications: G2, F3, E4

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1 Introduction

The post-Global Financial Crisis (GFC) period features fundamental changes to the monetary policy environment. Quantitative easing (QE) programs adopted by major central banks led to an expansion of central banks' asset holdings. To finance these QE purchases, commercial banks' cash holdings at central banks (known as bank reserves) materially increased beyond the statutorily required levels. Using newly constructed daily balance sheets for U.S. globally systemically important banks (GSIBs), we highlight the crucial role of bank reserves in supporting short-term liquidity provision by large global banks, especially during episodes of funding stress.

We focus on the two most important types of short-term dollar lending: dollar lending via repurchase agreements (known as repos) and dollar lending via the foreign exchange (FX) swap market. In a repo agreement, a cash loan is collateralized by securities such as Treasury securities. Dollar lending via FX swaps can also be viewed as a form of secured lending collateralized by foreign currency — the borrower receives dollars and posts foreign currency at the spot exchange rate at the inception of the trade and promises to repurchase the foreign currency with dollars at the forward exchange rate at maturity.

We document an important new intermediation model used by global banks in short-term funding markets, which we label as "reserve-draining intermediation." Under this new intermediation model, global banks increase additional short-term dollar lending by reducing their reserve holdings. The reserve-draining intermediation model sharply contrasts with banks' traditional intermediation models. Before the GFC, commercial banks relied heavily on overnight unsecured borrowing from the federal funds market to manage their daily liquidity needs. However, as bank reserves became more abundant, the total size of the federal funds market declined from over $200 billion before the GFC (Afonso, Entz and LeSueur

(2013)) to the current level of about $70 billion.[1] Separately, broker-dealers primarily relied on a traditional intermediation model known as "matched-book intermediation", which consists of borrowing from cash-rich lenders, such as money market funds, and lending to clients in need of dollars, such as hedge funds (Bank for International Settlements (2017)). After the GFC, partly due to regulatory changes, the gross volumes of collateralized borrowing and lending intermediated by large broker-dealers contracted significantly.[2]

We first present a conceptual framework in which banks optimize reserve and liquidity intermediation in the short-term funding market based on the trade off of fulfilling their roles in payment services versus funding intermediation. In this simple model, banks chooses the level of reserves and short-term secured lending given the financing in deposit and wholesales funding market. As banks are leverage constrained, an increase in the demand for secured lending has to be met by banks reducing their reserves to increase their supply of secured loans, or "reserve-draining intermediation." Ex-ante, banks have to hold reserves in expectation of volatility in intra-day payment flows, and these reserves can be used to satisfy increases in the demand for secured lending.

We empirically document the crucial role of reserves in supporting banks' liquidity provision post-GFC through a forensic account of U.S. GSIBs' short-term dollar intermediation activities at the daily frequency. This empirical exercise could not be performed in the past due to the absence of high-frequency balance sheet data broken down by currencies and instruments. As part of the regulatory effort to calculate the Basel III liquidity coverage ratio (LCR), the Federal Reserve started to collect detailed daily consolidated bank balance sheet information (and for material entities) by currency for the largest U.S. banks in the

[1] Furthermore, when excess reserves became abundant post-GFC, most of the federal funds market volume took the form of foreign banks borrowing from federal home loan banks to arbitrage the spread between the interest on reserves and the federal funds rate. U.S. banks account for very little of the federal funds transaction volume post-GFC (McGowan and Nosal (2020); Anderson, Du and Schlusche (2020)).

[2] Based on the primary dealer statistics published by the Federal Reserve Bank of New York, the total amount of primary dealers' repo lending collateralized by U.S. Treasury bonds reached $3 trillion in March 2008. However, the post-GFC Treasury repo lending has averaged about $1.8 trillion between 2009 and 2020, a 40% decline relative to their pre-GFC peak. Gross repo borrowing by primary dealers follows very similar patterns.

FR2052a *Complex Institution Liquidity Monitoring Report*, starting in December 2015. We use aggregated data from the FR2052a report for six GSIBs headquartered in the United States: Bank of America, Citigroup, Goldman Sachs, JP Morgan, Morgan Stanley, and Wells Fargo to shed light on the global dollar intermediation activities of the largest U.S. banks.[3]

We analyze the U.S. GSIBs' balance sheet responses to two types of dollar funding shortages: on quarter-ends and on days with increases in Treasury General Account (TGA) balances (Hamilton (1997)). We show that repo spreads and FX swap spreads are significantly wider on these days. First, quarter-ends are associated with tight dollar funding conditions in our sample period partly because banks have incentives to scale back balance-sheet-intensive arbitrage and intermediation activities to "window-dress" regulatory ratios on quarter-ends.[4] Second, an increase in the Treasury's TGA balance at the Federal Reserve, either due to an increase in the net issuance of Treasury securities or higher tax payments (or lower expenses), increases the demand for dollar funding. The primary objective of our paper is to examine U.S. GSIBs' intermediation activities during these challenging liquidity episodes, rather than analyzing the full supply and demand factors during these episodes.

We show that U.S. GSIBs modestly increase their short-term dollar lending in repo and FX swap markets during these two types of dollar-shortage events. Importantly, reserve-draining intermediation is the dominant channel for U.S. GSIBs to increase their dollar liquidity provision in our sample period. In other words, the additional short-term lending from U.S. GSIBs is largely financed by a reduction in reserve balances at the Fed rather than additional repo borrowing or deposit inflows.

We find additional evidence for the reserve-draining intermediation channel by studying the direction and intensity of intra-firm liquidity flows within BHCs. Given that most of

[3]There are currently eight GSIBs in the United States. We exclude the Bank of New York Mellon and State Street from our sample due to their specialization in the custodian business.

[4]In most non-U.S. jurisdictions, the Basel III leverage ratio is calculated using quarter-end snapshots of bank balance sheets. For U.S. banks, the LR is calculated based on the daily average of bank assets. The quarter-end effects in repo and FX swap rates have been documented in Du, Tepper and Verdelhan (2018a). Some quarter-end effects in money markets prior to the introduction of Basel III regulations are documented in Munyan (2017) and Fleckenstein and Longstaff (2020), but the effects became much larger starting in 2015, when the public disclosure of the Basel III leverage ratio began.

the short-term liquidity provision is done by broker-dealers, but only depository institutions can hold reserves, intra-firm transfers between broker-dealers and depository institutions are crucial. To keep the reverse repo lending position steady while cutting external repo borrowing, the broker-dealer arm increases internal repo borrowing from the non-broker dealer arm of the bank. The non-broker dealer arm of the bank (largely depository institutions), in turn, finances the intra-firm transfer through a reduction in reserve balances.[5] The internal liquidity sharing between depository institutions and broker-dealers adds a new dimension to banks' internal liquidity management across different states or countries, such as in Campello (2002), Cetorelli and Goldberg (2012), and Schnabl (2012).

Although there are important differences between large U.S. and foreign banks, we also find evidence that reserves also play an important role in supporting the *net* liquidity provision of large foreign banks. Using data on the repo and reserve activities of foreign banking organizations (FBOs) in the United States, we provide cross-sectional support to the reserve-draining intermediation channel. We find that banks that drain reserve the most are the ones that increase their net repo lending the most on quarter ends and during days with TGA increases.

However, the total supply of reserves is largely determined by Fed's balance sheet policy. Holding the size of the Fed's assets constant, a reduction in the reserve balances of U.S. GSIBs must translate into an increase in the reserve balances of other banks in the system or an increase in non-reserve liabilities of the Federal Reserve.[6] We show that the distribution of reserves among U.S. GSIBs, foreign banks, and other U.S. banks reacts strongly to dollar funding conditions. Using daily data on reserve balances for all banks, we find that reserve balances of large foreign banks also follow qualitatively similar patterns as those of U.S.

[5] We note that intra-firm transfers that are used to accommodate cash demands at the entity level are mainly achieved through internal repo transactions, as such transactions protect individual entities from a resolution planning standpoint. Additionally, this type of transaction is exempted under certain circumstances from the Regulation W quantitative limits on transactions between depository institutions and affiliates within a BHC.

[6] The three most important non-reserve liability items are currency in circulation, reverse repo positions of non-banks at the Fed, and the TGA.

GSIBs, whereas smaller domestic banks are passive recipients of reserve inflows on quarter-ends, and are little involved in intermediating TGA fluctuations related to net Treasury issuance.

The central role of reserves to absorb large dollar funding shocks helps us better understand the money market turmoil in September 2019, during which the repo rate increased by nearly 10 percent and the FX swap market rate increased by 6 percent. Before the rate spikes, the total amount of reserves in the banking system reached multi-year lows as a result of the Fed's balance sheet normalization process.[7] We show that foreign banks under-drained their reserves relative to their normal response to the TGA fluctuations on September 16.[8]

Since excess reserves for the whole banking system can only be created by the Fed, our results suggest that a large Fed balance sheet is important even when short-term interest rates are well above the zero-lower bound. Echoing previous work that discussed the role of balance sheet policy as a financial stability tool (Greenwood et al., 2016), our findings suggests that large Fed balance sheet policy alleviates intermediary frictions in the short-term funding market. Drawing on the lessons from the first balance sheet normalization post-GFC, as the Fed is starting another tightening cycle post-COVID, the question about reserve demand and optimal balance sheet size has become an area of active research (Alfonso et al. (2022) and Lopez-Salido and Vissing-Jorgenson (2022)). Besides a large Fed balance sheet, we also discuss other alternatives that can also ameliorate dollar funding crunches, such as the new standing repo facility, and potential changes to the LR calculation and the intraday liquidity requirements.

[7] Appendix Figure A1 shows the evolution of the Federal Reserve's balance sheet post-GFC.

[8] The money market turmoil in September 2019 prompted many commentary pieces from policymakers and market observers. Pozsar (2017, 2019) voiced concerns with excess balance sheet normalization prior to the repo market turmoil and detailed potential liquidity concerns associated with Treasury settlements. Gagnon and Sack (2019) made several suggestions focusing on the Federal Reserve's operational framework including the setting of a standing repo facility, higher reserve levels, and explicit directives to control the repo rate. Tarullo (2019) highlights several questions yet to be addressed with the current monetary policy and regulatory frameworks. Avalos, Ehlers and Eren (2019) attributes part of the repo turmoil to hedge funds' use of repo. Afonso, Cipriani, Copeland, Kovner, La Spada and Martin (2020) provides a detailed account of the event and highlights the role of reserves and interbank market frictions. Anbil, Anderson and Senyuz (2020) emphasizes trading relationships in the repo market turmoil.

In addition, our paper provides new insights into the role of global banks in providing liquidity by exploiting synergies between the traditional banking and "shadow banking" arms within BHCs. The role of traditional banks in supplying liquidity through their issuance of demand deposits has been widely recognized in earlier studies that emphasize liquidity transformation (Diamond and Dybvig (1983)), information-insensitive claims (Gorton and Pennacchi (1990)), connections between loans and deposits (Kashyap, Rajan and Stein (2002)), and market power in the deposit markets (Drechsler, Savov and Schnabl (2017)). The GFC has led to a separate line of inquiry into the role of non-depository financial institutions, generally referred to as "shadow banks", that engage in repo financing and liquidity transformation (Gorton and Metrick (2012); Krishnamurthy, Nagel and Orlov (2014) and Kirk et al. (2014)). While the literature has articulated important differences between traditional commercial banks and shadow banks (for example, Hanson et al. (2015)), the two types of entities are often studied in silos and their linkages are little understood. The shared usage of reserves and internal liquidity between depository institutions and their affiliated dealers documented in our paper, highlight the importance of having both traditional banks and broker-dealers organized under the same BHC structure.[9]

Furthermore, our framework captures the trade-off between the payment and depository functions of a BHC versus the liquidity intermediation functions that also reside within the broker-dealer subsidiaries of banks. This model echoes recent work relating the effect of payment risks on lending functions (Li and Li, 2021; Li et al., 2022; Goldstein et al., 2023; Parlour et al., 2022) as well as earlier discussions of narrow payment banks.[10] Our model also highlights that increased payment flow and associated variance in deposit demand reduces banks ability to intermediate and lend in short-term funding markets. As such, our paper is relevant to the possible concerns associated with increased deposit outflow risks arising due

[9]In discussing specific business models of broker-dealers, Kirk et al. (2014) also point out the possibility for a dealer bank to source financing for a customer internally, without the need to attract external funds. They refer to these activities as dealers' "internalization" activities. Therefore, reserve-draining financed repo and FX swap lending is one specific type of internalization activity for dealers.

[10]See, for instance, Fisher (1935); Tobin (1963, 1987); Pennacchi (2012); Cochrane (2014)

to faster settlement (e.g. T+1 settlement in equities and corporate bonds begain in May 2024) and technological innovations like mobile banking and tokenized deposits, which aim to increase the speed and velocity of bank reserve-based payment flows.[11]

Last but not the least, from an international finance perspective, given the predominant role of the U.S. dollar in global trade and financial transactions (for example, Bruno and Shin (2015), Maggiori, Neiman and Schreger (2020), Gopinath et al. (2020), and Bank for International Settlements (2020)), short-term dollar funding is the lifeblood of the modern financial system.[12] Covered interest rate parity (CIP) deviations capture a picture of some recurrent strains in global dollar funding conditions post-GFC. On the pricing side, we meticulously construct overnight CIP deviations based on central bank deposit rates, which provide a clean measure of riskless profits that large global banks can make by engaging in reserve-based CIP arbitrage.[13] On the quantity side, our paper provides the first granular account of balance sheet adjustments of U.S. GSIBs in response to fluctuations in CIP deviations, and quantify the amount of CIP arbitrage.

The rest of the paper is organized as follows. Section 2 provides background and a conceptual framework for large banks' liquidity provision activities. Section 3 discusses the data and key measurement issues. Section 4 presents main results on U.S. GSIBs' response to dollar funding shortages. Section 5 discusses the implications of our main empirical findings. Section 6 concludes.

[11] Examples of central bank projects aimed to increase settlement network speed and interoperability include Project Agora (Bank for International Settlements, 2024a), Regulated Liability Network (Federal Reserve Bank of New York, 2023), and Project mBridge(Bank for International Settlements, 2024b).

[12] The liquidity and safety of dollar-denominated assets are the bedrock of the international financial system, such as in Farhi and Maggiori (2018), Gopinath and Stein (2018), He, Krishnamurthy and Milbradt (2019) and Jiang, Krishnamurthy and Lustig (2020).

[13] This is different from the large literature on CIP deviations based on bank rates, Treasury and corporate bond yields (for example, Du, Tepper and Verdelhan (2018a); Du, Im and Schreger (2018b); Jiang, Krishnamurthy and Lustig (2018, Forthcoming); Anderson, Du and Schlusche (2020); Liao (2020); Liao and Zhang (2020))

2 Short-Term Dollar Liquidity Provision by Global Banks

In this section, we first describe dollar liquidity provision in two crucial markets, the repo and FX swap markets. We then introduce two types of intermediation methods: matched-book and reserve-draining intermediation, which are used to finance the provision of short-term dollar liquidity. Finally, we introduce a conceptual framework to motivate banks' liquidity provision activities.

2.1 Dollar Lending in the Repo and FX Swap Markets

We focus on the two most important types of collateralized short-term lending done by U.S. GSIBs: dollar lending in the repo market and dollar lending in the FX swap market. These two types of lending are the most liquid and scalable components of these banks' overall dollar lending. As opposed to traditional bank loans to businesses and households, banks can easily change the scale of these positions on a daily basis.

Figure 1 shows schematically these two types of dollar lending. As shown in Panel A, at the inception of a dollar repo loan, a bank (e.g., JP Morgan) lends dollars against some collateral, most commonly U.S. Treasury securities. At maturity, the bank receives the principal and interest payment in dollars and returns the collateral. Repo lending is referred to as a reverse repo position on the bank's balance sheets. We can directly observe the amount of reverse repo positions denominated in dollars from our constructed balance sheet.[14]

Panel B of Figure 1 shows the mechanics of dollar lending in the FX swap market, which is also a form of collateralized lending in the sense that the foreign currency is posted as collateral against U.S. dollar lending. To lend dollars in the FX swap market (e.g., the dollar-yen swap market), at the inception of the trade, the bank lends dollars through an FX swap dealer, receives yen in exchange at the spot exchange rate, and on-lends the yen. The

[14] We also consider fixed-income security lending and borrowing positions that are much smaller in size relative to repo and reverse repo positions but are functionally similar in our analyses.

bank has the option to on-lend the yen without credit risk, for example, by depositing the yen at the Bank of Japan's deposit facility or lending it in the Japanese repo market backed by Japanese government bonds. In addition, the bank promises to buy dollars for yen at the forward exchange rate. At maturity, the bank receives the yen principal and interest payment and fulfills the terms of the forward contract by exchanging yen for dollars.

2.2 Matched-Book and Reserve-Draining Intermediation

How do U.S. GSIBs finance their short-term dollar liquidity provision? We now discuss two types of intermediation methods, matched-book and reserve-draining, which allow banks to scale up or down short-term dollar lending in the repo and FX swap markets at a high frequency. We illustrate these two intermediation methods in Figure 2.

To start, Panel A of Figure 2 presents the baseline balance sheet that consists of dollar-denominated short-term scalable assets, namely reverse repos (RRP), short-term FX swap lending (FX Lend), and drainable excess reserve balances.[15] The last item, drainable excess reserves, measures excess reserves that the bank holds at the Federal Reserve beyond those determined by reserve requirements and other regulatory demands. Post-crisis liquidity regulations have increased banks' demand for reserves, over those usually maintained for the traditional deposit-reserve requirement. However, the exact amount of drainable reserves is unknown, but is certainly lower than total excess reserve balance. On the liability side of our scalable balance sheet, we have repos and deposits, which fund reverse repo, FX swap lending, and drainable excess reserve positions.[16]

[15] By combining the foreign currency on-lending and an FX swap, we treat synthetic dollar lending in the FX swap market as an on-balance-sheet item.

[16] We purposely exclude unsecured wholesale funding instruments (such as fed funds, eurodollars, commercial paper and certificate of deposits) from the liabilities because U.S. GSIBs' reliance on these sources of unsecured wholesale funding is small during our sample period based our data. This fact is also separately documented in Anderson, Du and Schlusche (2020). As presented in Figure 5, U.S. GSIBs have smaller repo positions compared to their reverse repo positions, so a certain amount of deposits is needed to support the short-term dollar liquidity provision. However, since deposits are rather sticky, the bank cannot rely on deposits to scale their liquidity provision at a high frequency.

The first intermediation method, matched-book intermediation, is illustrated by Panel B of Figure 2, which features simultaneous changes in the bank's assets and liabilities. For example, if the bank wants to lend additional dollars in the repo market, it needs to borrow additional dollars in the repo market. On the bank's balance sheet, we can see that an increase in the reverse repo position is matched by the same increase in the repo position. Any matched-book intermediation transactions result in a larger balance sheet for the bank.

The second intermediation method, reserve-draining intermediation, is illustrated by Panel C of Figure 2. It features a change in the composition of assets while maintaining the overall size of the balance sheet unchanged. In this case, the bank can "drain" reserves to finance an expansion of repo lending, without additional borrowing. On the bank's balance sheet, we can see that the increase in the reverse repo position is matched by a reduction in the drainable reserve balance by the same amount. There are no changes to banks' liabilities.

Intra-firm transfers between depository institutions and broker-dealers within the BHC play a central role in reserve-draining intermediation. As shown in Figure 3, only depository institutions have reserve accounts at the Federal Reserve, but most of the reverse repo and repo positions are booked on the broker-dealers' balance sheet. The mechanics of the reserve-draining intermediation is that the depository institutions reduce their reserve balance and lend the cash to a broker-dealer within the same BHC through an internal repo position, the broker-dealer then uses the internal repo from the depository institution to finance its additional external repo lending. After netting out internal repo positions, the overall size of the BHC's balance sheet remains unchanged after additional reserve-draining intermediation.[17]

There are important differences between matched-book and reserve-draining intermediation. First, the two intermediation methods have different regulatory implications for the

[17] Regulation W, which implements sections 23A and 23B of the Federal Reserve Act, establishes restrictions on transactions between depository institutions and its affiliates. The regulation sets quantitative limits on transactions that are covered by the rules. Importantly, transactions that are collateralized by U.S. government securities are not subject to the quantitative limits (equivalent to 10% of capital stock and surplus).

leverage constraint. Ex-post, additional matched-book intermediation increases the overall size of the bank balance sheet, but additional reserve-draining intermediation leaves the overall balance sheet size unchanged at the BHC level. However, from an ex-ante perspective, banks need to hold more reserves in preparation for reserve-draining intermediation, which also use balance sheet space when these reserves are not exempt from the leverage ratio calculation.

Second, holding reserves and lending in the repo and FX swap markets have different implications for banks' intraday liquidity profile.[18] Reserves are banks' "checking account" balance at the Federal Reserve and can be used to settle transactions in real-time. Short-term lending in the repo and FX swap markets lock in banks' liquidity on the overnight basis or for a few days. Banks cannot use repo and FX swap market lending to meet intraday liquidity demands. The need for maintaining sufficient amount of intraday liquidity to avoid tapping into the Fed's daylight overdraft facility (Copeland, Duffie and Yang (2020)) could act as an important reason for banks to hold more "drainable" reserves beyond the usual regulatory demand.

Third, both intermediation methods are subject to different capital market and organizational frictions. For matched-book intermediation, despite repos being one of the most liquid short-term funding instruments, banks may still have difficulty scaling up repo activities to the desired level due to various money market frictions, especially during periods of funding stress. One notable friction is the sticky pre-existing borrower-lending relationships in money markets, as documented in many previous studies, such as Chernenko and Sunderam (2014), Li (2021), Anbil, Anderson and Senyuz (2020) and Aldasoro, Ehlers and Eren (2022). In contrast, reserve-draining intermediation removes the need for banks to obtain external funding ex-post. However, reserve-draining intermediation is also subject to frictions beyond regulatory capital and liquidity metrics. In particular, large banking organizations

[18]For the Basel III LCR, matched-book intermediation is LCR-neutral if the change in the repo and reverse positions have the same maturity and collateral. Reserve-draining intermediation is also LCR-neutral if the increase in the reverse repo position is collateralized by U.S. Treasury securities, as reserves and Treasury securities both count towards Level 1 high quality liquidity assets.

might face limits and frictions towards internal liquidity sharing across material entities and jurisdictions.

2.3 Conceptual Framework

To illustrate the mechanics of short-term liquidity provision within large banking organizations, we now present a toy model to motivate our subsequent empirical analysis. We abstract from several important real-world considerations in order to deliver key insights parsimoniously.

The framework centers around a representative bank holding company. In this simplified consolidated bank balance sheet, assets consist only of secured loans L to the short-term funding market and reserve holdings at the central bank R. These secured loans refer to the reverse repo and FX swap lending described above. On the liability side, banks have only deposit D, equity E and short-term borrowing B, which resembles tri-party repo borrowing from money market funds.

In this simple setup, there are no long-term assets or debt on the bank balance sheet. Banks exists to offer depository and payment services as well as provide intermediation in short-term funding market, between the money market funds that are cash-rich and institutional repo or FX borrowers that are cash-poor but collateral-rich.

The bank's balance sheet adding-up constraint is given by:

$$L + R = B + D + E. \tag{1}$$

Additionally, the bank is subject to the leverage ratio constraint:

$$\frac{L + R}{E} \leq \gamma, \tag{2}$$

where γ is the maximum total non-risk-weighted leverage that can be taken by the bank. Note that the γ can either represent the regulatory limit, or bank's self-imposed risk management limit, which can be more conservative than the regulatory limit.

One important role of the bank in the model is to fulfill depository and payment services. We assume that the cost of deposits is zero, i.e. a zero-interest checking account, but the amount of deposits are exogenously determined, and that the bank can earn either a risk-free interest rate r for reserves held at the central bank or a short-term secured lending rate i. The bank can also borrow an amount B in the wholesale funding market at the borrowing rate b. This borrowing can represent funding from money market funds in the tri-party repo market. For this baseline model, we leave the cost of wholesale funding b as given, though it can be endogenized to be an increasing function of the amount of borrowing, for example, $b = \beta B$, reflecting frictions in the money market funds that make it increasingly costly to scale up borrowing.

A key benefit of holding reserves over secured lending is that reserves can meet intraday payment needs. We model the cost of deviating from a narrow bank structure, in which all deposits are held in the form of reserves, by specifying the cost $c\left(\frac{R}{D}\right)$ as a function of the reserve-to-deposit ratio. This reflecting the necessity of reserves for intra-day payments. Reserves are needed to buffer against volatilities in intraday payment flows denoted by p. Following Miron (1986), we define the cost function as:

$$c\left(\frac{R}{D}\right) = \frac{(p - \mathbb{E}(p))^2}{2}\left(\frac{R}{D} - 1\right)^2. \tag{3}$$

Equation 3 shows that deviation from narrow bank structure, in which $R/D = 1$, has non-zero cost that scales with the variance of payment flows.

The bank's objective is to maximize its profit by choosing the optimal levels of L and R given leverage constraint:

$$\max_{L,R} \mathbb{E}\, iL + rR - bB - c\left(\frac{R}{D}\right) \tag{4}$$

At the optimum, a profit-maximizing bank would maximize $L+R$ so that the SLR binds with equality $(L+R)/E = \gamma$. The solution to the optimization problem yields banks' demand for reserves R^d and their supply of secured loans L^s as follows:

$$R^d = D\left(1 - \frac{(i-r)D}{s^2}\right) \tag{5}$$

$$L^s = \gamma E - D + \frac{(i-r)D^2}{s^2}, \tag{6}$$

where $s^2 \equiv \mathbb{E}(p - \mathbb{E}(p))^2$ is the variance of intra-day payment flow.

We note that an important intermediation spread is the secured lending rate minus the risk-free interest rate on reserves, $i-r$, which captures the profit that the bank earns by reducing reserves to support secured lending. Note that, $i-r$, is usually positive given that reserve is the ultimate safe and most convenient asset. In practice, $i-r$ can be negative, reflecting market segmentation that non-banks cannot hold reserves or cross-subsidy for bank's other activities with clients such as broker-dealer activities. If $i - r \leq 0$, there is little incentives to for banks to use reserve to support secured lending in the absence of cross-business subsidies, and therefore excess reserves accumulate and banks derive intra-day liquidity benefits from holding excess reserves. When $i - r > 0$ is positive, the profit opportunity incentivizes banks to deviate from a full reserve model and reduces reserves to support secured lending L to earn the intermediation spread.

The provision of secured loans is lower when the variance of intra-day payment flow s^2 is high, as banks are more inclined to hold closer to full reserves when facing more volatile payment flows.[19] In other words, funding market intermediation is less attractive when the bank is forced to focus on its core function of providing deposit and payment services.

We close the model with market clearing for secured loans by assuming that the demand for short-term funding in the secured loan market is downward sloping with respect to the interest rate, i.[20] Loan market clearing can be expressed as:

$$L^s = L^d \equiv Y - mi + \delta, \tag{7}$$

where Y represents a fixed aggregate demand (e.g., long-term demand for repo by the levered sector associated with securities trading, and FX hedging demand by non-U.S. institutions invested in dollar assets), δ denotes exogenous demand shocks, and m is the elasticity of demand for secured loans.

The equilibrium intermediation spread is then:

$$i - r = \frac{s^2\left(Y - mi + \delta - \gamma E + D\right)}{D^2}. \tag{8}$$

This implies that the spread widens when idiosyncratic loan demand (δ) is high, leverage (γ) is low, or intra-day payment needs (s^2) are high. A larger deposit base mitigates this effect.

Substituting equation 8 into equation 5, we obtain the equilibrium reserve demand:

$$R^d = \gamma E - (Y - mi + \delta). \tag{9}$$

Given an exogenous positive secured loan demand shock (δ), the change in the matched-book (MB) intermediation is given by $\Delta MB = \min(\Delta L, \Delta B)$, and the reserve-draining (RD) intermediation is given by $\Delta RD = \Delta L - \Delta MB$. In our stark example that the leverage constraint is constant and always binds, the size of bank balance sheet is fixed,

[19]Tokenized deposits, an experimental construct that involves tokenizing bank deposits on blockchains for payment use cases is possibly an example of high s^2 payment flow that requires narrow bank structure with full reserves as banks' assets.

[20]We can extend the model to show a linkage between lending and borrowing rats and aggregate borrowing by incorporating additional relationships, e.g. $i = b(B) + \alpha$. The key intuitions of the model are unchanged.

so banks cannot expand their balance sheet through more matched book intermediation, $\Delta MB = 0$, and therefore, $\Delta RD = -\Delta R = \Delta L$, reserve-draining intermediation provides all the additional secured loans.

This simple model delivers the intuition that banks hold reserves ex-ante to buffer against intra-day payment flow variance and reserve-draining intermediation is the dominant intermediation method in response to liquidity demand shocks when the leverage constraint is binding. We can relax the model feature that the leverage constraint always binds with equality, and enrich the simple model to allow banks to maintain a capital buffer. As long as the marginal cost to the bank of running down the capital buffer increases, bank approaches its leverage constraint, it would still prefer to predominately use reserve-draining intermediation in response to large loan demand shocks.

3 Data and Measurements

In this section, we first describe the main data used for our empirical analysis and present some summary statistics for U.S. GSIBs' balance sheet. We then describe how we measure secured lending activities and key intermediation spreads.

3.1 Daily Bank Balance Sheets for U.S. GSIBs

We construct detailed bank balance sheets at the daily frequency using data collected by the Federal Reserve using form FR2052a, *Complex Institution Liquidity Monitoring Report*. These data are used for the calculation of the Basel III LCR, which requires that banks hold enough high quality liquid assets to fund net expected cash outflows for 30 days. These bank-level data contain a detailed breakdown of individual banks' asset inflows and liability outflows on a consolidated basis, as well as by material legal entities. Banks with \$700 billion or more in total consolidated assets or \$10 trillion or more in assets under custody are required to report this information on each business day beginning in December 2015.

Our analysis focuses on the aggregate data for six U.S. GSIBs: Bank of America, Citigroup, Goldman Sachs, JP Morgan, Morgan Stanley, and Wells Fargo.[21] As the data collection is designed for LCR assessment rather than balance sheet reporting, we perform a manual mapping of the inflow and outflow product categories collected in FR2052a to asset and liability line items in the quarterly call reports collected through FR Y-9C forms at the consolidated BHC level. The balance sheet assembly and matching process is meticulous and achieved through iterative comparison with the FR Y-9C data.[22]

There are several novel aspects of the LCR assessment data that relates to our analysis. First, the data capture the global activities of reporting U.S. banks, which allows for a comprehensive analysis of these institutions' exposure in different currencies and locations. Second, the data is collected daily and as such, offers a look into the high-frequency changes that these institutions make to their balance sheets. Third, the data allows us to assess the intermediation activities at the consolidated level and the material legal entity level. This allows us to assess whether banks move funds across material entities to manage their liquidity, as a result of specific events. Last, the granularity of the inflow and outflow data also provides a view into hard to find details about bank balance sheet items, including the remaining maturity and the collateral type used, when it is applicable.

To shed additional light on foreign banks' liquidity provision activities, we rely on two main data sources. In addition to the daily reporting requirement for U.S. GSIBs, the FR 2052a data also collects month-end liquidity reports for large foreign banking organizations (FBOs) in the United States. In addition, we make use of the dealer-level data collected in form FR 2004a, which reports weekly financing activities for primary dealers for U.S.

[21]Though the data give us visibility to bank-level details, we are unable to analyze and disclose the bank-level dis-aggregated data due to data confidentiality requirements.

[22]The FR2052 data is mainly composed of inflow items that correspond generally to assets and outflow items that correspond generally to liabilities. However, there are caveats to these generalizations. We exclude a number of the inflow and outflow categories in the LCR assessment that are off-balance-sheet or contingency facilities, e.g. loan or liquidity facilities on which either the banks or their clients can draw on. For some inflow and outflow LCR items, we rely additionally on the collateral type reported for the proper assembly of the balance sheet snapshots. We discuss the comparison between FR2052a and FR Y-9C in greater detail in Internet Appendix A. Internet Appendix Figure A3 shows that the key balance sheet items from the two data sources are broadly in line.

government securities. The current list of 24 primary dealers includes 18 dealers affiliated with foreign banks.

3.2 Summary Statistics of Balance Sheets by Currency

Figure 5 shows the balance sheet of dollar-denominated assets and liabilities aggregated across the six U.S. banks in our sample. We can see that the overall assets and liabilities of these banks are broadly equivalent in size, with the assets averaging to $7.4 trillion and liabilities averaging to $7.2 trillion. The gap in dollar-denominated assets and liabilities only averages to 4% of total assets. Loans represent the largest asset category and deposits represent the largest dollar-denominated liability. The short-term liquid component of the balance sheet, such as reverse repos (and repos), cash and reserves, and Treasury securities account average to about $2 trillion.

Appendix Figure A2 shows the evolution of assets and liabilities denominated in euros (EUR), yen (JPY), sterling (GBP), and Australian (AUD) dollars, respectively. The size of all foreign-currency-denominated assets is about $1.7 trillion and the average size of all foreign currency denominated liabilities is about $1.4 trillion. The foreign currency funding gap, or the difference between assets and liabilities denominated in foreign currencies, is about to $300 billion, or 17% of the size of total foreign currency assets. In contrast to the dollar-denominated balance sheet items, the foreign currency balance sheets have a markedly lower fraction of loans in total assets and a lower fraction of deposits in total liabilities. Reverse repos and repos represent the largest balance sheet items denominated in foreign currency.

3.3 Measurements of FX Swap Lending

The challenge to measure dollar lending via the FX swap market is that the position is off balance sheets and not directly observable. However, given that net dollar lending via the FX swap market is accompanied by foreign-currency on-lending on balance sheets, we can construct an empirical proxy for net FX lending positions based on balance-sheet items. Our benchmark measure for short-term FX swap lending (*Short-Term FX Swap Lend*) is equal to the sum of net repo lending in foreign currency and excess reserve balances in foreign currency:

$$\textit{Short-Term FX Swap Lend} = \textit{FC Reverse Repo - FC Repo} + \textit{FC Excess Reserve.} \quad (10)$$

The assumption behind this measure is that banks choose secured foreign currency on-lending to minimize their credit risk so that an increase in the short-term dollar lending in the FX swap market (e.g. for the dollar-yen FX swap) is associated with an increase in the reverse repo position in yen (not matched by an increase in the repo position in yen) or an increase in the reserve balances at the Bank of Japan. While the high-frequency variation in our *Short-Term FX Swap Lend* measure provides relevant information about the fluctuations in short-term dollar lending in the FX swap market, the level of *Short-Term FX Swap Lending* could overstate the amount of FX swap lending. This is because banks may hold excess reserves in foreign currency for reasons other than supporting dollar lending in the FX swap market. In Internet Appendix Section B, we present robustness checks for our main results using an alternative proxy of FX swap lending that takes the difference between total foreign currency assets and foreign currency liabilities.

Figure 4 shows the amount of reverse repo positions, our proxy for short-term dollar lending in the FX swap market, along with the total reserve balances at the Federal Reserve for our sample of U.S. GISBs. We can see that reverse repo positions is the largest item totaling over $1 trillion. Our proxy for FX swap lending is significantly lower and averages to about $300 billion in our sample period. It is worth noting that since late 2017, when the Federal Reserve started reducing the size of its balance sheet, the decline in reserves balances has been associated with a significant increase in the reverse repo position.

3.4 Measurements of Intermediation Spreads

Banks engage in dollar intermediation activities because they earn an intermediation spread, and these intermediation spreads increase during episodes of dollar funding shortages. The exact intermediation spread depends on the intermediation method and funding market.

In the repo market, the spread on the matched-book intermediation that the bank can earn is determined by the difference between the U.S. GSIBs' funding cost in the repo market and its lending rate in the reverse repo market. We use the triparty Treasury repo rate as the proxy for GSIBs' repo funding rate and the General Collateral Financing (GCF) repo rate as the proxy for their lending rate in the reverse repo market.[23] Alternatively, for the reserve-draining intermediation, the bank earns an intermediation spread captured by the difference between the reverse repo lending rate and the opportunity cost of not holding reserves, which equals the foregone interests on reserves (IOR). We use the GCF-IOR spread as the repo spread for reserve-draining intermediation.[24] Panel (A) of Figure 6 shows these two repo intermediation spreads. We can see that the GCF-triparty spread is almost always positive. Outside the large spikes on period ends, the GCF-triparty spread is on average about 10 basis points in our sample period. In contrast, the GCF-IOR spread was negative until early 2018 and then became positive and of similar magnitude compared to the GCF-triparty repo spread. The sign-switch for the GCF-IOR spread likely reflects the fact that as the amount of drainable reserves declined for large banks, constraints on reserve-draining activities became more binding, and as a result, banks started to charge a positive intermediation spread between the reverse repo rate and the IOR.

[23]The triparty repo market is where large, high-quality, dealers borrow from U.S. money market funds, and the GCF repo market is where large dealers lend to smaller dealers. As a result, the GCF-triparty repo spread measures the compensation that large dealers earn when providing matched book intermediation. Note that many dealer-client repo transactions occur in the bilateral repo market, where information is less readily available. Bowman, Louria, McCormick and Styczynski (2017) document that the top 90 percentile of repo rates in the cleared bilateral repo market (the FICC-DVP market) tracks the GCF repo rate very closely.

[24]We also present results on an additional spread measure using SOFR minus IOR to show the impact on the benchmark rate that has replaced LIBOR.

In the FX swap market, we measure the intermediation spread for lending dollars as the *overnight* CIP deviations between overnight central bank deposit rates.[25] We conduct a meticulous calculation for the overnight FX swap rate following a strict set of market conventions, the first time in the literature to our knowledge, in order to be as analogous as possible to an overnight dollar reverse repo.[26] Panel (B) of Figure 6 shows the spread between the swapped BOJ and ECB deposit rates in dollars and the IOR paid by the Federal Reserve. Excluding the large period-end spikes, the average FX swap spreads are 15 and 25 basis points for the yen and the euro, respectively, despite the BOJ's and the ECB's negative deposit rates. Once we swap these negative deposit rates into dollars overnight, they are more attractive than the IOR paid by the Federal Reserve. Unlike the GCF-IOR spread, the FX swap spread based on central bank deposit rates is largely positive throughout our sample, including in the earlier sample when the drainable excess reserves at the Federal Reserve were more abundant.

Intermediation fees represent the shadow costs associated with the balance sheet constraint. We note that lending dollars in the FX swap market is on average more profitable than lending dollars in the repo market. The higher intermediation fee reflects additional balance sheet constraints associated with lending dollars in the FX swap market relative to lending in the repo market. These additional balance sheet considerations may include

[25] This is the spread on the reserve-draining intermediate in the FX swap market, and the matched-book FX swap spreads are similar in levels and are not separately shown here.

[26] To calculate overnight FX-implied dollar funding rate, we use the following formula:

$$r_{implied} = ((1 + r^* * N/d) * (S - \phi_{TN}/D)/(S - \phi_{TN}/D - \phi_{ON}/D) - 1) * (d/N),$$

where $r_{implied}$ is the FX-implied dollar rate, r^* is the non-dollar interest rate on reserve, S is the spot exchange rate, ϕ_{TN} and ϕ_{ON} are the forward points on the overnight and tomorrow next contracts, $d = 360$ is the day count convention, D is the forward point multiplier, and N is the number of calendar days from valuation to settlement date following FX holiday calendar conventions. This formula is more involved than the textbook forward and spot relation since the market convention in FX is that the spot exchange rate is quoted to settle on $T + 2$, effectively making spot contracts a two-day forward exchange rate. To obtain the overnight implied rate, it is important to adjust the spot exchange rate to a hypothetical contract that settles at T rather than $T + 2$.

additional contributions of FX swaps to the GSIB capital surcharge and the implications of the cross-jurisdictional nature of FX swaps for resolution planning rules.[27]

4 Global Banks' Response to Dollar Funding Shortages

In this section, we discuss the balance sheet response of U.S. GSIBs and selected foreign banks on quarter-ends and in response to TGA fluctuations. We highlight the role of reserves in supporting liquidity provision during these tight funding episodes. We focus on the aggregate results for U.S. and foreign banks in this section, and the cross-sectional variations in banks' responses during these episodes are discussed in Section 4.4.

4.1 Dollar Funding Shortages on Quarter-Ends and Large TGA Days

In this subsection, we describe two types of dollar funding shortages. First, the dollar funding conditions are particularly tight on quarter-ends. The quarter-end liquidity premium arises in our sample period in part due to banks' window dressing activities on quarter-ends to have better reported Basel III regulatory ratios (Du, Tepper and Verdelhan (2018a); Cenedese, Della Corte and Wang (2021); Egelhof, Martin and Zinsmeiste (2017)). Of particular importance, in most non-U.S. jurisdictions the Basel III LR is assessed using the snapshot of banks' balance sheet size on quarter-ends.[28] This reporting requirement incentivizes foreign banks to significantly reduce matched-book dollar intermediation activities on quarter-ends in order to have better reported LRs, contributing to spikes in short-term intermediation spreads. In contrast to the foreign banks, U.S. banks calculate the LR based on the daily-

[27] The GSIB surcharge score takes into account five dimensions of banks' activities, including size, interconnectedness, substitutability (or the use of short-term wholesale funding under the U.S. implementation), complexity, and cross-jurisdictional activities. Dollar lending in the FX swap markets can potentially increase banks' GSIB score in all dimensions. In addition, dollar lending in the FX swap market financed via reserve-draining reduces banks' liquidity at the Fed and increases their liquidity in foreign central banks (Panel B in Figure 1). This redistribution of liquidity may be constrained by resolution planning rules, which require U.S. banks to maintain sufficient liquidity inside the United States (to be discussed in more details in Section ??).

[28] In addition to quarter-end reporting, banks in some jurisdictions follow Basel III guidelines for calculating the LR using month-end averages of banks' assets within a quarter. U.K. banks switched from three month-end-averaging for the LR calculation to daily-averaging beginning in 2018.

average of assets in each quarter. Therefore, U.S. banks have considerably more balance sheet space for dollar intermediation activities on quarter-ends compared to foreign banks.

Second, fluctuations in the TGA account balance are also significantly correlated with dollar funding conditions. The TGA contains cash balances that the U.S. Treasury holds at the Federal Reserve. Other things being equal, an increase in the TGA balance corresponds to a reduction in the overall cash for the entire banking system, making dollar liquidity more scarce. This is because a higher TGA balance, either due to higher net Treasury issuance or tax payments, corresponds to a transfer of cash from the bank account of the buyer of the Treasury or the taxpayer to the U.S. Treasury's account at the Fed.[29] Furthermore, an increase in the net issuance of new Treasury bonds puts additional pressure on the repo market as the new Treasury bonds are often financed in the repo market. Similarly, Hamilton (1997) has used Treasury cash balances in commercial banks to identify liquidity shocks.[30] Since May 2015, the TGA balance has been particularly volatile, ranging from a minimum of \$23 billion to a high of \$440 billion. The weekly changes in the TGA balance have a standard deviation of \$40 billion, with a maximum weekly change exceeding \$100 billion. Appendix Figure A5 presents the time series of the TGA balance.[31]

Table 1 shows regression results capturing the relation between quarter-ends and fluctuations in the TGA balance. The first four columns show the effects on daily changes in various repo spreads and the last two columns show the effects on daily changes in the FX swap spreads. The independent variables are the $Qend_t$ and $Qstart_t$ indicator variables,

[29] TGA balances from the Treasury and reserve balances from banks at the Federal Reserve are considered liabilities in the Fed's balance sheet. Keeping the level of Fed assets constant, an increase in TGA balances should be accompanied by a reduction in reserve balances or of other Fed liabilities. The evolution of the Federal Reserve balance is plotted in Appendix Figure A1.

[30] The methodology in Hamilton (1997) exploits the forecasting error in Treasury cash holdings in private banks, a setup specific to the pre-GFC regime in which the Federal Reserve conducted daily open market operations to control the Fed Funds rate based on forecasts of banking reserves.

[31] Prior to 2009, the Treasury held most of its cash balances in commercial bank deposit accounts through the Treasury Tax and Loan program. The Treasury shifted to holding cash balances at the Federal Reserve in the fall of 2008 to facilitate the Fed's large expansion of lending to financial firms (Santoro, 2012). In May 2015, the Treasury expanded its TGA balance to protect against "a potential interruption in market access," with a minimum balance of \$150 billion (Treasury Quarterly Refunding Statement, May 2015).

which denote the last and the first business day of the quarter, and daily changes in the TGA balance, ΔTGA_t.

We can observe clear quarter-end effects on intermediation spreads, as captured by the coefficients on the quarter-end and quarter-start indicator variables. On the last day of the quarter, repo spreads increase between 8 to 32 basis points. FX swap spreads increase over 100 basis points and 400 basis points for the dollar-euro and the dollar-yen swap, respectively. These quarter-end spikes quickly normalize after the end of the quarter, as indicated by negative coefficients on $Qstart_t$ of similar magnitude compared to the coefficients on $Qend_t$. Furthermore, fluctuations in the TGA balance, ΔTGA_t are also significantly positively correlated with intermediation spreads. In particular, a 100 billion increase in the TGA balance is associated with an increase in repo spreads of between 4 and 7 basis points and FX swap spreads of between 26 and 46 basis points. Figure 7 visualizes the strong positive relationship between the SOFR-IOR spread and the daily fluctuation in the TGA balance.[32]

4.2 Dollar Intermediation During Quarter-Ends

4.2.1 U.S. GSIBs during Quarter-Ends

We first examine the quarter-end dynamics of U.S. GSIBs' intermediation activities using an event study approach. Reserves play a key role in supporting the liquidity provision of U.S. GSIBs on quarter-ends. Figure 8 presents changes in U.S. GSIBs' scalable balance sheet items near quarter-ends. The horizontal axis indicates the number of business days from the adjacent quarter-end. In terms of short-term dollar lending, the figure shows that U.S. GSIBs maintain their dollar reverse repo position steady and increase their dollar lending in the FX swap market by \$20 billion on quarter-ends. This modest increase in overall short-term dollar lending is financed entirely by draining reserves, as opposed to additional borrowing in

[32] Besides the quarter-ends and the TGA fluctuations, in Internet Appendix C, we also discuss the impact of fluctuations in the Fed's SOMA portfolio, another potentially important driver of dollar funding conditions, on intermediation spreads and quantities.

the repo market. Repo borrowing of U.S. GSIBs actually declines by \$40 billion on quarter-ends, but reserves decline by \$60 billion. The overall draining in reserves is enough to fully offset the \$40 billion decline in repo borrowing and to support a steady amount of net repo lending and a \$20 billion increase in FX swap lending on quarter-ends. The higher amount of lending in the FX swap market by U.S. GSIBs on quarter-ends likely reflects the higher intermediation fees earned in the FX swap market.

In terms of economic magnitude, even though the quarter-end effects of \$40 billion increase in the net repo lending and \$20 billion increase in the FX swap market lending appear small when compared to the gross borrowing and lending positions in money markets, these effects become more significant when compared with net liquidity provision (gross borrowing minus gross lending). For example, based on the primary dealer statistics published by the Federal Reserve Bank of New York, the total net repo and securities borrowing against Treasury securities by all primary dealers is \$52 billion on average in our sample period. Based on the 2020 ECB money market report, European banks on net borrow about \$50 billion from U.S. counterparties in the FX swap markets.

As illustrated in Figure 3, since depository institutions hold reserves and broker-dealers do most of the short-term lending, the quarter-end reserve-draining activities should be accompanied by internal liquidity sharing between broker-dealers and non-broker-dealer affiliates.[33] Figure 9 shows that this is indeed the case. On quarter-ends, the broker-dealer arms of the U.S. GSIBs reduce their external repo borrowing by about \$40 billion (left panel), which accounts for almost the entire decline in the total repo borrowing of these BHCs. To replace the lost external funding, broker-dealers turn to internal funding from non-broker-dealer entities in the same BHC (right panel). Broker-dealers' net internal repo borrowing increases by \$40 billion. Again, this internal transfer is made possible by the non-broker-dealer entities (e.g. depository institutions) draining reserves from their Federal Reserve accounts. Market

[33]We note that since the FX swap market is off-balance-sheet, the intra-office transfer between broker-dealers and non-broker-dealer affiliates largely captures intra-office liquidity sharing needed to support lending in the repo markets.

observers have previously commented on the use of reserves by banks to finance short-term lending, an intermediation activity termed "reserve fracking" (Pozsar, 2017). Our findings provide micro-evidence that is consistent with reserve fracking on quarter-ends. Meanwhile, our results highlight the important role of liquidity management within BHCs to absorb high-frequency liquidity shortages (Cetorelli and Goldberg (2012)).

4.2.2 Foreign Banks during Quarter-Ends

Given the prominent role of the U.S. dollar in international financial markets, foreign banks also play an important role in the intermediation of dollar funding. In this subsection, we highlight some differences between foreign banks' intermediation activities and those of the U.S. GSIBs, particularly on quarter-ends.

Differences in regulations between foreign and U.S. banks lead to significant differences in their activities on quarter ends. Most importantly, as discussed before, in many non-U.S. jurisdictions, the LR is calculated based on the quarter-end snapshot of bank balance sheets, whereas the LR for U.S. banks is calculated based on daily average assets. Therefore, foreign banks face incentives to contract their balance sheets on quarter-ends by cutting down low-margin balance sheet intensive activities, including matched-book repo intermediation.

In our sample period, the FR 2052a required daily reporting for the U.S. operations of four foreign banks that met criteria for the Large Institution Supervision Coordinating Committee (LISCC) supervisory program. Using the aggregate data of these four FBOs. Figure 10 shows that the U.S.-based entities of the four foreign banks contract their repo lending by \$60 billion on quarter-ends, in direct contrast to a steady reverse repo position of the U.S. GSIBs. Meanwhile, repo borrowing of these foreign banks contracts by \$80 billion on quarter-ends. Reserves decline by about \$20 billion, which is equal to the \$20 billion increase in the net repo lending by foreign banks.[34] These movements in foreign banks' balance sheets show a clear substitution between reserve holdings and net repo lending on

[34] Note that we only observe the U.S. operations of these foreign banks, so we cannot construct our measure of dollar lending in the FX swap market

the asset side, despite the overall decrease in some of these institutions' balance sheets due to the quarter-end reporting of the leverage ratio.

Furthermore, using month-end information for 22 large FBOs reported through an abbreviated version of the FR 2052a form, we find that the quarter-end reverse repo position is on average \$80 billion lower than the non-quarter-end month-ends, whereas the quarter-end repo position is on average \$130 billion lower. The \$50 billion increase in the net repo lending on quarter ends relative to non-quarter-end month-ends is again financed via draining reserves.[35]

Overall, we find that reserves play a similarly important role in supporting an increase in the *net* liquidity provision of foreign banks, despite a significant contraction in foreign banks' gross lending on quarter-ends.

4.3 U.S. GSIBs' Balance Sheet Response to TGA Fluctuations

4.3.1 Baseline Results

The effect of increases in the TGA balance on U.S. GSIBs' intermediation activities follows similar patterns compared to the quarter-end responses from these banks. U.S. GSIBs draw down reserves to fund reverse repo and FX swap lending as the TGA balance increases.

Table 2 presents quantity regressions for intermediation activities with respect to TGA fluctuations, controlling for quarter-end effects.[36] The regression coefficient on ΔTGA_t for reserves (column 1) indicates that each dollar of TGA balance increases is associated with around 18 cents of reserve drainage for our sample of U.S. GSIBs. Both repo and reverse repo

[35] The quarter-end effects estimated from month-end balance sheets are likely to be underestimated given that the LR is calculated based on the month-end balance sheets in some jurisdictions, so some banks also contract their month-end balance sheets.

[36] These coefficients on the quarter-end and quarter-start dummies have smaller magnitudes than the multi-day responses shown in Figure 8. This is in part due to the fact that the adjustment for short-term intermediation activities with maturities greater than overnight can take place a few days before the quarter-ends. It is also possible that large banks have some difficulty in fully adjusting their balance sheets in just a single day. The inability of banks to adjust their balance sheet despite their natural role in intermediation and arbitrage activities in response to large increases in funding spreads speak to papers on slow-moving capital and asset price dynamics (Duffie, 2010; Greenwood, Hanson and Liao, 2018a).

positions are reduced, but the decline in repo borrowing is larger, leading to a small increase in net reverse repo lending (columns 2-4). Instead of repo market financing, the banks rely on reserve drainage to make up for the reduced repo borrowing. Additionally, these banks also lend more dollars through FX swaps as indicated by column 5. Concurrently, U.S. GSIBs experience small deposit outflows (column 6), which likely reflect a transfer from depositors' accounts to the TGA account to finance the increase in the TGA balance. Finally, U.S. GSIBs increase their outright Treasury holdings (column 7), partly in response to the rising net Treasury issuance associated with the TGA increase.[37] We note that the amount of reserve drainage roughly matches the cash used to provide short-term funding and outflows due to deposit and Treasury holdings. This finding confirms that we are capturing the most scalable components of the bank balance sheet at a daily frequency.

Given that TGA fluctuations are not strictly shifters of the liquidity demand, one important caveat is that these reduced-form regression estimates should not be interpreted as elasticities of U.S. GSIBs' intermediation activities. We discuss the price-quantity relationship implied from these estimates in Internet Appendix H.

4.3.2 Time variations in the effects of TGA fluctuations

So far, we have presented results for the full sample period. We now run our baseline regressions in Table 2 using a one-year rolling window. Figure 11 shows the rolling regression coefficients on the TGA fluctuations for reserves, net repo lending, FX swap lending and the SOFR-IOR spread. We can see that as the total amount of reserves get scarcer for the whole banking system in the second half of the sample, the repo spread becomes more sensitive to TGA fluctuations. Recent work by Alfonso, Giannone, Spada and Williams (2022) use these time-varying coefficients to infer whether the total reserves are scarce or abundant for the whole banking system.

[37] In Appendix F, we provide a detailed discussion of fluctuations in Treasury holdings.

Meanwhile, U.S. GSIBs are important liquidity provider, as they remain active in draining reserves to provide net lending in the repo and FX swap market throughout our sample period. The regression coefficient on the TGA for reserve draining varies over time, but became less negative in 2019 relative to mid-2018, which is consistent with the fact that it was more difficult to drain reserves when the overall reserve level became significantly lower.

4.3.3 Decomposition of TGA fluctuations

In this subsection, we decompose daily fluctuations in the TGA balance, ΔTGA_t, into two components. The first component summarizes daily changes in the net issuance of Treasury securities, denoted by ΔTGA_t^{Tsy}. The second component reflects daily changes in the TGA account unrelated to net Treasury issuance, denoted by ΔTGA_t^{Other}. Therefore, we have that

$$\Delta TGA_t = \Delta TGA_t^{Tsy} + \Delta TGA_t^{Other}.$$

We study the differential impact of the two components on the intermediation spreads and banks' intermediation activities.

There are two important differences between ΔTGA_t^{Tsy} and ΔTGA_t^{Other} that motivate this empirical exercise. First, the role of banks' intermediation activities can differ significantly with respect to ΔTGA^{Tsy} and ΔTGA^{Other} because a large part of the demand for newly issued Treasury securities is financed via repos, whereas tax payments mainly come from household and corporate deposits. Furthermore, all six of our sample banks have a primary dealer subsidiary for Treasury securities. As a result, a large ΔTGA_t^{Tsy} can also increase primary dealers' own funding needs to finance their Treasury securities inventory. Second, ΔTGA_t^{Tsy} is fully anticipated, because Treasury auctions generally take place two days before the settlement and the maturity profile of existing Treasury securities is also public information. Meanwhile, ΔTGA^{Other} cannot be fully predicted, as it depends on the

U.S. Treasury's actual daily tax revenues and expenditures.[38] Therefore, the differential impact between ΔTGA^{Tsy} and ΔTGA^{Other} sheds light on the banks' reactions to both fully and imperfectly anticipated TGA fluctuations.

Appendix G discusses the pricing and quantity results for this TGA decomposition. We find that an increase in both components of the TGA balance tighten funding conditions, with TSY_t^{Tsy} primarily affecting the repo market and the TGA_t^{Other} primarily affecting the FX swap market. As a result, U.S. GSIBs increase their short-term liquidity provision in the repo market in response to TSY_t^{Tsy} and in the FX swap market in response to TGA_t^{Other}. Both types of short-term liquidity provision are financed by draining reserves.

Appendix G provides a further decomposition of the non-Treasury component of the TGA fluctuations, ΔTGA_t^{Other}, into an anticipated component and a non-anticipated component based on the forecasts provided by Wrightson ICAP. We find that the *anticipated* component of ΔTGA_t^{Other} drives the main results for intermediation spreads and intermediation activities. The findings that both ΔTGA_t^{Tsy}, which is fully anticipated, and the anticipated component of ΔTGA_t^{Other} drive significant price actions suggest the important role of frictions in repo and FX swap markets. These evidence is consistent with findings in the prior literature that *predicted* flows can result in price responses, such as in the U.S. Treasury market around Treasury auctions (Lou et al. (2013)) and in equity markets after index inclusion (for example, Shleifer (1986)) or dividend payments (Hartzmark and Solomon (2021)), and the slow-moving capital literature in general (Mitchell, Pedersen and Pulvino (2007), Duffie (2010) and Greenwood, Hanson and Liao (2018b), among others).

4.4 Cross-Sectional Analysis of Reserve-Draining Intermediation

In this section, we first provide cross-sectional support for the reserve-draining intermediation strategy by linking variations in reserve draining to repo market lending across banks. We

[38] Household and corporate tax payment dates are associated with large ΔTGA^{Other}, but the exact magnitude of the daily change is only known ex-post.

then discuss impact of quarter-ends and TGA fluctuations on the distribution of reserves across banks.

4.4.1 Cross-Bank Variations in Liquidity Provision

In our main analysis, we only use the aggregated FR 2052a data for the six largest U.S. GSIBs. In this section, we extend our analysis to additional banks to provide cross-sectional support that reserve-draining intermediation is crucial to liquidity provision in the repo markets *across* banks. We primarily make use of the following three additional data sources collected by the Federal Reserve to examine the relationship between net repo lending and reserve behavior for a broader set of global banks. These datasets include (1) primary dealer financing statistics reported in the FR 2004; (2) large foreign banking organization's (LFBO) monthly liquidity reports from the FR2052a data; and (3) the daily reserve balances available at the Federal Reserve. For the expanded list of sample banks, we focus on the 18 global banks in the overlapping sample between the list of primary dealers and the banks covered in the regular FR2052a and the LFBO reports. The list of banks and their nationality are provided in Appendix Table A5.

For the repo and reverse repo data, Schedule C of the FR 2004 form provides weekly statistics of the primary dealers' repo and reverse repo positions at the dealer level. The LFBO report provides detailed month-end balance sheets for FBOs in the United States. We focus on banks' *net* liquidity provision in repo market, or the NRRP, which is equal to the difference in their reverse repo and repo positions. Similar to our benchmark analysis, we aim to obtain two estimates of NRRP changes by bank: the quarter-end effects in NRRP, $\beta^{NRRP-QE}$, and the sensitivity of NRRP with respect to TGA fluctuations, $\beta_i^{NRRP-TGA}$.

We estimate quarter-end effects in the NRRP position for each bank, $\beta_i^{NRRP-QE}$ from the monthly LFBO report using the following regression:[39]

$$NRRP_{i,m} = \alpha + \beta_i^{NRRP-QE} \times Qend_m + \epsilon_{i,m}, \tag{11}$$

where $NRRP_{i,m}$ is the month-end net repo lending of bank i, and $Qend_m$ is the quarter-end dummy for the monthly observations (equals 1 if the month is March, June, September, and December and equals 0 otherwise). The coefficient on the quarter-end dummy, $\beta_i^{NRRP-QE}$, captures the quarter-end effect on the NRRP as it captures the difference between average quarter-end positions and the non-quarter-end month-end positions.

To estimate the dealer-specific sensitivity of the NRRP position with respect to TGA fluctuations, $\beta_i^{NRRP-TGA}$, we run regressions of weekly changes in the NRRP positions from the FR 2004 on weekly changes in the TGA balance.

$$\Delta NRRP_{i,t} = \alpha_i + \beta_i^{NRRP-TGA} \times \Delta TGA_t + \epsilon_{i,t}.$$

To increase the power of the weekly analysis, we focus on positive TGA fluctuations only, which generally tighten funding conditions.[40]

For reserves, we estimate the quarter-end effects in reserves using daily data, β_i^{RSV-QE}, and the sensitivity of daily changes in reserves to the daily changes in the TGA balance, $\beta_i^{RSV-TGA}$. With the four estimates β_i^{RSV-QE}, $\beta_i^{NRRP-TGA}$, $\beta_i^{NRRP-QE}$, and $\beta_i^{RSV-TGA}$ available for each bank, we now examine the cross-sectional correlation among these estimates.

[39] Since very few quarter ends fall on the FR2004 publication dates, the weekly FR2004 data cannot be used to estimate dealer-specific quarter-end effects in repo activities.

[40] Positive weekly TGA flucations have significantly larger effects on the NRRP position than negative TGA fluctuations. Since we lose considerable statistical power by moving from daily to weekly regressions, we choose to focus on the positive TGA fluctuations to distinguish among differential responses across banks in our sample.

Panel A of Table 3 presents the cross-correlation table for these four estimates. First, we find strong cross-sectional support that reserve-draining is used to support net repo lending. We note that the quarter-end effects for reserves, β_i^{RSV-QE}, and for NRRP, $\beta_i^{NRRP-QE}$, are strongly negatively correlated across banks with a correlation of -76%. This suggests the banks that drain more reserves tend to be the ones that increase net repo lending more on quarter-ends. Similarly, with respect to TGA fluctuations, we see another strongly negative correlation between $\beta_i^{RSV-TGA}$ and $\beta_i^{NRRP-TGA}$ at -65%, which suggest that banks that respond to TGA fluctuations by draining reserves more also tend to be the ones that increase net repo lending more.

Second, by comparing quarter-end and TGA estimates, we find that banks that increase net repo lending more on quarter-ends also tend to be the ones that increase net repo lending more with respect to TGA increases, with a 54% correlation between $\beta_i^{NRRP-QE}$ and $\beta_i^{NRRP-TGA}$. In general, large banks are more aggressive in reserve draining to support net repo lending. Panel B of Table 3 shows correlations between the four estimates with the average repo lending and average reserve balances. We can see a strong size effect in the sense that banks with more reserve balances and that do more repo lending on average tend to have a larger reduction in reserves and a larger increase in their net repo lending in response to negative funding conditions.

4.4.2 Reserve Distribution among U.S. GSIBs, Foreign and Other U.S. Banks

The results described in the previous sections highlight the crucial role of reserves in U.S. GSIBs' dollar intermediation strategy. These institutions substitute excess reserves at the Fed for repo or FX lending as intermediation spreads increase. However, from an aggregate financial-system-perspective, the overall level of bank reserves is determined by the size of the Federal Reserve's assets, holding other non-reserve liability items of the Federal Reserve constant. Any decrease in the reserve holdings of some institutions has to end up in other institutions' balance sheets. The distribution of reserves across institutions in the system may have implications for the level of aggregate financial intermediation activities. Moreover, data on reserve holdings can also shed light on whether other institutions conduct reserve-dependent intermediation strategies similar to those followed by the six U.S. GSIBs.

To conduct our tests, we use information collected by the Federal Reserve on daily reserve balances at financial institutions. Besides the six U.S. GSIBs, we create two additional groups composed of foreign financial institutions and other smaller domestic institutions.[41] We note that only foreign BHCs with U.S. branches and commercial bank subsidiaries can hold reserves at the Federal Reserve, thus the group of foreign banks mainly consists of very large FBOs. As shown in Figure A6, reserve balances for U.S. GSIBs and foreign banks trended down between 2018 and 2019, consistent with the normalization process of the Federal Reserve's balance sheet. This trend was less pronounced for smaller domestic banks, which held relatively stable balances of reserves in those years.

We also collect information on balances at the overnight reverse repurchase agreement facility (ON RRP). This facility is used by the Federal Reserve to control the federal funds rate by selling securities to eligible non-bank counterparties with an agreement to repurchase them the next day (Klee et al., 2019). Thus, an increase in ON RRP transactions drains reserves from the system, which should mirror the change in reserves at the three groups of banks previously described.

In Table 4, we estimate the same specifications as in Table 2, using the change in the reserve balances of financial institutions and the change in the ON RRP as the dependent variables.[42] Focusing on the coefficients on the quarter-end ($Qend_t$) and quarter-start ($Qstart_t$) dummies, we find that at quarter ends, both reserve holdings of U.S. GSIBs and foreign banks decrease substantially, with most of those balances moving to the smaller domestic banks or the ON RRP. As noted previously, the drop in reserves balances at the U.S. GSIBs is driven by their reserve-draining intermediation strategy, where they substitute reserves for repo and FX lending.

[41] We include Bank of New York Mellon and State Street in the group of other domestic institutions.
[42] The results in column 1 are identical to those presented in column 1 of Table 2.

In the case of foreign banks, the drop in reserves on quarter-ends is larger, \$94 billion (versus \$29 billion for U.S. GISBs), which is likely driven by at least two factors. First, foreign banks could also be conducting some reserve-draining intermediation to support *net* liquidity provision, despite a contraction in gross liquidity provision (as demonstrated in Figure 10). Second, in addition to using reserve to provide short-term lending, fluctuations in the IOER arbitrage positions are an important driver of reserve dynamics for foreign banks. The IOER arbitrage involves short-term borrowing in the unsecured money markets (such as the federal funds and Eurodollar markets) and parking the proceeds at the Fed, earning the IOER. Foreign banks account for the bulk of the IOER arbitrage, in part because some of their operations are not required to pay the Federal Deposit Insurance Corporation (FDIC) deposit insurance fees (Anderson, Du and Schlusche (2020)).[43] The scale-back in IOER arbitrage activities accounts for the additional quarter-end effects in the reserve holdings for foreign banks. After subtracting off the estimated IOER arbitrage position for all foreign banks from Anderson, Du and Schlusche (2020), we find that foreign banks reserve decline by about \$50 billion on quarter-ends.

In terms of the effects of TGA fluctuations on the distribution of reserves across banks, we first note that the sum of the coefficients on ΔTGA_t^{Tsy} and ΔTGA_t^{Other} across the three types of banks and the ONRRP adds up to around negative one. This confirms that an increase in the TGA has to be offset by an equal decline in reserves and other non-reserve liabilities of the Federal Reserve. In response to ΔTGA_t^{Tsy}, we observe that U.S. GSIBs' and foreign banks' reserves and the ONRRP decline significantly, with the decline in foreign banks' reserves being the largest. Smaller U.S. banks' reserves balances are little changed in response to ΔTGA_t^{Tsy}. These results suggest that in addition to U.S. GSIBs, large foreign

[43] The difference in the insurance fees imposed by the FDIC in part explains why foreign banks account for the bulk of the IOER arbitrage. U.S. branches and agencies of foreign banks generally do not have access to insured deposits in the United States, and do not pay the FDIC deposit insurance fees. U.S. banks are required to pay the fee on the total assets of the depository institutions beginning 2011. The exact FDIC fee for a bank varies according to the size and complexity of the bank, but can go up to 8 basis points for a large bank like J.P. Morgan (Whalen, 2011; Kreicher, McCauley and McGuire, 2013).

banks also play an active role in intermediating an increase in the net issuance of Treasury securities.

The effects of ΔTGA_t^{Other} on reserve distribution are somewhat different. As discussed in Section 4.3.3, an increase in ΔTGA_t^{Other} is associated with deposit outflows due to households and firms withdrawing bank deposits to pay for taxes. The larger reduction in reserves than deposit outflows for U.S. GSIBs signals reserve-draining intermediation activities. For foreign banks and smaller domestic banks, we do not have direct daily data on their dollar deposits. However, given that foreign banks in the U.S. do not have a significant deposit base, and that most of the smaller domestic banks are primarily funded with deposits, the negative coefficients on ΔTGA^{Other} for foreign banks and smaller domestic banks likely reflect different drivers: foreign banks might also engage in reserve-draining intermediation, whereas other smaller domestic banks passively accommodate deposit outflows to pay for TGA increases.

In sum, beyond the six U.S. GSIBs, it appears that foreign banks also conduct reserve-based intermediation activities to some degree, as shown by qualitatively similar patterns in the changes of reserve balances compared to the U.S. GSIBs. These reserve-draining activities reduce the share of reserves held by large banks after the funding shortage. In contrast, smaller domestic banks that are less involved in these markets are passively accommodating the reserve flows. The redistribution of reserves has implications for the overall level of financial intermediation and the various dollar funding spreads. We will return to these distributional issues in our analysis of the repo rate spike in September 2019 in Section 5.

5 Liquidity conditiomplications for Monetary Policy

In this section, we first discussed the the funding crunch that took place in mid-September 2019, which signalled the banking system approached its lowest comfortable level of reserves. We examine the behavior of the global banks right before the funding crunch and in response to the Fed interventions. Anchored in this event, and the subsequent market disruptions during the early days of the COVID-19 pandemic, we also discuss some policy considerations, especially in situations when the reserve balances decline to levels that may disrupt money market intermediaton.

5.1 Repo Spike and Lowest Comfortable Level of Reserves

The funding crunch in September 2019 happened against the backdrop of declining aggregate reserve levels as the Fed normalized the size of its balance sheet by reducing the size of its securities holdings. Reserves across all banks reached their multi-year lows around $1.4 trillion. On Monday, September 16, the TGA balance increased by $83 billion, and the benchmark SOFR-IOR spread ended the day 23 basis point higher — a four-standard deviation increase. On September 17, the overnight repo rate spiked to a high of 10% and the volume-weighted SOFR benchmark settled at 5.25% — 3.15% above the interest paid on reserves. The repo market stress also strongly spilled over to the FX swap market, which priced the implied dollar funding rates at above 5% intraday. These price responses are outsized relative to the $83 billion TGA increase (Figure 7).[44] Figure 12 shows the intraday movements in the overnight repo rate and the implied dollar funding rates from the FX swap market.[45]

Using information for the U.S. GSIBs in our sample, we find that the one-day response of these institutions to the large TGA increase on September 16 was generally consistent with their typical reaction to TGA shocks.[46] Panel A of Figure 13 shows the one-day changes in select balance sheet items on September 16 compared to the predicted range of response based on coefficient estimates in Table 2. The actual response is within the 95% confidence interval of the predicted response for most balance sheet items. Reserves declined around

[44] Furthermore, the multivariate comparison of the predicted versus actual spread changes based on coefficients estimated in Table 1 shows that the changes in SOFR-IOR were 20 basis points higher than the estimated fit on September 16 and 282 basis points higher than the fit on September 17. This outsized price reaction raises questions on the activities of intermediaries.

[45] A detailed discussion of intraday movements in these rates is provided in Appendix Section D.

[46] We focus on the one-day change from Friday, September 13 to Monday, September 16, despite the fact that the largest price action occurred on September 17. This is because the Fed intervened in the morning of September 17 and our balance sheet numbers as of the end of day on September 17 already reflect the Fed's intervention.

$22 billion, which is slightly lower than the predicted decline. Dollar lending against foreign cash collateral, FX Lend, increased slightly above the top of the predicted range while net repo lending against security collateral remained roughly constant.

While we cannot expand our analysis to non-U.S. GSIBs due to the lack of FR2052a reporting for these institutions, our reserve-based intermediation channel nonetheless helps us shed light on the likely culprit of the September 2019 funding crunch. Panel B of Figure 13 presents the estimated versus actual changes in reserve holdings at the Federal Reserve for the same three groups of banks described in Section 4.4.2: our sample of U.S. GSIBs, foreign banks, and other smaller domestic banks. The predicted changes are based on Table 4. The results show that in contrast to U.S. GSIBs, which drained reserves slightly more than predicted, foreign banks significantly under-reacted to the TGA increase on the 16th. Foreign banks reduced their total reserve balance by $14 billion on the 16th, compared to a predicted change of $40 billion. Other smaller domestic banks' reserve behavior on the day is quite in line with our prediction. Furthermore, on September 17, 2019, foreign banks increased their reserves by $58 billion, an amount that is roughly on par with the total draw on the Fed repo facility reinstated for the first time since the GFC on that same day. In contrast, U.S. GSIBs drained their reserves further by $14 billion. This provides an additional signal that foreign banks might have hit the limit of drainable reserves and contracted their dollar intermediation on the 16th.

In addition to the likely breakdown of reserve-based intermediation to absorb a large TGA shock due to the lack of drainable reserves, structural shifts in the broker-dealers' own Treasury financing needs might have also contributed to the dollar funding shortage. In particular, against the backdrop of the Federal Reserve's balance sheet normalization process and gradual reserve declines in banking entities, the broker-dealer arms of the banks transitioned from net lending to net borrowing in the repo market. Their extra financing needs were used to support the accumulation of Treasury holdings in an environment with a flat to negative yield curve that reduced end-buyers' demand for Treasury securities. Moreover, the dealers' repo financing was increasingly reliant on posting lower-quality collateral and shortening the maturity of borrowing, characteristics that are indicative of a funding crunch. We discuss these developments in more details in Appendix E.

5.2 The Fed Repo Facility and post-September 2019 events

The acute funding shortage in September 2019 prompted the Federal Reserve to reinstate its repo lending facility that had been inactive since the GFC. As the repo rate spiked to a high of 10% on September 17, 2019, the Fed established a repo facility with up to $75 billion in initial drawing capacity. After this event, the Fed carried out daily overnight and term repo auctions through year-end 2019 and into 2020. The onset of the COVID-19 market turmoil in March 2020 led to another funding crunch with the GCF-IOR spread increasing to a high of 76 basis points and FX overnight funding spreads increasing by as much as 6%. Appendix Figure A10 shows the evolution of funding spreads since September 2019.

Primary dealers were the only private sector counterparties that were allowed to borrow at the Fed repo facility in September 2019. The red line in Figure 14 plots the U.S. GSIBs' take-up at the Fed repo facility (through their primary dealer subsidiaries). The repo facility take-up is high when the funding condition is tight. We see solid take-up reaching around $80 billion in the immediate aftermath of the September 2019 repo spike. The take-up reached a pre-COVID peak at $120 billion on December 31, 2019, and later peaked at $170 billion during the COVID-related market turmoil in March 2020. Furthermore, the Fed repo facility possibly reduced the need for broker-dealers to draw on the BHC's internal liquidity from affiliated depository entities and supported a substitution away from reserve-based intermediation to matched-book intermediation. The blue line in Figure 14 plots the broker-dealers' net internal borrowing from depository institutions. Increases in the usage of the Fed repo facility tend to match declines in repo borrowing from internal sources within the BHC.

The repo facility was effective in enabling banks to on-lend official liquidity support. Table A10 shows regression results of daily changes in the U.S. GSIBs' dollar intermediation activities on changes in Fed repo take-up. Each dollar increase in the bank's Fed repo facility borrowing is correlated with a net increase in repo lending of around 75 cents and FX-swap-based dollar lending of around 25 cents. Consistent with our baseline result, the net increase in repo lending is predominantly driven by the bank's reduction of borrowing from external cash lenders and a somewhat smaller increase in reverse repo lending to other counterparties.[47]

5.3 Implications for the Fed's balance sheet policy and for regulatory policy

The decrease in the level of reserves due to the Fed's balance sheet normalization process which ended in the September 2019 episode, highlighted the need to assess what that minimum level of reserves should be. Since the overall level of reserves is largely determined by the Federal Reserve, their crucial role for controlling short-term interest rates, as we have noted, underscores the importance of the Fed's balance sheet policy. A larger Fed balance sheet is generally associated with more reserves available to the banking sector, which facilities reserve-draining intermediation, but may tighten the LR constraint other things being equal. As the Fed continues its quantitative tightening process post-COVID-19 pandemic, assessing that minimum level of reserves is important to avoid a potential repeat of the September 2019 episodes. In this section, we discuss how the banks own ex-ante bank balance sheet constraints associated with a large Fed balance sheet can be mitigated, and describe additional regulatory policy changes that can lower the barriers to reserve-draining intermediation.

[47] Besides the repo facility, in response to the COVID-19 induced market turmoil in March 2020, the Federal Reserve launched a host of other liquidity facilities to restore liquidity in the short-term funding markets. Most notably, the central bank dollar liquidity swap lines reached their peak usage at around $440 trillion, which mainly funded foreign banks through the dollar auctions set up by central banks with swap line agreements with the Fed. We present results for our baseline price and balance sheet regressions in the post-September 2019 sample period in Appendix Tables A11 and A12. In particular, we observe that fluctuations in the TGA balance remain significantly correlated with repo spreads and dollar intermediation activities.

First, a small (large) Fed balance sheet does not translate one-for-one into a small (large) balance sheet for the banking sector due to the banking sector's overall demand for HQLAs to comply with liquidity regulations. For example, during the previous Federal Reserve balance sheet normalization period from October 2017 to August 2019, the total reserves of all commercial banks in the U.S. declined by about $750 billion, but their holdings of Treasury and agency securities increased by about $450 billion, according to statistics published in the H.8 statistical release. More generally, banks optimize their balance sheet between holding reserves and engaging in other business activities. A higher reserve level does not necessarily lead to a more binding LR. Appendix Figure A11 shows the average ratio of reserves to total assets and the average SLR for our sample U.S. GISBs. While the average reserve to total asset ratio declined from 7.5% in 2016 to 4% in 2020, the SLR was stable at around 6.5% to 7%. In fact, periods of high reserves are actually associated with a slightly higher SLR, which indicates more balance sheet slack.

Second, more recently, the ONRRP facility has become an important tool to relieve banks' LR constraint form a large Fed balance sheet. The take-up on the ONRRP facility grew from near zero in March 2021 to a peak of almost $2.6 trillion at end-2022. This large take-up in the ONRRP facility breaks the mechanical relationship between the size of the Fed balance sheet and the total level of reserves supplied to the banking sector, making bank reserves an endogenous outcome of banks' and non-banks' demand for cash. When the banking sector becomes too LR constrained, it can push deposits away to non-banks such as MMFs, and non-banks can then park the proceeds at the Fed. The level of reserves in the banking sector does not need to grow beyond banks' balance sheet capacity.

Besides the Fed balance sheet policy, additional changes to regulations and monetary policy implementation can also help ameliorate dollar funding crunches. First, an exemption of reserves from the LR calculation would significantly reduce the cost of reserve-draining intermediation, as it reduces the ex-ante balance sheet cost of holding reserves. Between April 2020 and April 2021, the Fed temporarily exempted reserves and Treasury securities from the eSLR calculation. Even though a further extension to this exemption was not granted, the Fed announced that it would seek comment on measures to adjust the SLR calculation. Second, a relaxation of the rules and supervision regarding intraday liquidity requirements could reduce banks' intraday liquidity buffers and increase the amount of drainable reserves for the system. Third, the Fed established the standing repo facility in 2021 and broadened the eligible counterparties from primary dealers only to regulated banks and broker-dealers. As we discussed in Section 5.2, official funding from the Fed repo facility substitutes for the need of reserve-draining intermediation.

6 Conclusion

In this paper, we have documented a fundamental change to how large global banks manage and provide short-term liquidity post-GFC. In particular, bank reserves played a crucial role in supporting the well-functioning of dollar short-term funding markets prior to COVID-19 pandemic. We document that in this period, U.S. GSIBs reduced their reserves at the Fed in order to lend in the repo and FX swap markets during periods of dollar funding shortages. The internal liquidity sharing within the BHC between broker-dealers and non-broker-dealer entities enables this reserve-based intermediation. These activities became feasible as a result of the ample reserve environment set by the Federal Reserve after the GFC. However, as the level of bank reserves declined when the Fed's balance sheet normalization process started in 2017, reserve-draining intermediation activities of global banks became impaired, leading to the stress observed in money markets in September 2019.

More generally, the interaction between financial regulations and monetary policy has become more complex post-GFC. Regulatory reforms that build the resilience of the financial system increase balance sheet costs for large global banks to intermediate in short-term funding markets, which could undermine the effectiveness of U.S. monetary policy transmission. Given the critical role of bank reserves in liquidity provision in the new regulatory environment, central bank balance sheets and interest rate policies are intricately linked.

Absent any change in the monetary or regulatory frameworks, a large Fed balance sheet is necessary to ensure ample bank reserves, and thus a steady control over interest rates, even when the short-term interest rate is above the zero-lower bound.

Lastly, as the Federal Reserve winds down its massive balance sheet in response to the COVID-19 pandemic, the lessons learned from the earlier (and so far the only post-GFC) episode of Federal Reserve balance sheet normalization before the COVID-19 pandemic can inform future monetary policy and its interaction with financial regulations.

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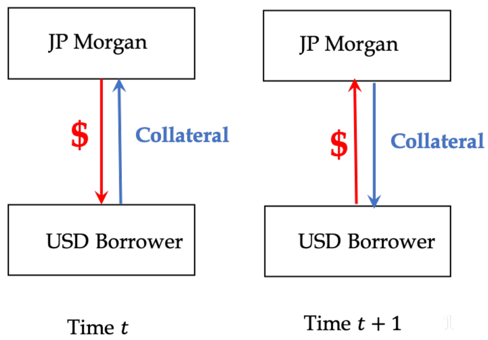
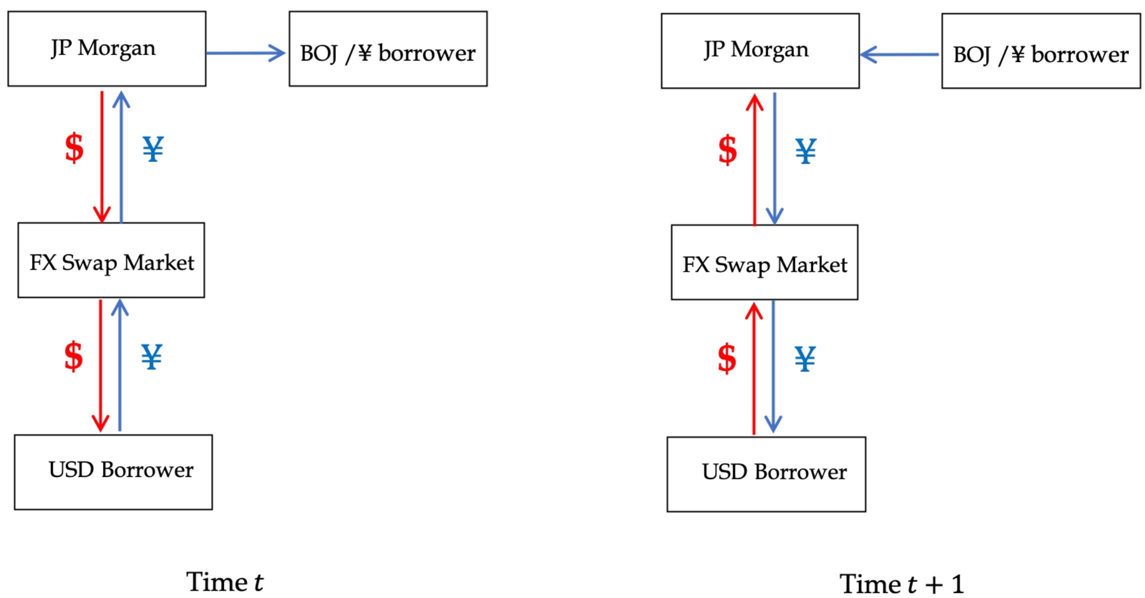
Figure 1: Cash flows for dollar lending in repo and FX swap markets

(A) Dollar lending in the repo market

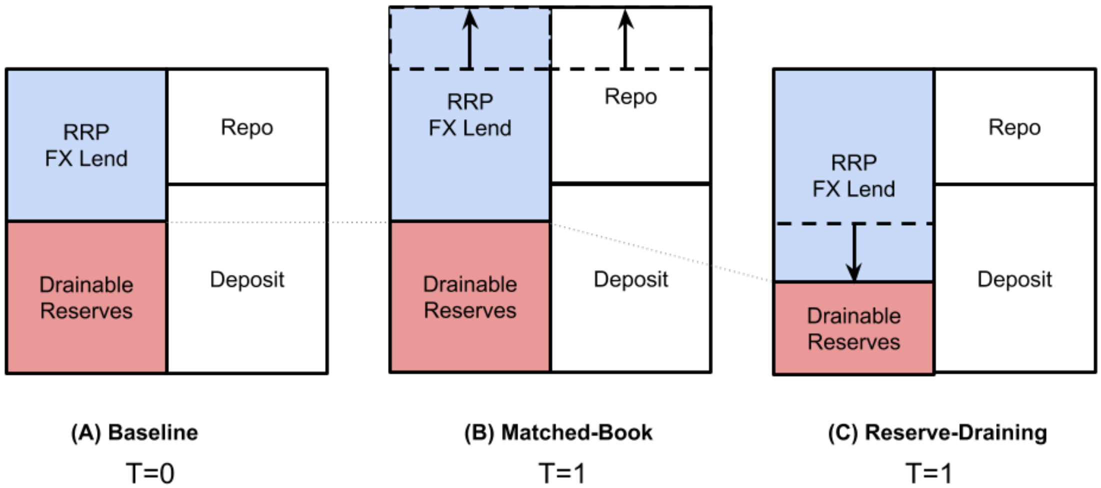


(B) Dollar lending in the FX swap market



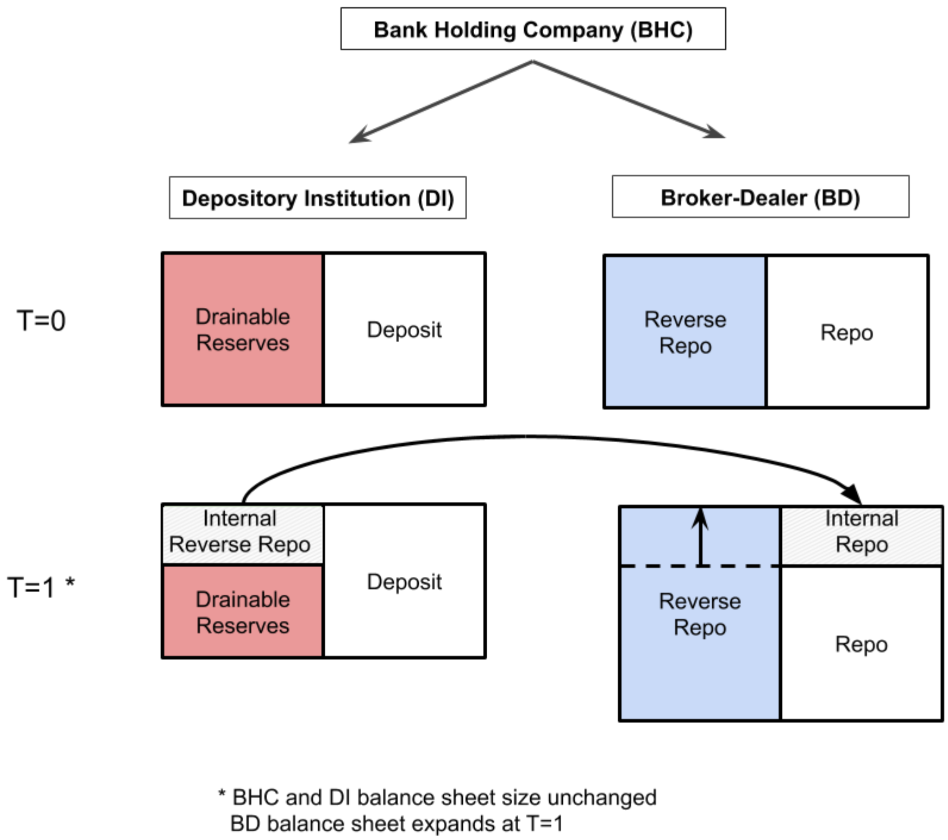
Notes: This figure shows a schematic representation of the dollar lending activities conducted by U.S. GSIBs. Panel (A) shows dollar lending in the repo market. Panel (B) shows dollar lending in the FX swap market.

Figure 2: An illustration of different types of dollar intermediation



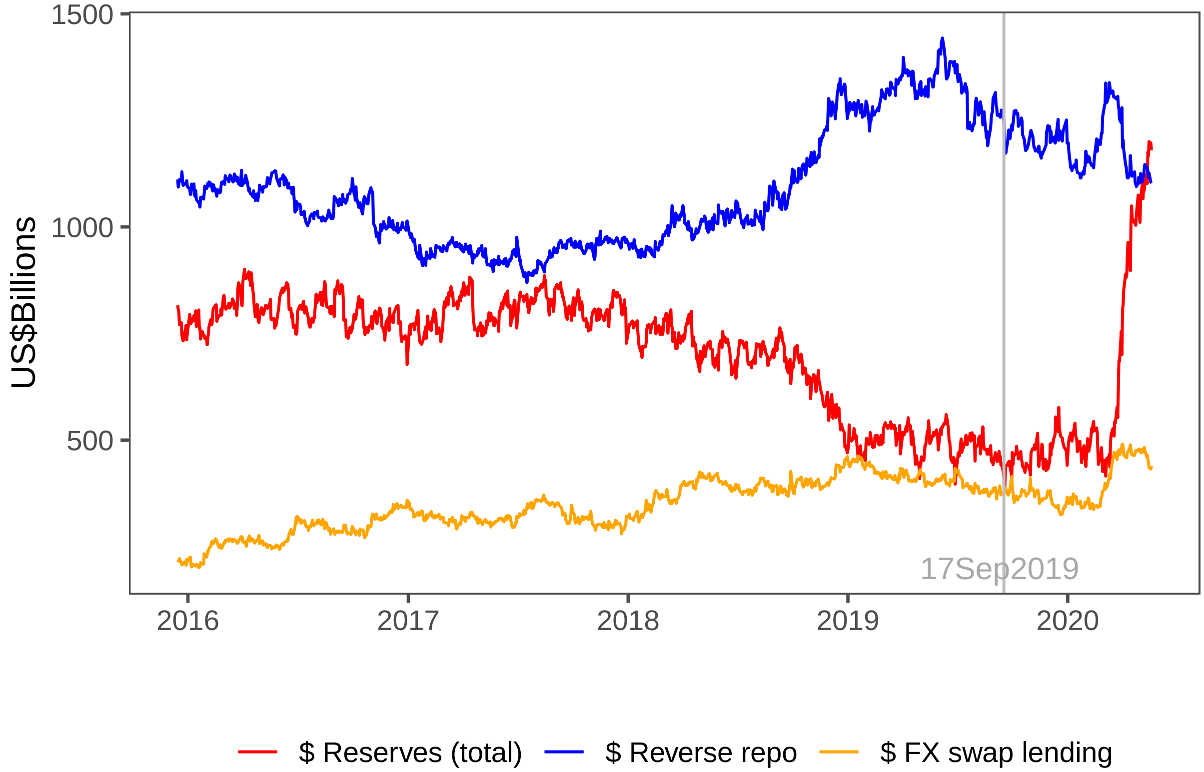
Notes: This figure shows the aggregate short-term scalable balance sheet for dollar liquidity provision and two types of dollar funding intermediation. Panel (A) shows the baseline balance sheet. The asset items include the sum of the reverse repos and FX swap lending in dollars (shown in blue), and drainable reserve balances at the Federal Reserve beyond the reserve requirement and other regulatory demand (shown in red). The liability items include repos and deposits denominated in dollars. Panel (B) shows matched-book intermediation through which a bank increases repo borrowing by the same amount as the increase in short-term dollar lending in repo and FX swap markets. Panel (C) shows reserve-draining intermediation through which a bank reduces its drainable reserve balances to increase its short-term dollar lending, while leaving the overall size of the bank balance sheet unchanged.

Figure 3: Intra-bank Transfer for Reserve-Draining Intermediation



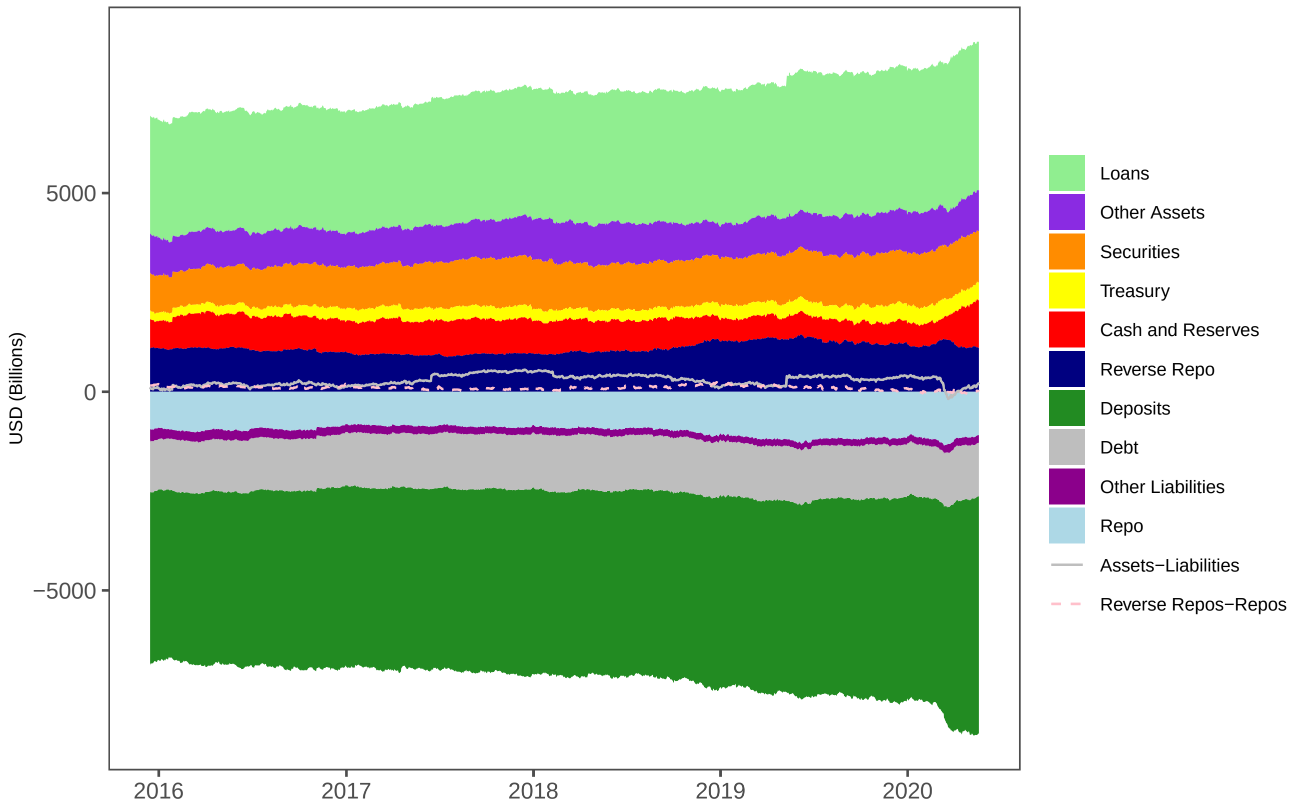
Notes: This figure illustrates the intra-office transfer between the depository institution (DI) and the broker-dealer (BD) subsidiary of the same bank-holding company (BHC) that enables reserve-draining intermediation. The top two diagrams show the baseline balance sheet for the DI and the BD at $T = 0$. The bottom two diagrams show the new balance sheets after additional reserve-draining intermediation at $T = 1$. The DI reduces its reserve balance, and transfers the proceeds to the BD through an internal reverse repo lending. The BD uses the additional funding from the internal repo position to expand its reverse repo position. Deposit and external repo positions remain unchanged. After netting out internal positions, the overall size of the BHC's balance sheet stays unchanged at $T = 1$.

Figure 4: U.S. GSIBs' dollar liquidity provision



Notes: This figure shows the time series of U.S. GSIBs' total dollar reserves in red, dollar reverse repo lending in blue, and dollar FX swap lending in orange. The discussions of these short-term scalable components of bank assets are provided in Section 3.3. The vertical gray line shows the beginning of the Fed repo facility on September 17, 2019. The sample is measured daily from December 2015 to May 2020.

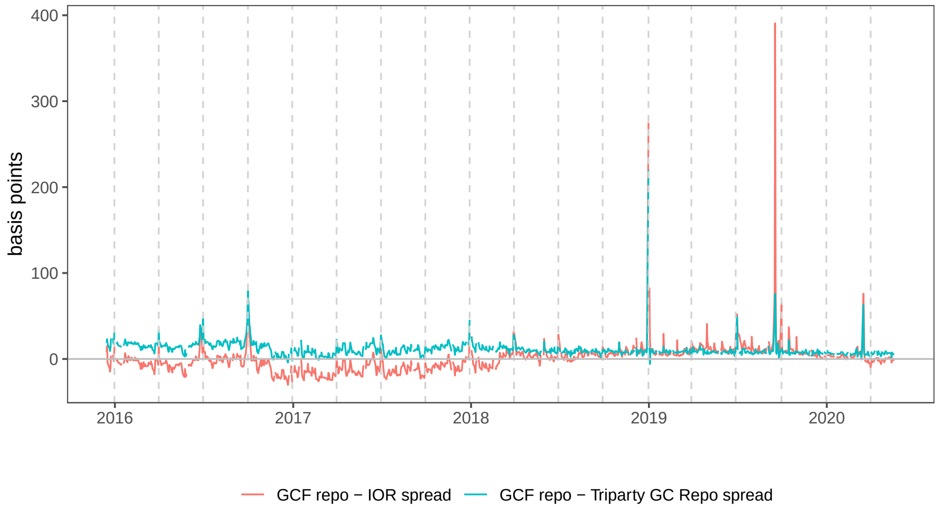
Figure 5: U.S. GSIBs balance sheet in dollars



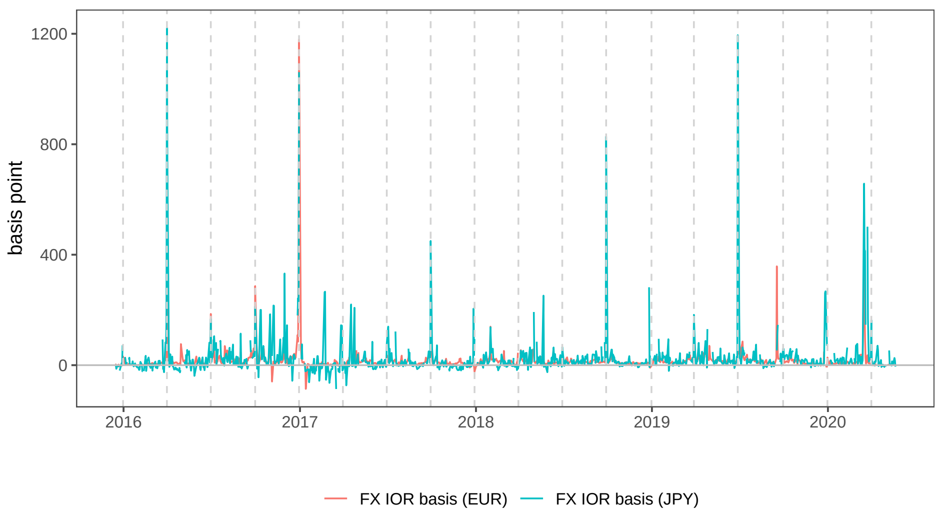
Notes: This figure presents the aggregate balance sheet for six U.S.GSIBs based on the FR 2052a data, including only items denominated in U.S. dollars. Items above zero are classified as assets and those below zero as liabilities. The solid line represents the difference between total assets and total liabilities, while the dashed line measures the net repo position of these banks. The sample period expands from December 2015 until May 2020.

Figure 6: Short-term intermediation spreads for dollar funding

(A) Repo intermediation spreads

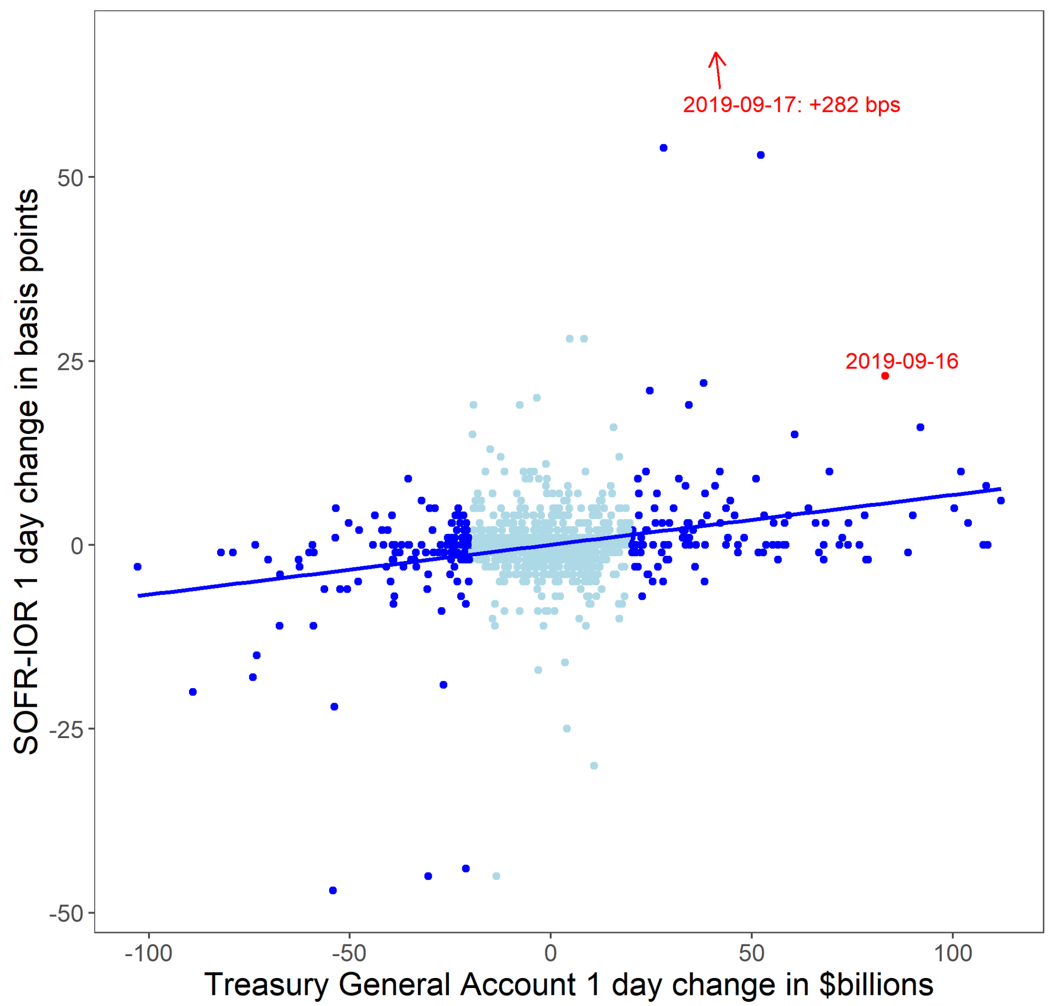


(B) FX swap intermediation spreads



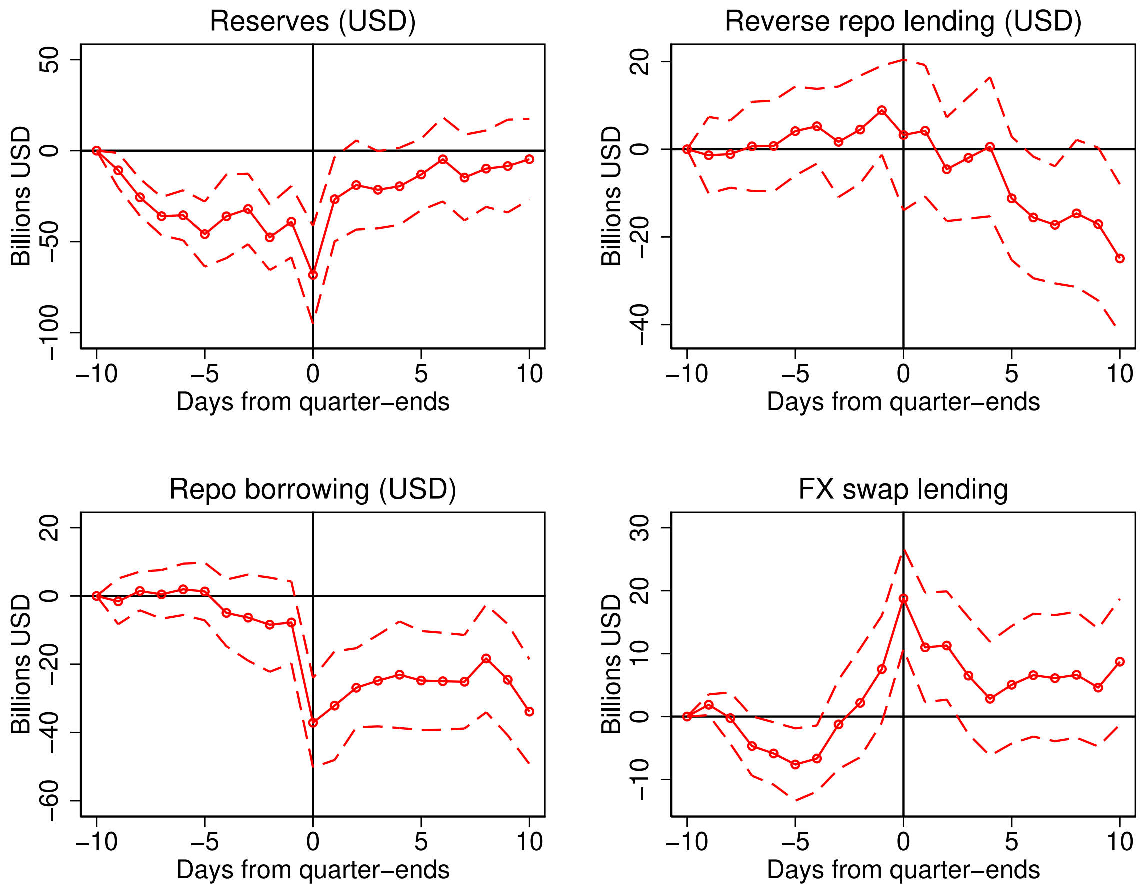
Notes: This figure shows various intermediation spreads for dollar funding intermediation. In Panel (A), we plot the difference between the GCF general collateral Treasury repo rate and interest on excess reserve (IOR) at the Federal Reserve ("GCF repo - IOR spread"), and the difference between the GCF and Triparty Treasury general collateral repo spread ("GCF Repo - Triparty GC Repo Spread"). In Panel (B), we plot the spread of the implied dollar funding rate by swapping the ECB deposit rate over the Fed IOR (FX IOR Basis (EUR)), and the spread of the implied dollar funding rate by swapping the BOJ deposit rate over the Fed IOR (FX IOR Basis (JPY)). The dashed vertical lines denote quarter-ends.

Figure 7: Treasury General Account and SOFR-IOR Spread



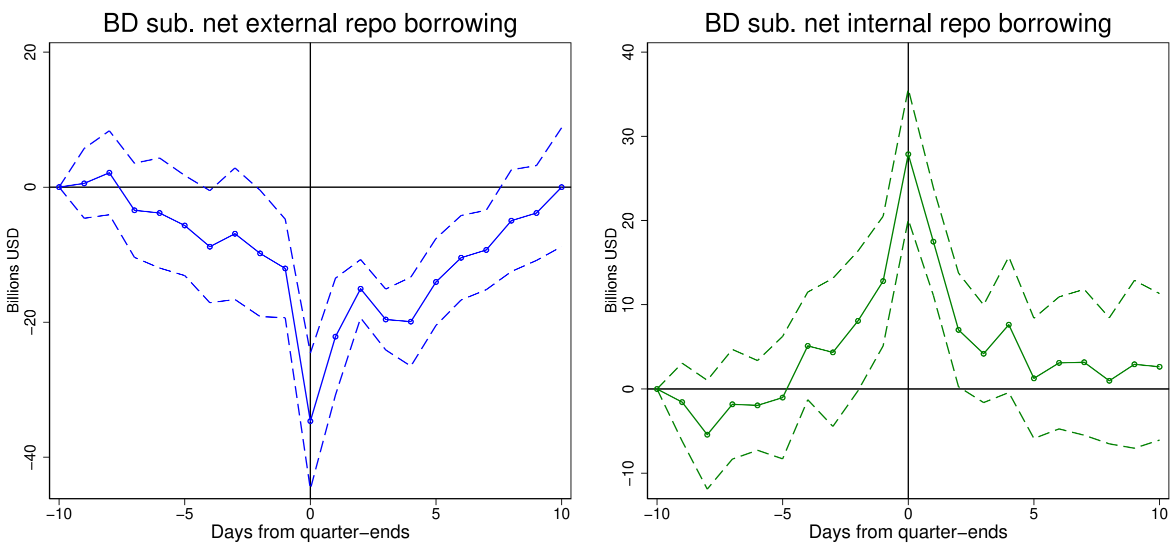
Notes: This figure shows a scatter plot between the daily changes in the spread between the secured overnight financing rate (SOFR) and the interest on excess reserves (IOR) at the Federal Reserve in basis points on the vertical axis, and the daily change in the Treasury General Account (TGA) balance in billions of dollar on the horizontal axis. Dark blue dots denote days with daily changes in the TGA balance greater than $20 billion in absolute value. The light blue dots denote days with daily changes in the TGA balance less than or equal to $20 billion. The straight line is the fitted regression line for large TGA change days, with the exception of September 17, 2019 and September 18, 2019 that are beyond the graph. The sample period is December 15, 2015 to May 18, 2020.

Figure 8: U.S. GSIBs' liquidity provision around quarter-ends



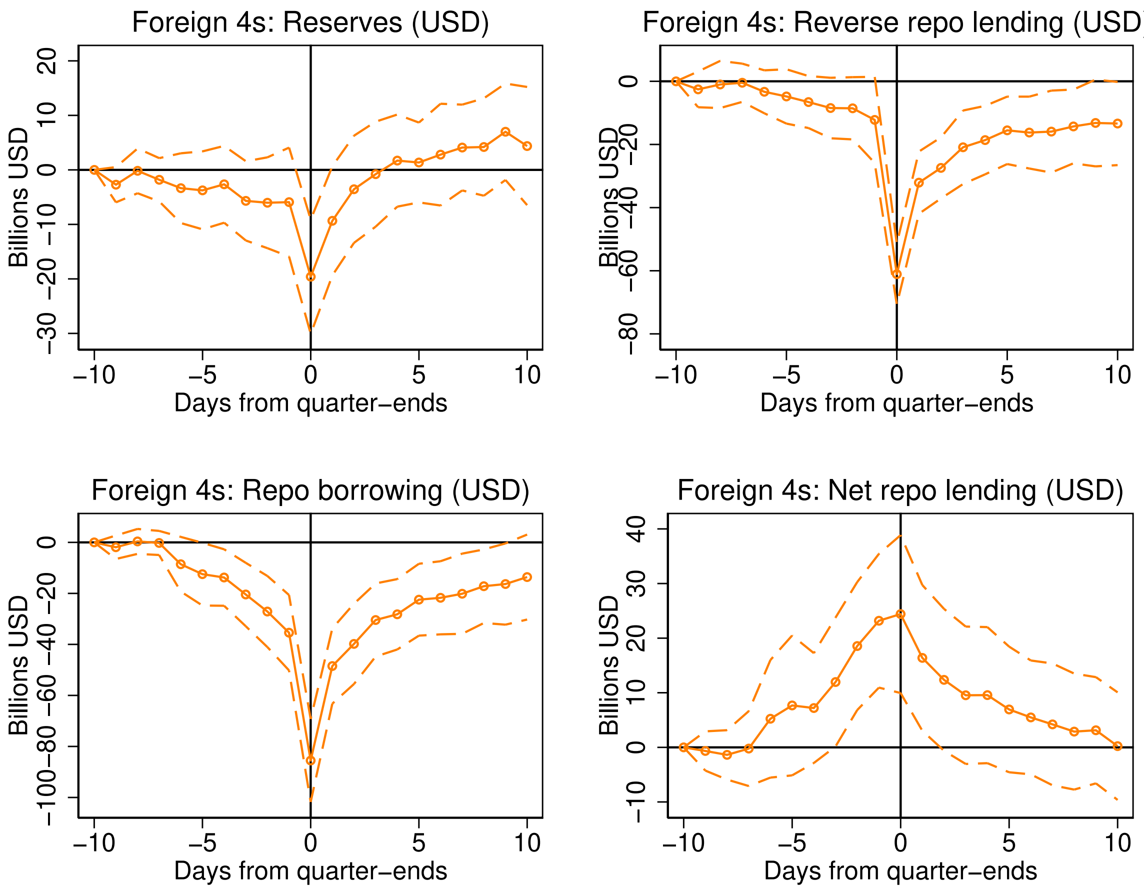
Notes: This figure shows quarter-end changes in U.S. GSIBs' dollar reserves, reverse repo lending, repo borrowing, and FX swap lending. The discussions of these liquidity measures are provided in Section 3.3. The dotted lines denote the 95% confidence interval with bootstrapped standard errors.

Figure 9: Broker-dealer dollar repo borrowing and intra-bank transfers near quarter-ends



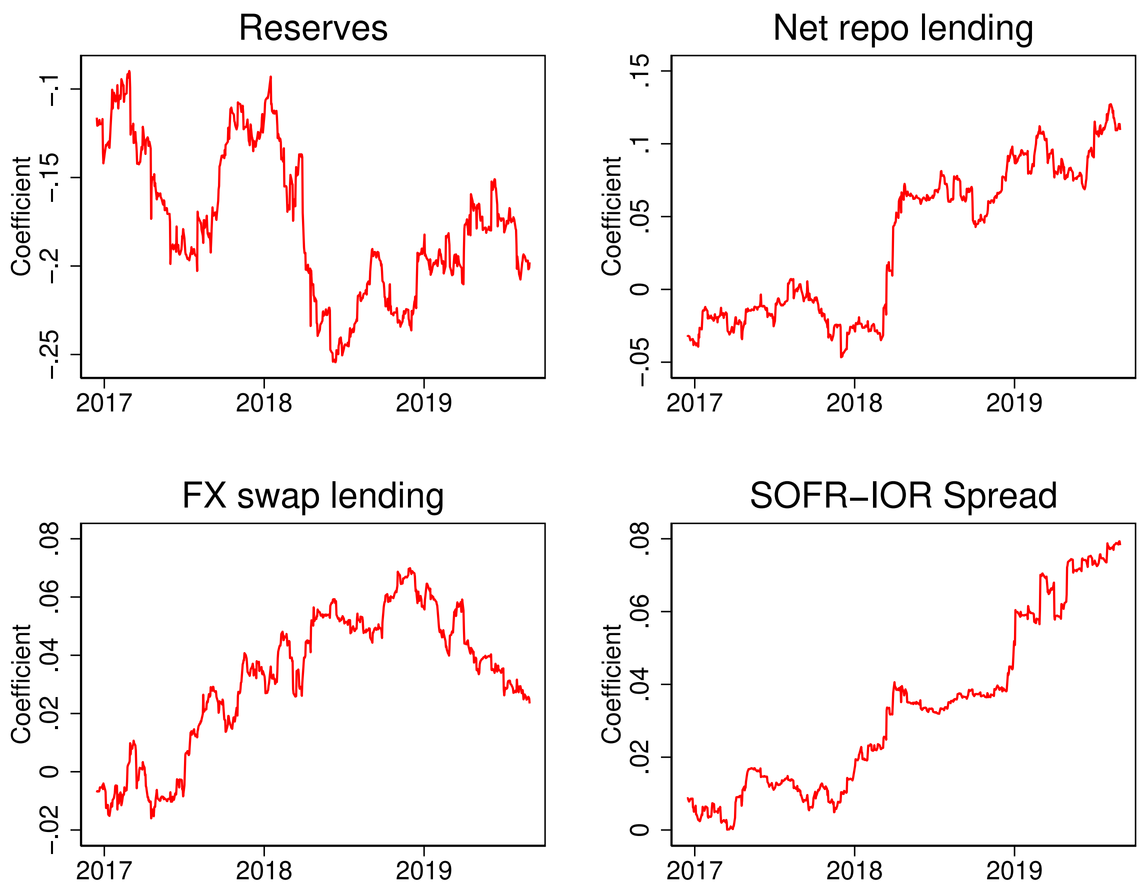
Notes: This figure shows quarter-end changes in external repo borrowing and net internal repo borrowing of the broker-dealer entities. The left panel shows broker-dealers external repo borrowing from unaffiliated third-party lenders. The right panel shows broker-dealers' net internal repo borrowing (gross internal repo borrowing minus gross internal repo lending) from affiliated non-broker-dealer entities. The dotted lines denote the 95% confidence interval with bootstrapped standard errors.

Figure 10: Foreign banks' liquidity provision around quarter-ends



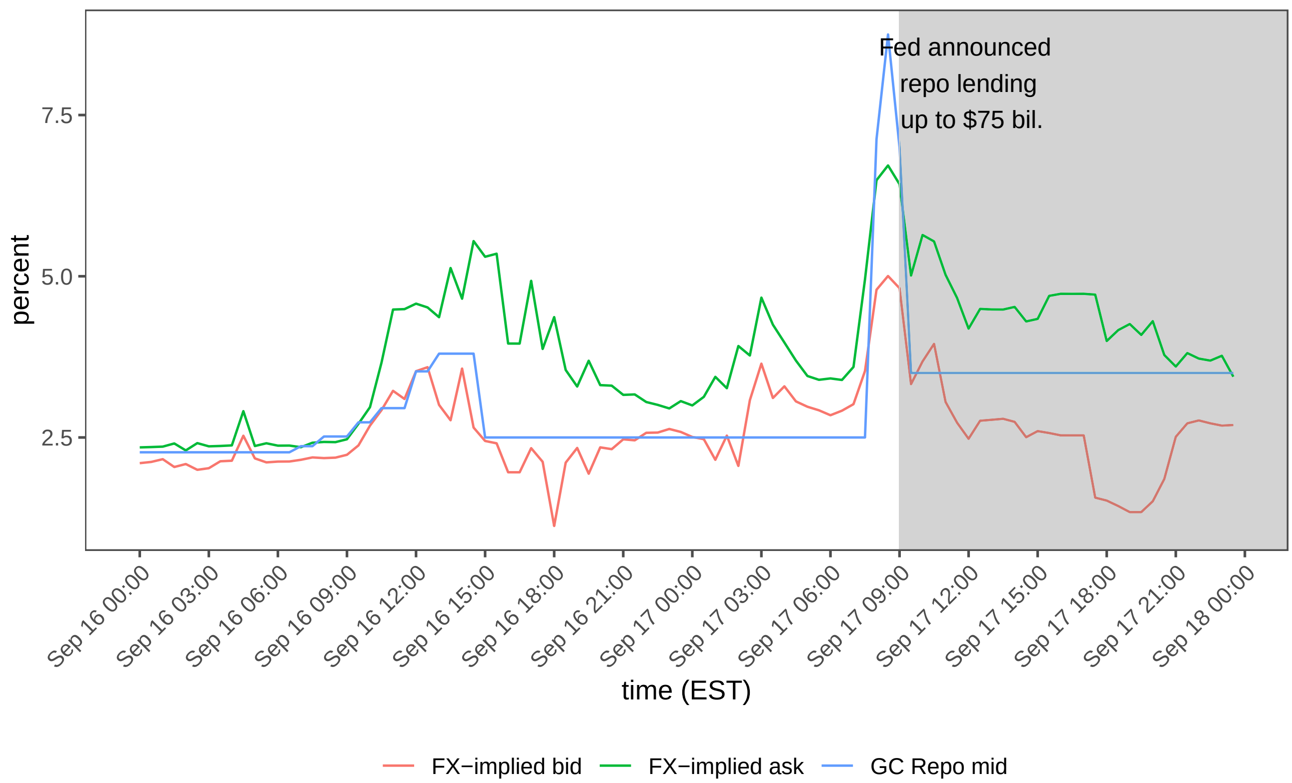
Notes: This figure shows quarter-end changes in foreign banks' dollar reserves, reverse repo lending, repo borrowing, and net reverse repo lending. The positions are aggregated across four foreign banking offices in the U.S. with daily reporting requirements for FR2052a. The discussions of these liquidity measures are provided in Section 3.3. The dotted lines denote the 95% confidence interval with bootstrapped standard errors.

Figure 11: Rolling regression coefficients on the effects of TGA fluctuations



Notes: This figure shows 1-year (252 business days) rolling-window regression estimates of the effects of daily TGA fluctuations on daily changes in reserves, net repo lending, FX swap market lending the SOFR-IOR spread. The regression specification is the same as in Table 2, including quarter-end and quarter-start dummies.

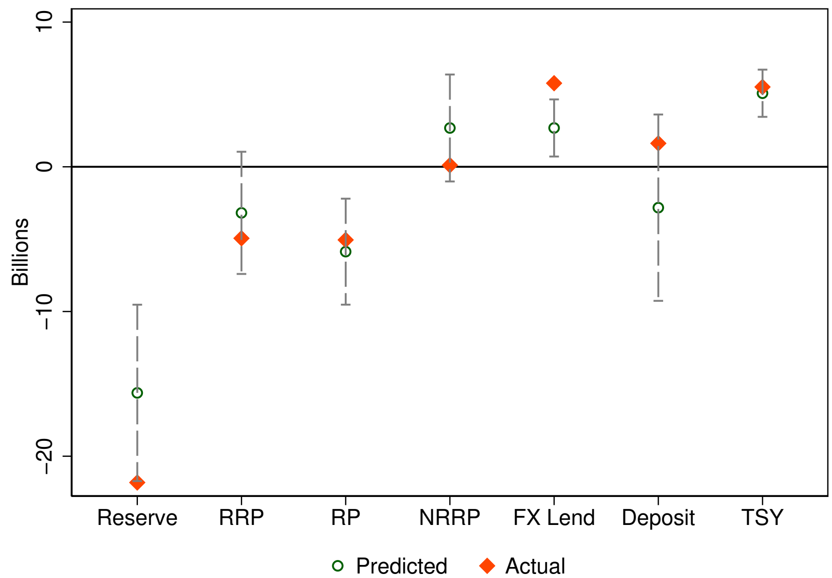
Figure 12: September 19 intraday overnight repo and FX-implied funding rates



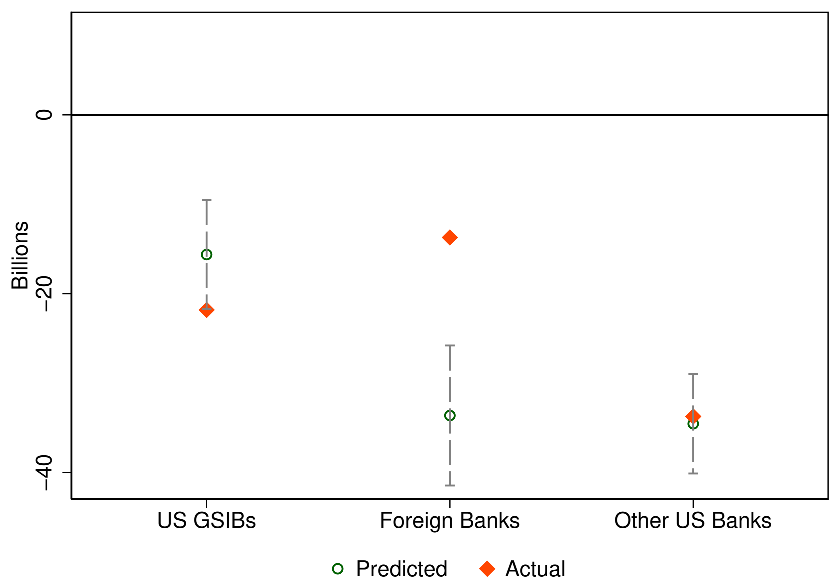
Notes: This figure shows the intraday repo rate and implied dollar funding rates from the FX swap market. The blue line shows the general collateral repo rate from the Thomson Reuters Tick History. The green and red lines show the bid and ask rate, respectively, for the implied dollar funding rate by swapping the deposit rate at the ECB into dollars on the overnight basis. The overnight implied FX swap rate is calculated based on the Bloomberg data with calculation details shown in Footnote 26.

Figure 13: Predicted and actual one-day change on September 16, 2019

(A) U.S. GSIBs' balance sheets

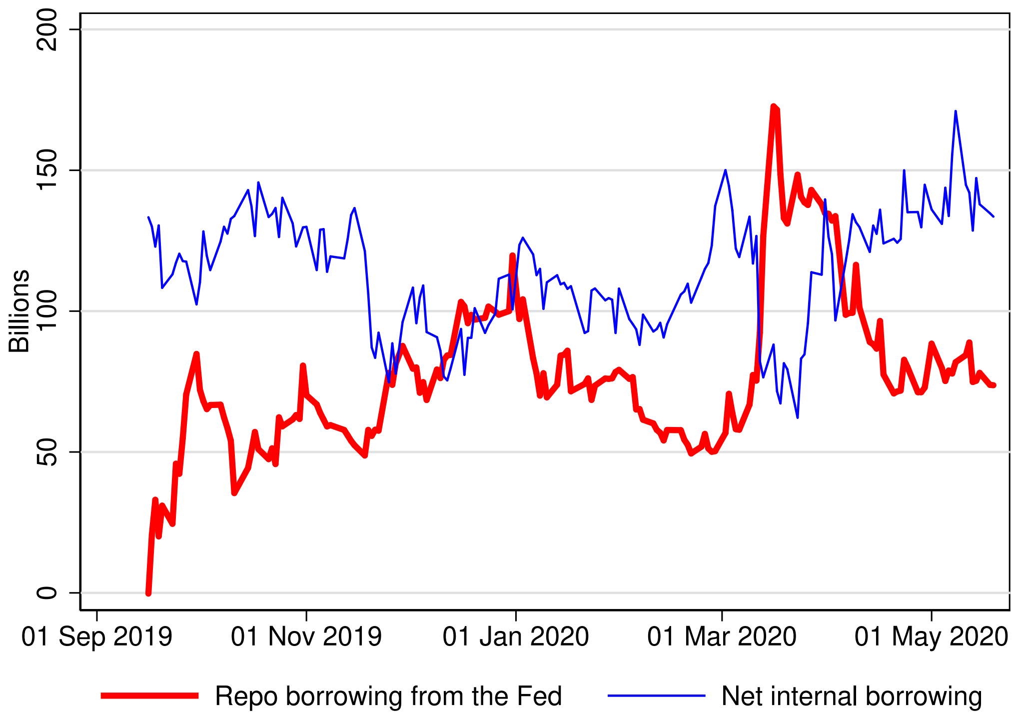


(B) Reserve balance of US GSIBs, foreign and other US banks



Notes: Panel A shows the predicted and actual one-day change in the intermediation activities of the U.S. GSIBs on September 16, 2019. The green dot shows the point estimate for the predicted one-day change based on the regression results in Table 2 and the $83 billion TGA increase on September 16, 2019. The vertical dashed line denotes the 95 percent confidence interval for the point estimate of the predicted change. Panel B shows the predicted and actual one-day change in the reserve balance of U.S. GSIBs, foreign banks, and other U.S. banks. The green dot shows the point estimate for the predicted one-day change based on the regression results in Table 4.

Figure 14: Broker-dealers Fed Repo Facility Usage and Internal-cash Substitution



Notes: This figure shows the Fed repo facility draw and internal repo borrowing (from affiliated depository institutions) by broker-dealer arms of U.S. GSIBs since the establishment of the repo facility on September 16, 2019.

Table 1: Impacts of Quarter-Ends and TGA Fluctuations on Intermediation Spreads

	(1) $\Delta SOFR-IOR$	(2) $\Delta GCF-IOR$	(3) $\Delta TGCR-IOR$	(4) $\Delta GCF-TGCR$	(5) $\Delta EURIOR$	(6) $\Delta JPYIOR$
$Qend_t$	12.9***	31.8**	8.45***	23.3*	136.8**	416.6***
	(3.21)	(15.8)	(3.13)	(13.1)	(59.9)	(117.8)
$Qstart_t$	-7.61**	-23.0*	-3.55*	-19.4	-138.7*	-268.3***
	(3.21)	(12.4)	(1.87)	(13.7)	(75.5)	(101.4)
ΔTGA_t	0.046***	0.070***	0.039***	0.032***	0.26***	0.46***
	(0.0087)	(0.016)	(0.0080)	(0.012)	(0.062)	(0.16)
Constant	-0.068	-0.14	-0.056	-0.073	0.29	-2.05
	(0.13)	(0.17)	(0.11)	(0.12)	(0.57)	(1.83)
N	933	930	933	930	902	837
R^2	0.21	0.19	0.14	0.14	0.22	0.36

Notes: This table shows the regression results of the quarter-end dummies and TGA fluctuations on daily changes in various intermediation spreads. The dependent variables are as follows: daily changes in the SOFR–IOR spread (Column 1), daily changes in the GCF repo–IOR spread (Column 2), daily changes in the Triparty (TGCR) repo–IOR spread (Column 3), daily changes in the GCF–TGCR repo spread (Column 4), daily changes spread between the overnight implied dollar rate by swapping the ECB deposit rate and the Fed IOR (Column 5), and daily changes in the spread between the overnight implied dollar rate by swapping the BOJ deposit rate and the Fed IOR (Column 6). The independent variables are as follows: $Qend_t$, a dummy variable indicating the last business day of the quarter; $Qstart_t$ a dummy variable indicating the first business day of the quarter, and ΔTGA, daily changes in the TGA balance. Robust standard errors are reported in the parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table 2: Impact of TGA and quarter-end constraints on Intermediation Activities

	(1) ΔRSV_t	(2) ΔRRP_t	(3) ΔRP_t	(4) $\Delta NRRP_t$	(5) ΔFX_t	(6) $\Delta Deposit_t$	(7) $\Delta TSY_t^{outright}$
ΔTGA_t	-0.18***	-0.042*	-0.078***	0.037*	0.031***	-0.035	0.060***
	(0.036)	(0.025)	(0.022)	(0.022)	(0.012)	(0.037)	(0.0095)
$Qend_t$	-26.7***	-5.50	-29.2***	23.7***	10.8***	2.61	3.32
	(7.31)	(6.53)	(4.60)	(4.97)	(3.12)	(4.23)	(2.82)
$Qstart_t$	39.1***	-0.037	3.01	-3.05	-7.38**	35.2***	-0.22
	(5.15)	(5.86)	(4.32)	(5.04)	(3.24)	(4.53)	(1.47)
Constant	-0.63	0.29	0.66	-0.37	0.13	0.067	0.13
	(0.61)	(0.48)	(0.41)	(0.40)	(0.23)	(0.61)	(0.20)
N	932	932	932	932	932	932	932
R^2	0.14	0.0059	0.099	0.061	0.063	0.059	0.044

Notes: This table shows regression results of one-day changes in the TGA account (ΔTGA_t), and quarter-end ($Qend_t$) and quarter-starts ($Qstart_t$) on daily changes in the U.S. GSIBs intermediation activities. The dependent variables are as follows: changes in reserves (Column 1), changes in dollar reverse repos (Column 2), changes in dollar repos (Column 3), changes in net dollar reverse repos, or the difference between reverse repos and repos in dollars (Column 4), changes in dollar lending in the FX swap market (Column 5), changes in dollar deposits (Column 6), and changes in outright Treasury holdings (Column 7). $Qend_t$ is a dummy variable indicating the last business day of the quarter, and $Qstart_t$ is a dummy variable indicating the first business day of the quarter. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table 3: Cross-bank Correlation Between Reserve Draining and Net Repo Lending ($N = 18$)

Panel A	$\beta_i^{NRRP-QE}$	β_i^{RSV-QE}	$\beta_i^{NRRP-TGA}$	$\beta_i^{RSV-TGA}$
$\beta_i^{NRRP-QE}$	1			
β_i^{RSV-QE}	-0.76	1		
$\beta_i^{NRRP-TGA}$	0.54	-0.33	1	
$\beta_i^{RSV-TGA}$	-0.61	0.32	-0.65	1

Panel B	$\beta_i^{NRRP-QE}$	β_i^{RSV-QE}	$\beta_i^{NRRP-TGA}$	$\beta_i^{RSV-TGA}$
$\overline{RRP}_i$	0.80	-0.65	0.73	-0.69
$\overline{RSV}_i$	0.77	-0.61	0.58	-0.88

Notes: This table shows cross-bank correlation between reserve draining and net repo lending activities. The variables are as follows: $\beta_i^{NRRP-QE}$ measures the quarter-end effects for net repo lending, β_i^{RSV-QE} measures the quarter-end effects for reserves, $\beta_i^{NRRP-TGA}$ is the regression beta of weekly changes in the net repo lending with respect to weekly TGA fluctuations, $\beta_i^{RSV-TGA}$ is the regression beta of daily changes in the net repo lending with respect to daily TGA fluctuations, $\overline{RRP}_i$ measures average repo lending over the sample period, and $\overline{RSV}_i$ measures the average reserve balance over the sample period. The sample period is December 1, 2015 to August 31, 2019. All estimates are done at each individual bank level, and the list of sample bank is provided in Appendix Table A5. More estimation details are discussed in Section 4.4.

Table 4: Impact of TGA and quarter-end constraints on reserve distribution

	(1) $\Delta RSV_t^{US-GSIBs}$	(2) $\Delta RSV_t^{Foreign}$	(3) $\Delta RSV_t^{Domestic}$	(4) $\Delta ONRRP_t$
$Qend_t$	-29.0***	-94.3***	14.6***	101.5***
	(7.37)	(19.1)	(4.69)	(16.9)
$Qstart_t$	38.1***	71.7***	-0.071	-109.0***
	(5.20)	(21.1)	(5.47)	(20.6)
ΔTGA_t^{Tsy}	-0.11**	-0.68***	-0.040	-0.11*
	(0.053)	(0.071)	(0.038)	(0.067)
ΔTGA_t^{Other}	-0.22***	-0.25***	-0.61***	0.15**
	(0.045)	(0.056)	(0.034)	(0.058)
Constant	-0.94	1.13	-2.28***	0.89
	(0.63)	(0.75)	(0.46)	(0.60)
N	932	931	931	931
R^2	0.14	0.36	0.38	0.42

Notes: This table shows regression results of quarter-end ($Qend_t$) and quarter-starts ($Qstart_t$), one-day changes in the net treasury issuance (ΔTGA_t^{Tsy}), and changes in the TGA account unrelated to net Treasury issuance (ΔTGA_t^{Other}) on daily changes in reserve balances for financial institutions and in the balance of the Federal Reserve's ON RRP facility. Column 1 shows regression results for changes in reserve balances for the six U.S. GSIBs in our sample, while column 2 shows results for foreign banks with U.S. branches and subsidiaries. Column 3 shows results for other U.S. banks not classified in the other two groups. Column 4 shows results for changes in the ON RRP facility. $Qend_t$ is a dummy variable indicating the last business day of the quarter, and $Qstart_t$ is a dummy variable indicating the first business day of the quarter. The sample period is December 15, 2015 until August 31, 2019. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Internet Appendix
"U.S. Banks and Global Liquidity"

Ricardo Correa Wenxin Du Gordon Liao

A FR 2052a and FR Y9-C Comparison

This comparison between the LCR assessment data and the FR Y-9C data serves two important functions. First, it verifies that the daily balance sheet snapshots assembled from the liquidity monitoring reports are of high quality and broadly match the public filings reported on quarter-ends. Second, the comparison highlights an advantage of the LCR monitoring data for assessing the gross amount of intermediation in dollar liquidity. As the FR Y-9C data defers to Generally Accepted Accounting Principles (GAAP) standards in the netting treatment of certain balance sheet items, matched-book exposures in repurchase agreements (repos) are significantly lower as reported in this form. For instance, the gross exposure in repo borrowing aggregated across the six GSIBs is around \$1.8 trillion at the end of 2018 according to the LCR data, but only around \$800 billion according to the FR Y-9C. The former more accurately reflect the volume of repo intermediation from other sources.[1]

Figure A3 shows that repo and reverse repo positions are significantly larger in FR2052a than in Y9-C. The net reverse repo positions from the two sources have similar trends. The other main asset and liability items from the two sources are broadly in line with each other.

B Alternative Measure of FX Swap Lending

As a robustness check, we use an alternative proxy for FX swap lending (*Total FX Swap Lend*), which takes the difference between foreign currency assets and foreign currency liabilities:

$$\textit{Total FX Swap Lend} = \textit{FC Total Assets - FC Total Liabilities.} \tag{A1}$$

Assuming that U.S. GSIBs fully hedge the currency risk of its assets and liabilities, then the gap between foreign currency assets and liabilities on balance sheets must be matched by dollar lending in the FX swap market off-balance sheets. Similar measures have been used in the literature to measure non-US banks' dollar borrowing in the FX swap market (for example, McGuire and Von Peter (2009) and Fender and McGuire (2010)). Compared to *Short-Term FX Swap Lend*, *Total FX Swap Lend* also capture long-term dollar lending in

[1] Daily triparty repo volume was around \$2.2 trillion and GCF repo was around \$700 billion at the end of 2018, according to the Federal Reserve Bank of New York. Additionally, sizable bilateral repo borrowings also make up a large part of the banks' repo exposure.

the FX swap market. Table A8 shows that the regression results based on the alternative FX lend measure are very similar to those based on our benchmark short-term FX-lending measure.

To assess whether U.S. GSIBs indeed hedge the foreign currency funding gap, we note that U.S. bank supervisors do not systematically collect data on the FX derivatives exposure by currency for banks' banking book. However, the FX swap exposure on banks' trading book can be inferred from the FR Y14Q *Capital Assessment and Stress Testing* form. We show that the foreign currency funding gap is directionally in line with the estimated FX swap exposure for long dollar positions in banks' trading books.

Figure A4 plots the foreign currency funding gap for the four major currencies, and our estimated FX swap exposure in the bank's trading book based on information included in the FR Y-14 data. We can observe that a positive foreign currency funding gap in euros, yen and sterling is indeed matched by a short position in the foreign currency and a long position in dollars in the FX swap market. Since the FR Y-14 data only capture FX swap exposure in the trading book, it is not surprising that these exposures are lower than the overall foreign currency funding gap. In the case of the euro, the correlation between the overall euro funding gap and the estimated short-euro-long-dollar FX swap position in the trading book is about 70%.

C Fluctuations in the Fed SOMA portfolio

Fluctuations in the Fed SOMA portfolio also affect dollar funding conditions. In our sample, between October 2017 and August 2019, the Federal Reserve reduced its Treasury holdings at the rate of $35 to $50 billion a month, a process known as the balance sheet normalization. A reduction in the SOMA's Treasury holdings corresponds to a reduction in the overall reserve balance for the banking system and an increase in the Treasury securities held by financial market participants, likely increasing financing needs and tightening funding conditions.

We now add the daily changes in the SOMA holdings into our benchmark price and quantity regressions (Tables 1 and 2). Table A6 shows the regression table for intermediation spreads. We can see that the changes in the SOMA portfolio, captured by the coefficient on $\Delta SOMA_t$, are generally negatively correlated with dollar intermediation spreads. As the Fed decreased the size of its SOMA portfolio (negative $\Delta SOMA_t$), intermediation spreads increased.

Table A7 shows the regression for U.S. GSIBs' intermediation activities. An increase in $\Delta SOMA_t$ generally works in the opposite way as an increase in the TGA balance, as an increase in $\Delta SOMA_t$ increases overall bank reserves and eases overall funding condition.

U.S. banks provide less dollar intermediation in response to an increase in $\Delta SOMA_t$ through an increase in reserve holdings and a reduction in net reverse repo lending and FX swap lending.[2]

D Intraday rate movements during the September 2019 event

This section describes the intraday movements in several rates during the September 16 and 17 event shown in Figure 12.

Even though the GC repo rate spiked to its high on Tuesday September 17, the repo market was already experiencing significant strains on Monday after the TGA balance increase. The morning of Monday, September 16th started with elevated but orderly secured funding rates. Both GC repo and FX implied dollar rate were trading around 2.5%, which is around 20 basis points higher than the previous trading day's close and 40 basis points higher than the interest on reserve. The bid-ask spread in FX swapped dollar funding was also relatively tight. The GC repo rate increased steadily throughout the day peaking around 4.5% (mid) by late afternoon, when the market closed for the day. The timing of the repo rate increase in late morning and early afternoon suggests that auction settlement-related financing is likely a driver of the repo rate increase.[3]

The elevated secured funding rates carried over to Tuesday from the day before. Despite the lack of additional Treasury settlement or tax payment on Tuesday (the TGA balance only increased by $8 billion on Tuesday), the GC repo borrowing rate quickly increased to a high of 10% by early-morning, when the bulk of the repo volume occurs, and the FX-implied funding rate reacted in lock step. Shortly after 9 a.m, the Federal Reserve Bank of New York announced that it would conduct repo operations and ultimately lent $53 billion to primary dealers in overnight repo. The secured funding rates declined sharply thereafter.

[2] We note that in our sample, the Fed reduced its balance sheet only on Treasury auction dates by not fully rolling over the maturing debt in its existing holdings. The coefficients on $\Delta SOMA_t$ are rather imprecisely estimated because $\Delta SOMA_t$ are equal to zero for most of the sample dates.

[3] Since the repo market starts trading early in the morning, a large fraction of trades were done before 9 a.m., around this time, $78 of new treasury issuance was settled through the Bank of New York Mellon (BNYM) (Since 2017, BNYM has been the sole provider of U.S. government securities settlement and triparty repo services for broker-dealers.). Primary dealers typically draw down or overdraft their clearing accounts at BNYM to fund the treasury settlement, and, over the course of the day, these dealers sell the new bonds in exchange for cash to "refill" their clearing account by 3:30 pm (Pozsar, 2019). A fraction of the newly issued treasury bonds were sold off to real-money investors, and the remaining portion of the new issuance were bought by levered investors or remained in dealer's inventory, both of which required repo financing.

E Dealer security financing needs

In this section, we present suggestive evidence that dealers' own security financing needs also contributed to the September 2019 liquidity crunch in addition to the breakdown of reserve-based intermediation.

Decomposing the balance sheet shifts by subsidiary, we find that the decline in reserves in depository institutions coincided with an increase in repo borrowing by the broker-dealer affiliates to finance the holdings of Treasury securities. Dealer accumulation of Treasury securities is likely related to reduced demand from real money institutions at Treasury auctions as the Treasury yield curve flattened and inverted throughout this period. Figure A7 shows that these broker-dealer reached their highest level of external repo financing (net reverse repo reached their lowest level) immediately prior to the repo rate spike. This financing need coincided with an increase in primary dealers' accumulation of coupon securities throughout 2018 and early 2019, as shown in Figure A8.[4]

Two additional trends that are typically associated with funding strains also emerged around the same time. First, broker-dealer were increasingly reliant on worse collaterals to finance their borrowings. Panel A in Figure A9 shows that broker-dealers have historically net lend out cash against Treasurys collateral, but net borrowed cash against non-Treasury collaterals. In 2019, broker-dealers reduced the net lending collateralized by Treasurys and increased the reliance on funding using non-Treasurys as collateral. An increasing fraction of the borrowing were backed by equities and Government Sponsored Enterprise (GSE) bonds. Second, dealers became more engaged in maturity transformation in 2019. Panel B in Figure A9 shows that while dealers continue to net lend the same amount of termed repo with maturity greater than one-week, they have started to borrow with short maturity repo contracts. Dealers became net borrowers of short-maturity repo, as opposed to net lender in earlier period.

The maturity and collateral mismatch observed in 2019 bear resemblance to the hallmarks of broker-dealer's repo financing just prior to the financial crisis. The key difference is that this time, the funding pressure arises from the need to finance Treasury securities, rather than illiquid securities.

F Outright Treasury holdings vs. repo-financed Treasury holdings

As noted previously, the six U.S. GSIBs in our sample have broker-dealer subsidiaries that are designated primary dealers for Treasury securities. Primary dealers are required to

[4] Primary dealers shown in Figure A8 include dealers beside those affiliated with the six GSIBs.

participate in all Treasury auctions and are the direct counterparties of the Fed to purchase Treasury securities during the Fed balance sheet taper. In this subsection, we provide a closer look at Treasury holdings' of the U.S. GSIBs.

In our previous analysis, we examined the response of outright holdings of Treasury securities in the dollar funding shortage. In addition, U.S. GSIBs can also change their Treasury holdings financed via repos. We measure the amount of repo-financed Treasury holdings as the amount of "non-rehypothecated" repo positions backed by U.S. Treasury collateral.[5] More details on the stylized facts and drivers of collateral-reuse based on FR 2052a data are discussed in Infante, Press and Saravay (2020) and Infante and Saravay (2020).

Table A9 shows the regression results for repo-financed Treasury holdings. We find that U.S. GSIBs' repo-financed Treasury holdings increase with the net issuance of Treasury securities and decrease with Fed SOMA portfolio holdings. Together with the outright Treasury holdings, for each \$100 billion increase in the Treasury net issuance, U.S. GISBs increase their total Treasury holdings by \$7 billion, half of which is through outright holdings and the other half is through repo-financing. The effect of Fed's balance sheet taper on U.S. GSIBs' Treasury holdings is significantly larger. For each \$100 billion taper of the SOMA portfolio, U.S. GSIBs increase Treasury holdings by \$30 billion, \$12 billion of which is through outright holdings and \$18 billion of which is through repo-financing. The amount of U.S. GSIBs' own Treasury financing needs could help explain the large price effects of $\Delta SOMA$ on various repo spreads in Tables A6.

G Different Component of TGA Fluctuations

Table A1 shows regression results for intermediation spreads. We can see that an increase in the overall Treasury net issuance, ΔTSY_t^{Tsy}, significantly increases all types of repo intermediation spreads. The effect of ΔTSY_t^{Tsy} on the FX swap spread is not statistically significant. In contrast, the TGA increase unrelated to Treasury issuance, ΔTGA_t^{Other}, primarily raises FX swap intermediation spreads. The differential pricing response to ΔTSY_t^{Tsy} and ΔTSY_t^{Other} highlights the different nature of these funding demands.

Table A2 shows the analogous quantity regressions for intermediation activities. An increase in ΔTGA_t^{Tsy} is associated with a significant increase in U.S. banks' reverse repo lending, a largely unchanged repo position, and thus, a significant increases in net reverse repo lending (columns 2-4). The increase in the net issuance of Treasury securities has little

[5] In contrast, if the Treasury-backed repo position is "rehypothecated", the bank re-pledges the Treasury collateral and no longer possesses the Treasury securities.

effect on FX lending (column 5). Overall, U.S. GSIBs run down reserves (column 1) and provide more repo lending to clients in response to the net issuance of Treasury securities.

The effects of ΔTGA^{Other} on intermediation activities are somewhat different. U.S. GSIBs contract both repo and reverse repo positions by a similar magnitude, leaving the net reverse repo position roughly unchanged (columns 2-4). However, U.S. GSIBs increase their dollar liquidity provision in the FX swap market significantly (column 5). This increase in FX swap lending is mainly financed via reserve-draining (column 1). Meanwhile, U.S. GSIBs experience deposit outflows (column 6) in these episodes, which likely reflect a transfer from depositors' accounts to the TGA account due to tax payments. However, the magnitude of the deposit outflow is significantly smaller than the reduction in the reserve balance, suggesting that reserves fall beyond a simple passive cash transfer between depositors and the TGA.

As discussed in Section 4.3.3, among all the TGA fluctuations, daily fluctuations related to Treasury issuance and redemption (ΔTGA_t^{Tsy}) are perfectly anticipated, whereas daily fluctuations in the other TGA component related to taxes and expenditure (ΔTGA_t^{Other}) may not be fully anticipated. We now show that *anticipated* TGA fluctuations unrelated to Treasury issuance and redemption are also driving a large part of our main results for intermediation spreads and U.S. GSIBs' intermediation activities.

To calculate the anticipated TGA fluctuations due to taxes and expenditure, we use daily forecasts for the TGA balance provided by Wrightson ICAP, a leading provider for U.S. fixed-income analysis with a wide readership among market participants. Starting in late 2017, Wrightson ICAP began to provide daily forecasts of the TGA balance for every business day in the following month. Separate forecasts are provided for TGA fluctuations related to the marketable Treasury debt and other components. We decompose the non-Treasury component of the TGA fluctuations into an anticipated (by Wrightson ICAP) and an unanticipated part as follows:

$$
\begin{aligned}
TGA_t^{Other} - TGA_{t-1}^{Other} &= \underbrace{(\widetilde{TGA}_{t-1}^{Other(t)} - TGA_{t-1}^{Other})}_{\text{Anticipated}} + \underbrace{(TGA_t^{Other} - \widetilde{TGA}_{t-1}^{Other(t)})}_{\text{Unanticipated}}, \\
&\equiv \Delta TGA_t^{Other-F} + \Delta TGA_t^{Other-UF}
\end{aligned}
$$

where $\widetilde{TGA}_{t-1}^{(t)}$ denotes Wrightson ICAP's forecast for the TGA balance at t forecasted at $t-1$. Therefore, $\Delta TGA_t^{Other-F}$ measures the difference between the TGA forecast for t forecasted at $t-1$ and the actual TGA balance at $t-1$, which is fully forecastable, and $\Delta TGA_t^{Other-UF}$ measures the difference between actual TGA balance at t and the previously forecasted balance, and therefore an unanticipated TGA shock. Therefore, we can now decompose TGA fluctuation into three components: Treasury-related, other forecastable, and other non-forecastable:

$$\Delta TGA_t = \Delta TGA_t^{Tsy} + \Delta TGA_t^{Other-F} + \Delta TGA_t^{Other-UF},$$

Tables A3 regresses daily changes in the same set of intermediation spreads as in Table A1 on the three components of the TGA fluctuations. In line with results in Table A1, we can see that the Treasury-related component drives daily changes in the repo spreads in Columns 1-4. Other components of TGA fluctuations affect FX swap spreads more. Interestingly, it is the forecastable component of other TGA fluctuations ($\Delta TGA_t^{Other-F}$) driving most of results for FX swap spreads. Similarly, Table A4 show that this forecastable component $\Delta TGA_t^{Other-F}$ is also correlated with repo and FX intermediation activities.

H Price-Quantity Relationships for Repo and FX Swap Market Lending

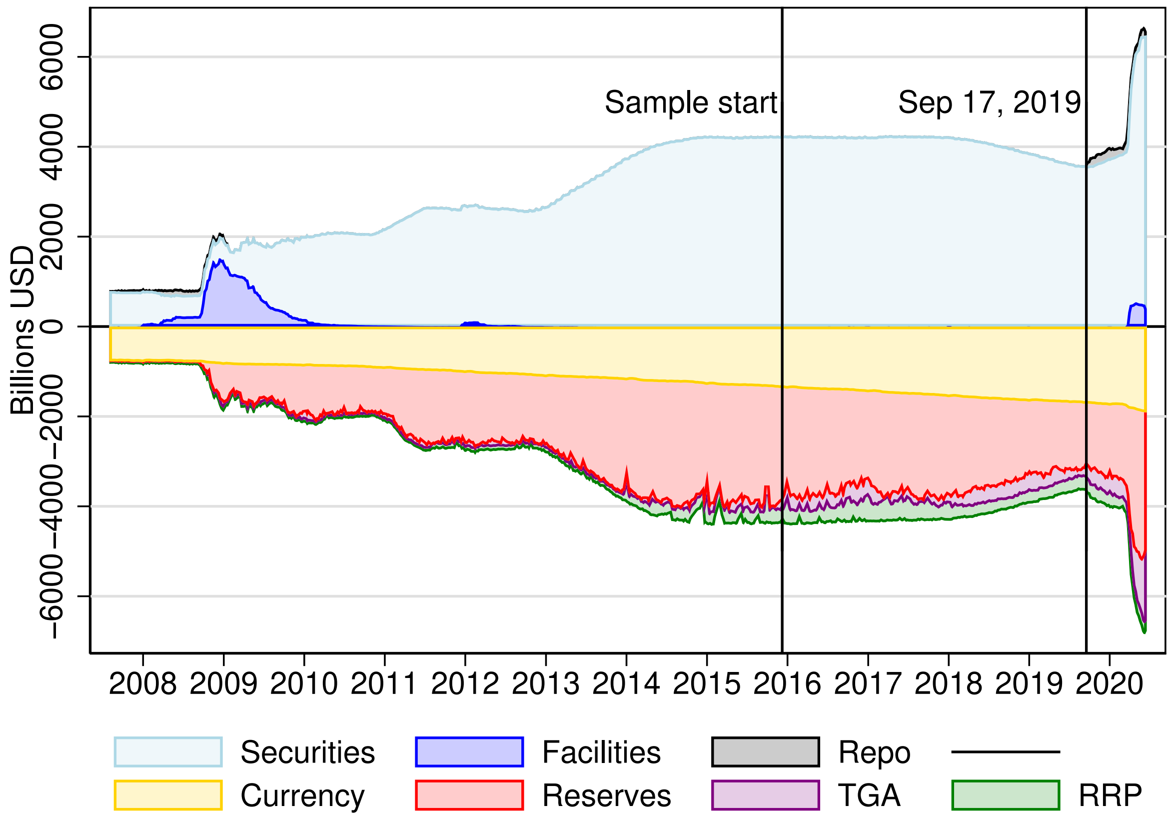
We have so far presented the price and quantity response to quarter-ends and TGA fluctuations separately. We now discuss the joint price-quantity relationship implied from these estimates. Since these are reduced-form estimates, we do not formally interpret our results as price elasticities of dollar liquidity supply. However, these price-quantity relationships are nevertheless useful to shed light on some quantitative differences in the U.S. GSIBs' reserve-draining activities in the repo and FX swap markets.

In particular, on quarter-ends, we observe a 12.9 basis point increase in the SOFR-IOR spread and a 137 basis point increase in the USD-EUR FX swap spread (Table 1), and at the same time, we also observe a \$40 billion increase in U.S. GSIBs' net repo lending and \$20 billion increase in FX swap market lending financed with a decrease in reserves (Figure 8). Taking these results together, we infer a \$3.1 billion increase in net repo lending in response to a 1 basis point increase in the repo intermediation spread on quarter-ends ($3.1 = 40/12.9$). Similarly, we assess a \$0.15 billion increase in FX swap market lending in response to a 1 basis point increase in the FX swaps intermediation spread on quarter-ends ($0.15 = 20/137$). In response to TGA fluctuations, our results imply a \$0.84 billion increase in repo lending in response to a 1 basis point increase in the repo intermediation spread and a \$0.12 billion increase in FX swap market lending in response to a 1 basis point increase in the FX swap intermediation spread.[6]

Therefore, on both quarter-ends and days with large TGA increases, U.S. GSIBs' reserve-draining activities react to repo intermediation spreads more aggressively. The more muted response to the FX swap spreads likely reflects additional balance sheet constraints due to the cross-jurisdictional nature of the FX swap lending).

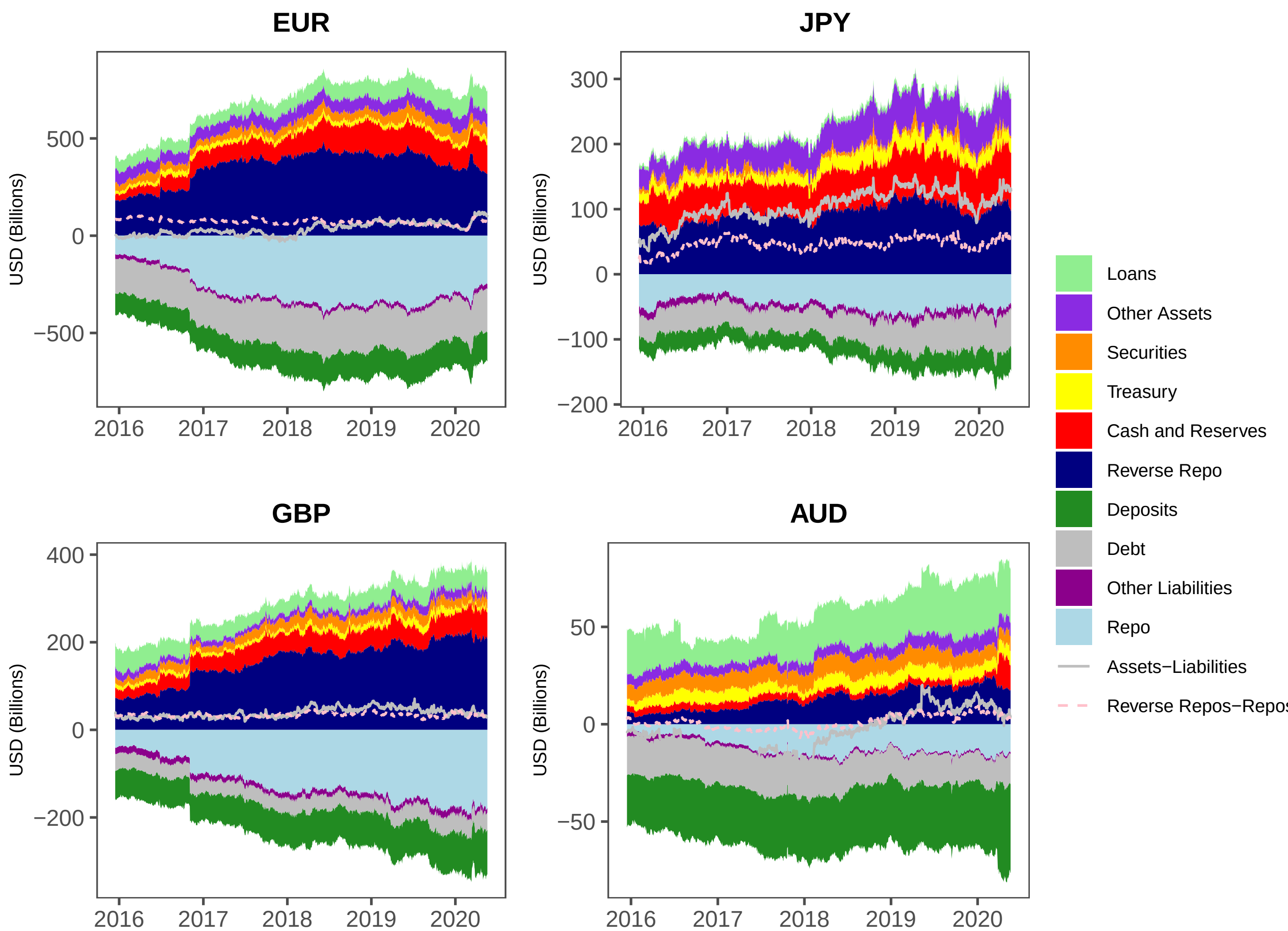
[6]Tables 1 and 2 imply that a 10 billion increase in TGA increases the SOFR-IOR spread by 0.46 basis points and increases net repo lending by \$0.37 billion, so this leads to a $0.37/0.46 = 0.84$ billion response per basis point change in the spread. Meanwhile, we find that a \$10 billion increase in the TGA increases the USD-EUR FX swap spread by 2.65 basis point and increases the FX swap market lending by \$0.31 billion, which implies $0.31/2.65 = 0.12$ billion response per basis point change in the spread.

Figure A1: Evolution of the Federal Reserve Balance Sheet Post-GFC



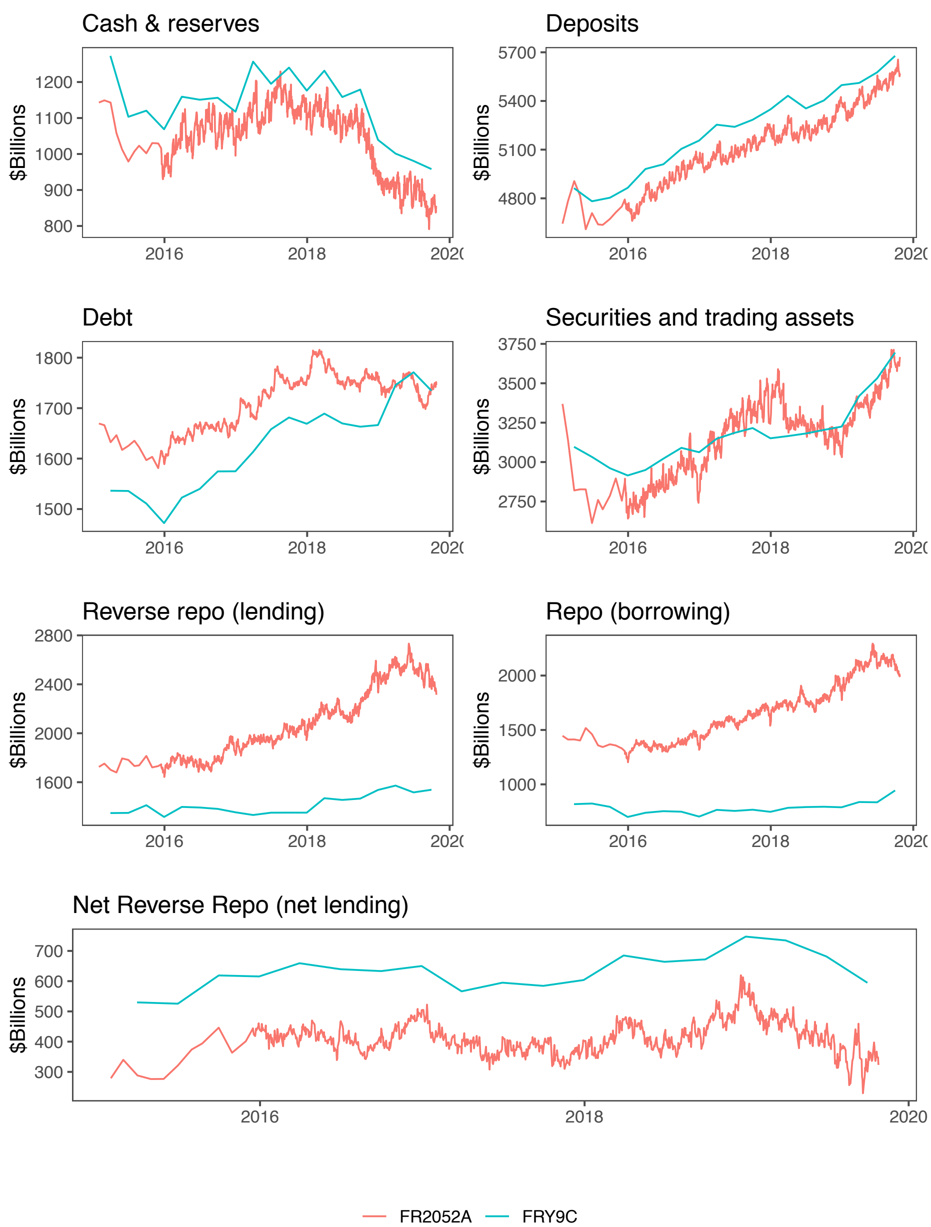
Notes: This figure plots major assets and liability items of the Federal Reserve post-GFC. "Securities" refers to outright securities holdings, "Facilities" denotes liquidity facility, including central bank swap lines; "Repo" denotes the repo facility; "Currency" denotes currency in circulation; "Reserves" denotes total bank reserves; "TGA" denotes the Treasury general account; and "RRP" denotes the reverse repo facility.

Figure A2: U.S. GSIBs balance sheet in other currencies



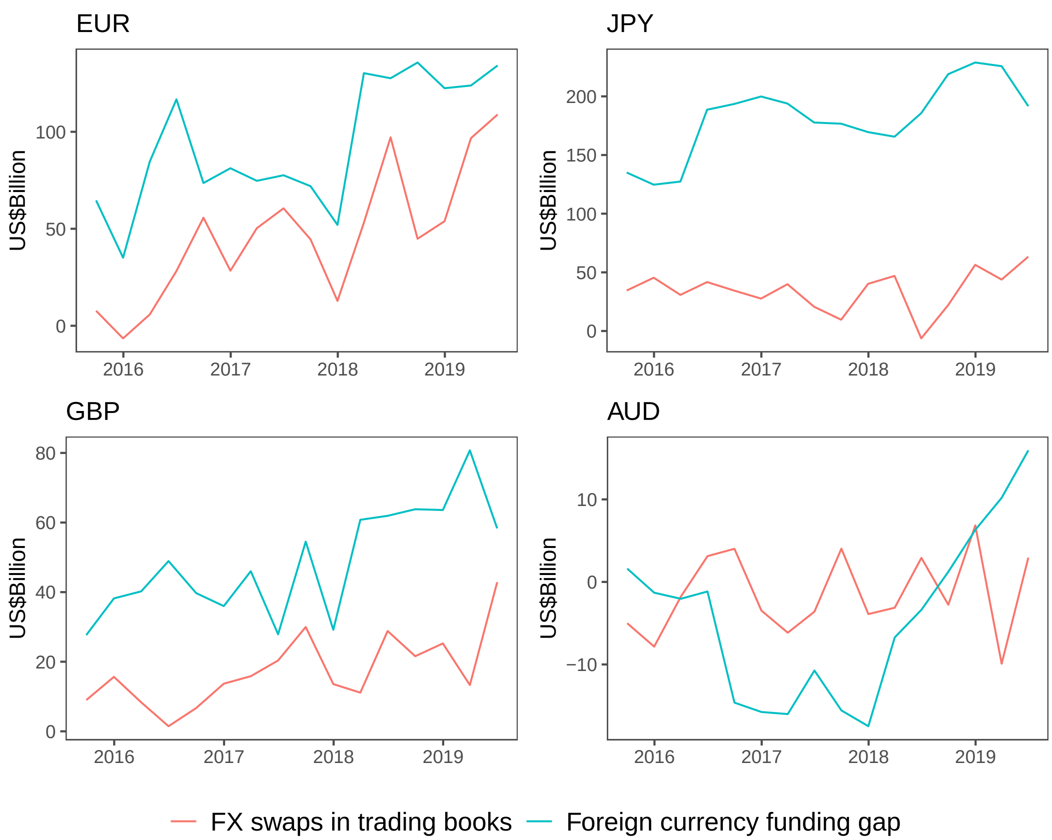
Notes: This figure presents the aggregate balance sheet for six U.S. GSIBs for items denominated in euros (EUR), Japanese Yen (JPY), British pounds (GBP), and Australian dollars (AUD) based on the FR 2052a data. Items above zero are classified as assets and those below zero as liabilities. The solid line represents the difference between total assets and total liabilities, while the dashed line measures the net repo position of these banks. The sample period expands from December 2015 until May 2020.

Figure A3: Comparison of FR 2052a and FR Y-9C



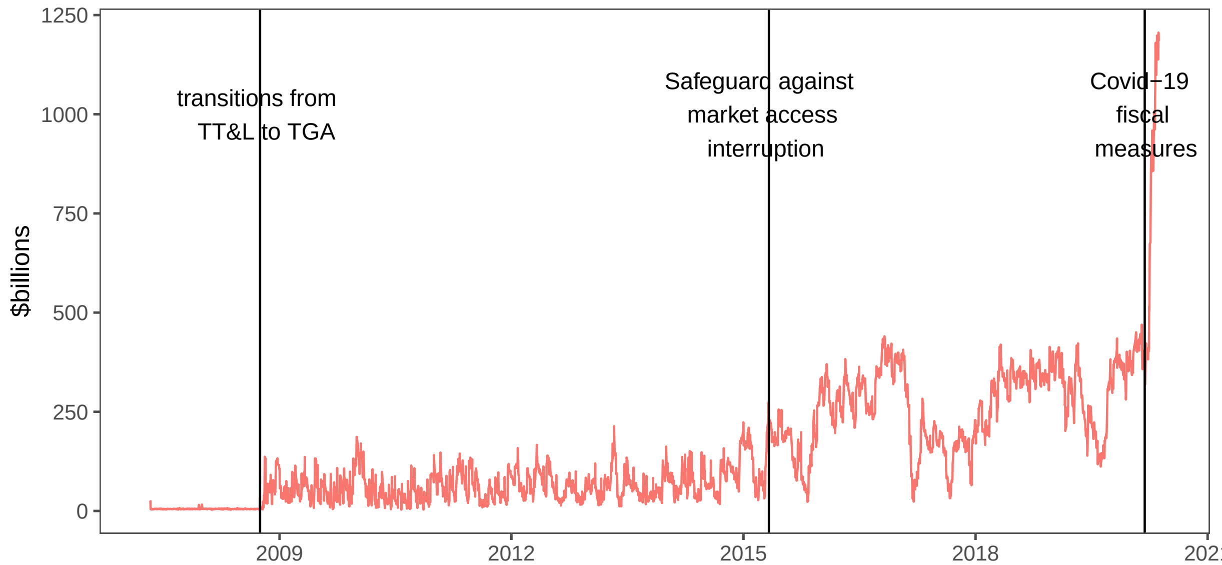
Notes: This figure provides a comparison between the balance sheet items constructed from various inflow and outflow product categories in FR 2052a and the reported balance sheet items in FR Y9-C.

Figure A4: U.S. GSIBs funding gaps by currency and FX swaps



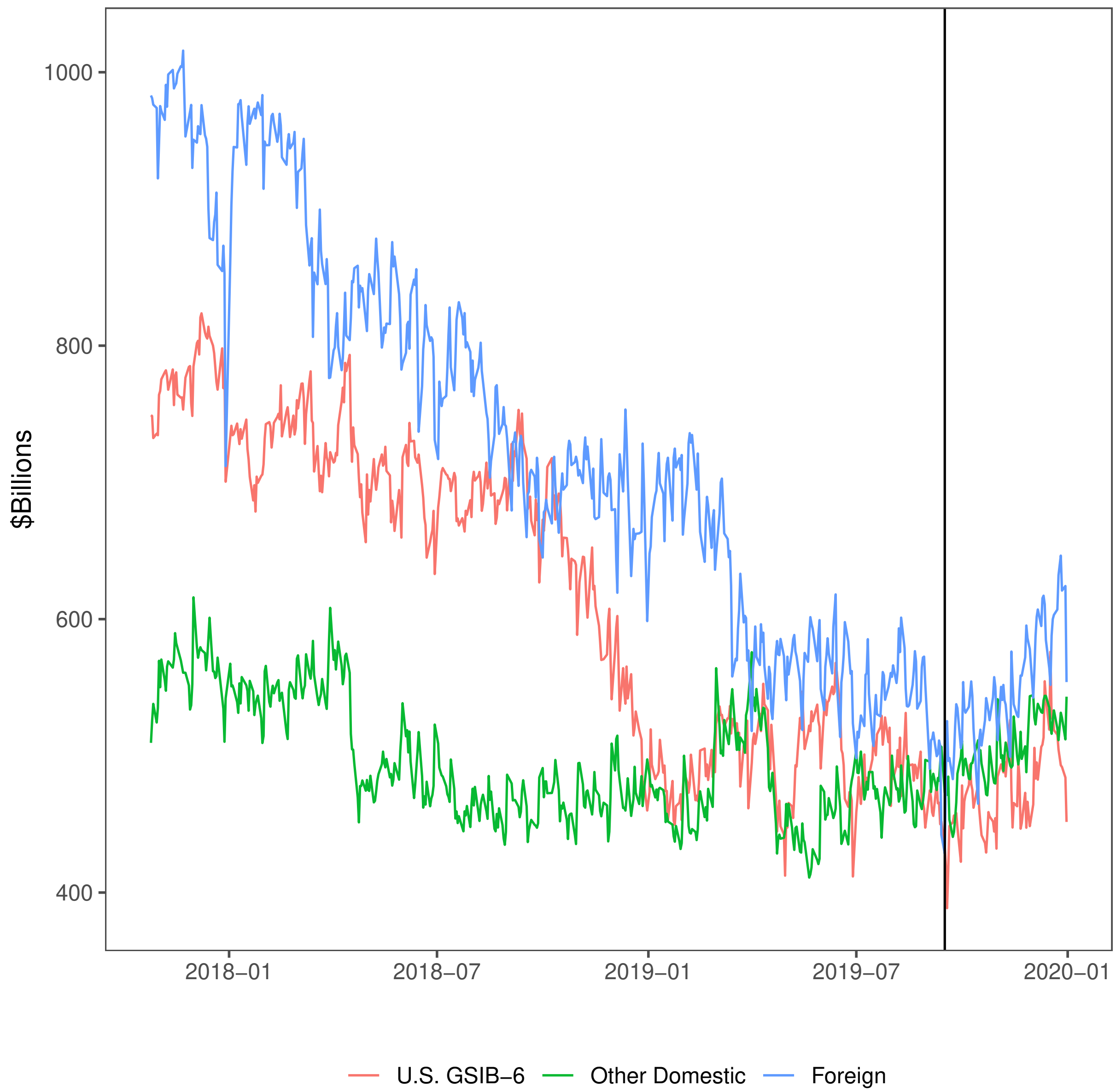
Notes: This figures shows the quarterly foreign currency funding gap as the difference between foreign currency assets and liabilities for U.S. GSIBs in blue based on the FR 2052a data for the EUR, JPY, GBP and AUD. The red line shows and the estimated FX swap exposure that goes long in dollars and short in the respective foreign currency from the Y14 data.

Figure A5: Fluctuations in the Treasury General Account Balance



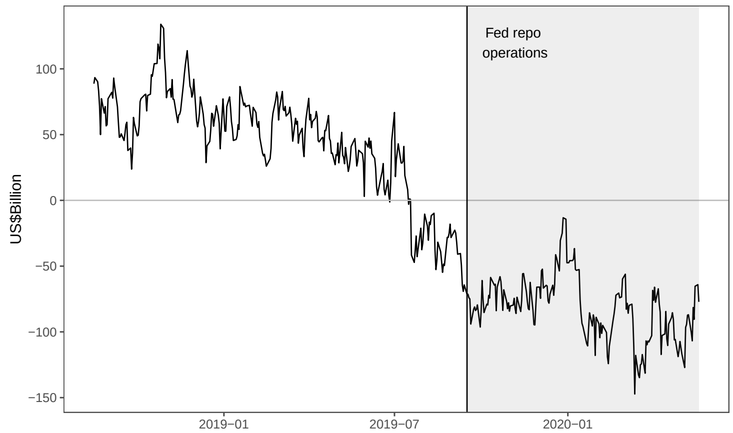
Notes: This figure shows time series of the Treasury General Account (TGA) balance. Prior to 2009, the U.S. Treasury they held most of its balances in commercial banks through the Treasury Tax and Loan Program. In May 2015, the Treasury expanded its TGA balance to protect against a potential interruption in market access. In March 2020, Increased fiscal spending relating to the COVID-19 pandemic further prompted large increase in the TGA account.

Figure A6: Dollar reserves by bank holding company entity type



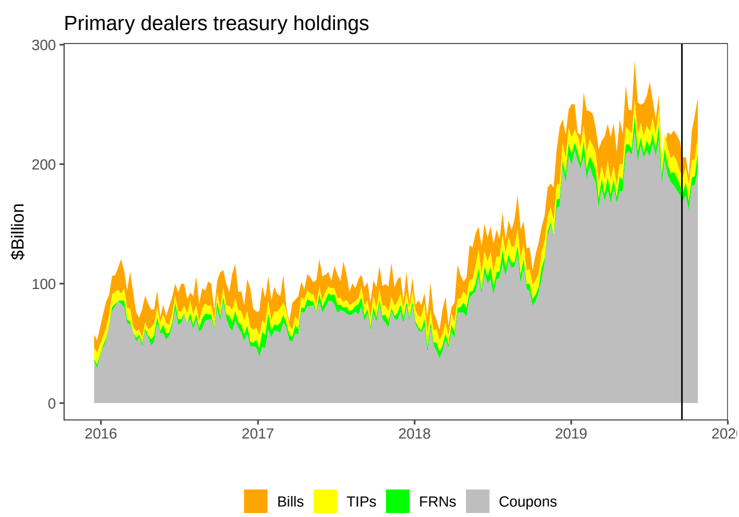
Notes: This figure shows the distribution of total reserve balances across different types of banks The blue line shows the reserve balances of the U.S. GSIBs in our sample. The red line shows the reserve balances of other U.S. banks. The green line shows the reserve balances of foreign banks. The vertical line denotes September 16, 2019.

Figure A7: Broker-dealer dollar net reverse repo



Notes: This figure shows the net reverse repo position (reverse repos minus repos) denominated in dollars for the broker-dealer entities of U.S. GSIBs in our sample. The shaded area denotes the period since the Fed introduced the repo facility on September 17, 2019.

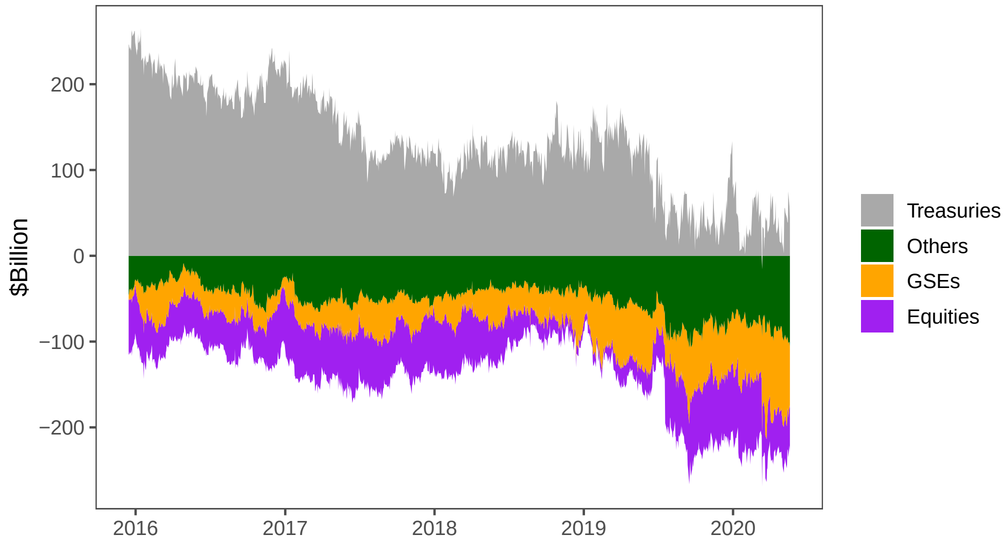
Figure A8: Prime dealers treasury holdings



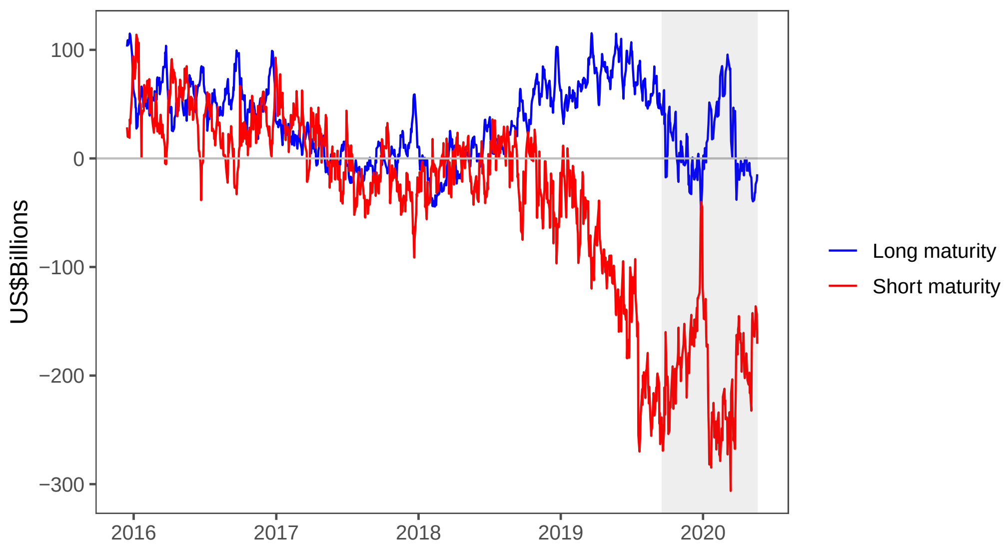
Notes: This figure shows the net Treasury holdings for all prime dealers (including primary dealers within our sample U.S. GSIBs and all other primary dealers). The data is from weekly public release of FR 2004 filings.

Figure A9: Broker-dealer dollar net reverse repo by collateral and maturity

(A) Collateral breakdown

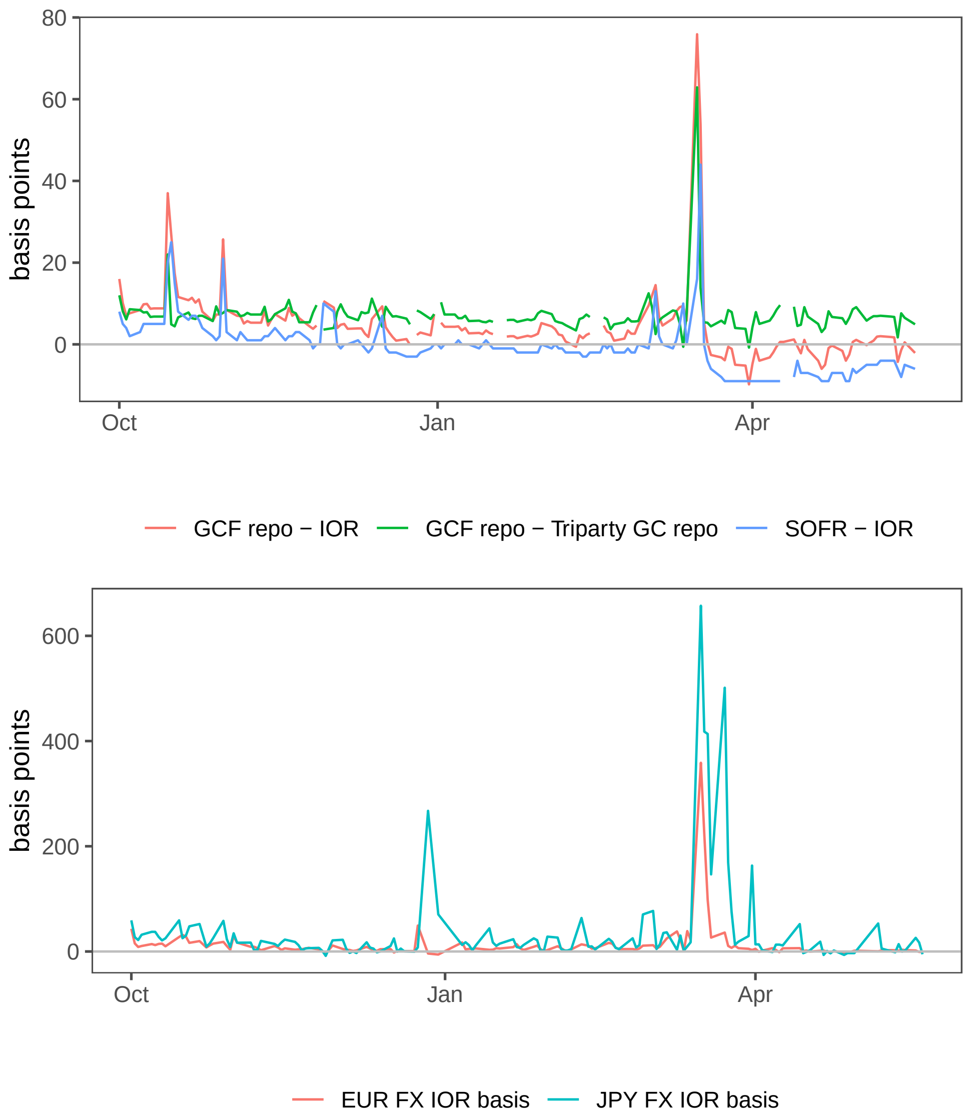


(B) Maturity breakdown:



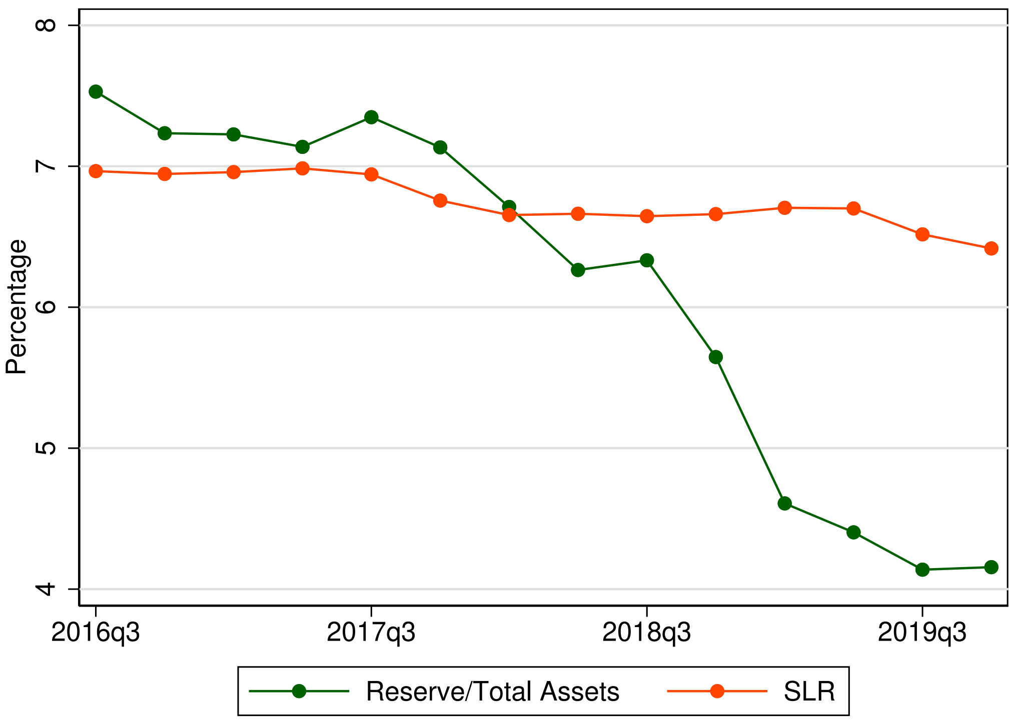
Notes: Panel (A) shows collateral breakdown of the net reverse repo position for the broker-dealer entities of the U.S. GSIBs. For a given collateral type, a positive number indicates that the broker-dealers are lending more than borrowing against the collateral. Panel (B) shows the maturity breakdown of the net reverse repo position for the broker-dealer entities of the U.S. GSIBs. Long-maturity refers to contracts with maturity greater than one week, and short-maturity refers to contracts with maturities of one week or less.

Figure A10: Dollar Funding Spreads Since September 2019



Notes: This figure shows the funding spreads since post the repo rate spike in September 2019. In the top panel, we plot the spread between the GCF general collateral Treasury repo rate and interest on excess reserve (IOR) at the Federal Reserve ("GCF repo-IOR"), the spread between the GCF and Triparty Treasury general collateral repo spread ("GCF Repo - Triparty GC Repo Spread"), and the spreaad between the Secured Overnight Financing Rate (SOFR) and the IOR ("SOFR-IOR"). In the bottom panel, we plot the spread of the implied dollar funding rate by swapping the ECB deposit rate over the Fed IOR ("EUR FX IOR basis"), and the spread of the implied dollar funding rate by swapping the BOJ deposit rate over the Fed IOR ("JPY FX IOR basis").

Figure A11: Reserve-Asset Ratio vs. SLR



Notes: This figure plots the average reserve to total asset ratio and the average SLR across our 6 U.S. GSIBs. The SLR was first published in 2016Q3.

Table A1: Impacts of Different Components of TGA Fluctuations on Intermediation Spreads

	(1) $\Delta SOFR-IOR$	(2) $\Delta GCF-IOR$	(3) $\Delta TGCR-IOR$	(4) $\Delta GCF-TGCR$	(5) $\Delta EURIOR$	(6) $\Delta JPYIOR$
ΔTGA_t^{Tsy}	0.10***	0.16***	0.083***	0.075***	0.085	0.15
	(0.012)	(0.021)	(0.010)	(0.018)	(0.067)	(0.17)
ΔTGA_t^{Other}	0.016	0.023	0.015	0.0086	0.34***	0.66***
	(0.0099)	(0.017)	(0.0092)	(0.014)	(0.079)	(0.21)
$Qend_t$	11.1***	29.0*	7.07**	21.9*	142.3**	426.0***
	(3.21)	(15.8)	(3.14)	(13.1)	(60.3)	(117.7)
$Qstart_t$	-8.41***	-24.2**	-4.18**	-20.0	-136.3*	-263.1***
	(3.23)	(12.3)	(1.94)	(13.6)	(75.4)	(99.1)
Constant	-0.31**	-0.52***	-0.25**	-0.26**	1.03	-0.63
	(0.12)	(0.17)	(0.10)	(0.13)	(0.65)	(2.10)
N	933	930	933	930	902	837
R^2	0.24	0.20	0.17	0.14	0.22	0.36

Notes: This table shows the regression results of different components of TGA fluctuations and the quarter-end dummies on daily changes in various intermediation spreads. The dependent variables are as follows: daily changes in the SOFR–IOR spread (Column 1), daily changes in the GCF repo–IOR spread (Column 2), daily changes in the Triparty (TGCR) repo–IOR spread (Column 3), daily changes in the GCF–TGCR repo spread (Column 4), daily changes spread between the overnight implied dollar rate by swapping the ECB deposit rate and the Fed IOR (Column 5), and daily changes in the spread between the overnight implied dollar rate by swapping the BOJ deposit rate and the Fed IOR (Column 6). The independent variables are as follows: ΔTGA_t^{Tsy}, net treasury issuance; ΔTGA_t^{Other}, daily changes in TGA balance unrelated to net Treasury issuance; $Qend_t$, a dummy variable indicating the last business day of the quarter; and $Qstart_t$ a dummy variable indicating the first business day of the quarter. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A2: Impacts of Different Components of TGA Fluctuations on Intermediation Activities

	(1) ΔRSV_t	(2) ΔRRP_t	(3) ΔRP_t	(4) $\Delta NRRP_t$	(5) ΔFX_t	(6) $\Delta Deposit_t$	(7) $\Delta TSY_t^{outright}$
ΔTGA_t^{Tsy}	-0.11**	0.15***	0.00027	0.15***	0.011	0.16***	0.043***
	(0.053)	(0.041)	(0.034)	(0.037)	(0.019)	(0.046)	(0.014)
ΔTGA_t^{Other}	-0.22***	-0.14***	-0.12***	-0.023	0.041***	-0.14***	0.069***
	(0.045)	(0.029)	(0.026)	(0.028)	(0.014)	(0.044)	(0.012)
$Qend_t$	-29.0***	-11.5*	-31.7***	20.2***	11.4***	-3.51	3.84
	(7.37)	(6.50)	(4.75)	(4.95)	(3.16)	(4.10)	(2.86)
$Qstart_t$	38.1***	-2.70	1.91	-4.61	-7.10**	32.4***	0.020
	(5.20)	(5.46)	(4.32)	(4.72)	(3.23)	(4.22)	(1.48)
Constant	-0.94	-0.53	0.32	-0.85**	0.22	-0.78	0.20
	(0.63)	(0.48)	(0.42)	(0.41)	(0.23)	(0.65)	(0.21)
N	932	932	932	932	932	932	932
R^2	0.14	0.051	0.11	0.082	0.065	0.088	0.046

Notes: This table shows regression results of one-day changes in the net treasury issuance (ΔTGA_t^{Tsy}), and changes in the TGA account unrelated to net Treasury issuance (ΔTGA_t^{Other}) on daily changes in the U.S. GSIBs intermediation activities. The dependent variables are as follows: changes in reserves (Column 1), changes in dollar reverse repos (Column 2), changes in dollar repos (Column 3), changes in net dollar reverse repos, or the difference between reverse repos and repos in dollars (Column 4), changes in dollar lending in the FX swap market (Column 5), changes in dollar deposits (Column 6), and changes in outright Treasury holdings (Column 7). $Qend_t$ is a dummy variable indicating the last business day of the quarter, and $Qstart_t$ is a dummy variable indicating the first business day of the quarter. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A3: Impacts ICAP TGA Forecasts on Intermediation Spreads

	(1) $\Delta SOFR-IOR$	(2) $\Delta GCF-IOR$	(3) $\Delta TGCR-IOR$	(4) $\Delta GCF-TGCR$	(5) $\Delta EURIOR$	(6) $\Delta JPYIOR$
ΔTGA_t^{Tsy}	0.13***	0.24***	0.13***	0.11**	0.077	0.29*
	(0.019)	(0.057)	(0.018)	(0.055)	(0.049)	(0.16)
$\Delta TGA_t^{Other-F}$	0.025	-0.0096	0.024	-0.033	0.16***	0.59**
	(0.016)	(0.039)	(0.016)	(0.037)	(0.047)	(0.28)
$\Delta TGA_t^{Other-UF}$	0.058	0.42*	0.054	0.37*	0.13	-0.52
	(0.048)	(0.23)	(0.048)	(0.22)	(0.11)	(0.57)
$Qend_t$	16.0**	45.2	14.9**	30.2	43.0**	560.0**
	(6.59)	(35.5)	(5.98)	(30.0)	(16.7)	(226.1)
$Qstart_t$	-5.05	-35.6	-6.17	-29.5	-37.9**	-489.9**
	(4.58)	(28.4)	(4.60)	(32.7)	(16.1)	(199.3)
Constant	-0.54**	-1.12***	-0.47**	-0.63*	0.44	-0.64
	(0.22)	(0.39)	(0.22)	(0.35)	(0.60)	(2.53)
N	402	399	402	399	384	358
R^2	0.28	0.25	0.26	0.16	0.24	0.55

Notes: This table shows the regression results of different components of TGA fluctuations and the quarter-end dummies on daily changes in various intermediation spreads. The dependent variables are as follows: daily changes in the SOFR–IOR spread (Column 1), daily changes in the GCF repo–IOR spread (Column 2), daily changes in the Triparty (TGCR) repo–IOR spread (Column 3), daily changes in the GCF–TGCR repo spread (Column 4), daily changes spread between the overnight implied dollar rate by swapping the ECB deposit rate and the Fed IOR (Column 5), and daily changes in the spread between the overnight implied dollar rate by swapping the BOJ deposit rate and the Fed IOR (Column 6). The independent variables are as follows: ΔTGA_t^{Tsy}, net treasury issuance; $\Delta TGA_t^{Other-F}$, the forecastable component (by Wrightson ICAP) of daily changes in TGA balance unrelated to net Treasury issuance; $\Delta TGA_t^{Other-UF}$, the unforecastable component (by Wrightson ICAP) of daily changes in TGA balance unrelated to net Treasury issuance; $Qend_t$, a dummy variable indicating the last business day of the quarter; and $Qstart_t$ a dummy variable indicating the first business day of the quarter. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01. ***p<0.01.

Table A4: Impacts ICAP TGA Forecasts

	(1) ΔRSV_t	(2) ΔRRP_t	(3) ΔRP_t	(4) $\Delta NRRP_t$	(5) ΔFX_t	(6) $\Delta Deposit_t$	(7) $\Delta TSY_t^{outright}$
ΔTGA_t^{Tsy}	-0.27***	0.25***	-0.021	0.27***	0.052**	0.14**	0.045**
	(0.070)	(0.059)	(0.048)	(0.046)	(0.024)	(0.061)	(0.018)
$\Delta TGA_t^{Other-F}$	-0.21***	-0.17***	-0.15***	-0.021	0.051***	-0.13**	0.046***
	(0.062)	(0.045)	(0.042)	(0.042)	(0.019)	(0.052)	(0.016)
$\Delta TGA_t^{Other-UF}$	-0.36**	-0.15	-0.066	-0.083	-0.00100	-0.48***	0.0096
	(0.17)	(0.13)	(0.12)	(0.11)	(0.060)	(0.18)	(0.053)
$Qend_t$	-31.1***	-19.0*	-30.1***	11.1	15.2***	-6.61	1.46
	(9.62)	(10.6)	(10.0)	(6.82)	(4.63)	(4.39)	(4.35)
$Qstart_t$	30.5***	11.7*	4.10	7.56	-13.2**	29.4***	-2.02
	(8.42)	(6.12)	(9.67)	(6.77)	(5.54)	(9.15)	(2.02)
Constant	-0.53	-0.73	0.56	-1.29*	0.14	-0.54	0.20
	(0.97)	(0.88)	(0.72)	(0.75)	(0.38)	(1.00)	(0.32)
N	402	402	402	402	402	402	402
R^2	0.16	0.11	0.095	0.11	0.12	0.11	0.030

Notes: This table shows regression results of one-day changes in the net treasury issuance (ΔTGA_t^{Tsy}), and changes in the TGA account unrelated to net Treasury issuance (ΔTGA_t^{Other}) on daily changes in the U.S. GSIBs intermediation activities. The dependent variables are as follows: changes in reserves (Column 1), changes in dollar reverse repos (Column 2), changes in dollar repos (Column 3), changes in net dollar reverse repos, or the difference between reverse repos and repos in dollars (Column 4), changes in dollar lending in the FX swap market (Column 5), changes in dollar deposits (Column 6), and changes in outright Treasury holdings (Column 7).The independent variables are as follows: ΔTGA_t^{Tsy}, net treasury issuance; $\Delta TGA_t^{Other-F}$, the forecastable component (by Wrightson ICAP) of daily changes in TGA balance unrelated to net Treasury issuance; $\Delta TGA_t^{Other-UF}$, the unforecastable component (by Wrightson ICAP) of daily changes in TGA balance unrelated to net Treasury issuance; $Qend_t$ is a dummy variable indicating the last business day of the quarter, and $Qstart_t$ is a dummy variable indicating the first business day of the quarter. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A5: List of Sample Banks used in the Cross-Sectional Analysis

Country	Bank Name
Canada	Bank of Montreal
Canada	Bank of Nova Scotia
Canada	Royal Bank of Canada
Canada	Toronto-Dominion Bank
France	BNP Paribas
France	Société Générale
Germany	Deutsche Bank
Japan	Mizuho Financial Group
Switzerland	Credit Suisse
Switzerland	UBS
United Kingdom	Barclays
United Kingdom	HSBC
United States	Bank of America
United States	Citigroup
United States	Goldman Sachs
United States	JP Morgan
United States	Morgan Stanley
United States	Wells Fargo

Notes: This table shows the name and nationality of the banks used in our cross-sectional analysis in Section 4.4

Table A6: Impacts of Quarter-Ends, TGA, and SOMA Fluctuations on Intermediation Spreads

	(1) $\Delta SOFR - IOR$	(2) $\Delta GCF - IOR$	(3) $\Delta TGCR - IOR$	(4) $\Delta GCF - TGCR$	(5) $\Delta EURIOR$	(6) $\Delta JPYIOR$
$Qend_t$	12.4***	30.4**	8.01***	22.3*	137.4**	416.3***
	(2.60)	(13.6)	(2.58)	(11.5)	(59.9)	(117.9)
$Qstart_t$	-11.0***	-31.8**	-6.35**	-25.5*	-153.2*	-257.2***
	(3.69)	(13.2)	(2.60)	(14.4)	(80.4)	(92.5)
ΔTGA_t	0.047***	0.072***	0.039***	0.033***	0.27***	0.45***
	(0.0084)	(0.016)	(0.0079)	(0.012)	(0.062)	(0.16)
$\Delta SOMA_t$	-0.58***	-1.51**	-0.48***	-1.03*	-2.68**	1.47
	(0.15)	(0.66)	(0.15)	(0.59)	(1.33)	(2.32)
Constant	-0.24**	-0.59**	-0.20*	-0.38*	-0.45	-1.66
	(0.12)	(0.24)	(0.10)	(0.20)	(0.65)	(1.93)
N	933	930	933	930	902	837
R^2	0.29	0.29	0.23	0.20	0.24	0.36

Notes: This table shows the regression results of the quarter-end dummies, TGA and SOMA fluctuations on daily changes in various intermediation spreads. The dependent variables are as follows: daily changes in the SOFR–IOR spread (Column 1), daily changes in the GCF repo–IOR spread (Column 2), daily changes in the Triparty (TGCR) repo–IOR spread (Column 3), daily changes in the GCF–TGCR repo spread (Column 4), daily changes spread between the overnight implied dollar rate by swapping the ECB deposit rate and the Fed IOR (Column 5), and daily changes in the spread between the overnight implied dollar rate by swapping the BOJ deposit rate and the Fed IOR (Column 6). The independent variables are as follows: $Qend_t$, a dummy variable indicating the last business day of the quarter; $Qstart_t$ a dummy variable indicating the first business day of the quarter; ΔTGA, daily changes in the TGA balance; $\Delta SOMA$, daily changes in the Fed portfolio holdings of Treasury securities. Robust standard errors are reported in the parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A7: Impact of TGA, SOMA, and quarter-end constraints on Intermediation Activities

	(1) ΔRSV_t	(2) ΔRRP_t	(3) ΔRP_t	(4) $\Delta NRRP_t$	(5) ΔFX_t	(6) $\Delta Deposit_t$	(7) $\Delta TSY_t^{outright}$
$Qend_t$	-26.2***	-6.57	-29.5***	23.0***	10.6***	1.78	3.23
	(7.42)	(7.27)	(4.81)	(5.19)	(3.15)	(4.47)	(2.83)
$Qstart_t$	42.0***	-6.78	0.92	-7.70*	-8.42**	29.9***	-0.75
	(5.48)	(5.32)	(4.20)	(4.25)	(3.27)	(4.67)	(1.52)
ΔTGA_t	-0.18***	-0.041*	-0.078***	0.037*	0.031***	-0.034	0.060***
	(0.036)	(0.025)	(0.021)	(0.022)	(0.012)	(0.038)	(0.0095)
$\Delta SOMA_t$	0.49	-1.15***	-0.36	-0.79***	-0.18	-0.90***	-0.090
	(0.31)	(0.30)	(0.26)	(0.25)	(0.12)	(0.24)	(0.056)
Constant	-0.48	-0.052	0.55	-0.61	0.082	-0.20	0.10
	(0.61)	(0.47)	(0.41)	(0.40)	(0.23)	(0.61)	(0.20)
N	932	932	932	932	932	932	932
R^2	0.14	0.044	0.10	0.086	0.067	0.073	0.046

Notes: This table shows regression results of one-day changes in the TGA account (ΔTGA_t), net SOMA purchase ($\Delta SOMA_t$), and quarter-end ($Qend_t$) and quarter-starts ($Qstart_t$) on daily changes in the U.S. GSIBs intermediation activities. The dependent variables are as follows: changes in reserves (Column 1), changes in dollar reverse repos (Column 2), changes in dollar repos (Column 3), changes in net dollar reverse repos, or the difference between reverse repos and repos in dollars (Column 4), changes in dollar lending in the FX swap market (Column 5), changes in dollar deposits (Column 6), and changes in outright Treasury holdings (Column 7). $Qend_t$ is a dummy variable indicating the last business day of the quarter, $Qstart_t$ is a dummy variable indicating the first business day of the quarter, ΔTGA, daily changes in the TGA balance, and $\Delta SOMA$, daily changes in the Fed portfolio holdings of Treasury securities.. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A8: Comparisons of FX Lending Measures

	(1) ΔFX_t	(2) ΔFX_t^{all}	(3) ΔFX_t	(4) ΔFX_t^{all}	(5) ΔFX_t	(6) ΔFX_t^{all}
$Qend_t$			10.6***	8.48***	11.4***	8.90***
			(3.15)	(2.36)	(3.17)	(2.42)
$Qstart_t$			-8.42**	-8.64***	-8.27**	-8.56***
			(3.27)	(2.70)	(3.29)	(2.71)
ΔTGA_t	0.040***	0.030**	0.031***	0.021*		
	(0.013)	(0.012)	(0.012)	(0.012)		
ΔTGA_t^{Tsy}					0.0039	0.0072
					(0.018)	(0.019)
ΔTGA_t^{Other}					0.045***	0.029**
					(0.015)	(0.014)
$\Delta SOMA_t$			-0.18	-0.20*	-0.22*	-0.22*
			(0.12)	(0.11)	(0.12)	(0.12)
Constant	0.19	0.18	0.082	0.10	0.19	0.16
	(0.24)	(0.24)	(0.23)	(0.24)	(0.23)	(0.24)
N	932	932	932	932	932	932
R^2	0.012	0.0065	0.067	0.049	0.070	0.050

Notes: This table shows regression results of one-day changes in the TGA account (ΔTGA_t), net SOMA purchase ($\Delta SOMA_t$), and quarter-end ($Qend_t$) and quarter-starts ($Qstart_t$) on daily changes in two measures of dollar lending in the FX swap market. The benchmark measure ΔFX_t is defined by Equation 10. The alternative measure ΔFX_t^{all} is defined by Equation A1. Column 5 and 6 shows additional breakdown of TGA into changes in net Treasury issuance (ΔTGA_t^{Tsy}) and other components of TGA(ΔTGA_t^{Other}). Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A9: Comparisons of Outright versus Repo-financed Treasury Holdings

	(1) ΔTSY_t^{all}	(2) $\Delta TSY_t^{outright}$	(3) $\Delta TSY_t^{fin.}$
$Qend_t$	-0.61	3.86	-4.47**
	(2.94)	(2.87)	(1.91)
$Qstart_t$	-1.48	-0.63	-0.85
	(1.81)	(1.50)	(1.43)
ΔTGA_t^{Tsy}	0.071***	0.039***	0.032**
	(0.016)	(0.014)	(0.012)
ΔTGA_t^{Other}	0.063***	0.071***	-0.0075
	(0.013)	(0.012)	(0.0090)
$\Delta SOMA_t$	-0.31***	-0.12**	-0.19**
	(0.095)	(0.060)	(0.085)
Constant	0.16	0.18	-0.023
	(0.22)	(0.21)	(0.15)
N	932	932	932
R^2	0.052	0.048	0.034

Notes: This table shows regression results of quarter-end dummies, net treasury issuance (ΔTSY_t^{Tsy}), daily changes in the TGA account unrelated to net Treasury issuance (ΔTGA_t^{Other}), daily changes in the Fed SOMA portfolio holdings ($\Delta SOMA_t$) on daily changes in Treasury holding-related positions. The dependent variables are as follows: ΔTSY_t^{All}, daily changes in total Treasury holdings of U.S. GSIBs, including outright holdings and repo-financed Treasury holdings (Column 1); $\Delta TSY_t^{outright}$, daily changes in outright Treasury holdings (Column 2); and ΔTSY_t^{fin}, daily changes in repo-financed Treasury holdings (Column 3). $Qend_t$, is a dummy variable indicating the last business day of the quarter, and $Qstart_t$ is a dummy variable indicating the first business day of the quarter. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A10: U.S. GSIBs' Fed Repo Line Usage and Intermediation Activities

	(1) ΔRSV_t	(2) ΔRRP_t	(3) ΔRP_t^{exFed}	(4) $\Delta NRRP_t^{exFed}$	(5) ΔFX_t
$\Delta FedRepo$	-0.026	0.29*	-0.50***	0.79***	0.26***
	(0.23)	(0.15)	(0.19)	(0.17)	(0.096)
Constant	4.96**	-0.83	-0.78	-0.056	0.13
	(2.34)	(1.51)	(1.16)	(1.40)	(0.71)
N	158	158	158	158	158
R^2	0.000	0.021	0.093	0.15	0.067

Notes: This table shows the relationship between U.S. GSIBs' draw on the Fed repo facility ($\Delta FedRepo$) and their various intermediation activities. The dependent variables are as follows: changes in reserves (Column 1), changes in dollar reverse repos (Column 2), changes in dollar repos excluding borrowings from the Fed repo facility (Column 3), changes in net dollar reverse repos excluding borrowings from the Fed repo facility (Column 4), changes in dollar lending in the FX swap market (Column 5). The sample period is from October 1, 2019 to May 18, 2020. Robust standard errors are reported in the parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A11: Impacts of Quarter-Ends, TGA, and SOMA Fluctuations on Intermediation Spreads: Post Sept 2019

	(1) $\Delta SOFR-IOR$	(2) $\Delta GCF-IOR$	(3) $\Delta TGCR-IOR$	(4) $\Delta GCF-TGCR$	(5) $\Delta EURIOR$	(6) $\Delta JPYIOR$
$Qend_t$	-1.65	-3.68	-0.061	-3.59	6.69	138.4**
	(1.97)	(6.38)	(2.92)	(3.79)	(21.7)	(58.5)
$Qstart_t$	-14.3	-12.4	-17.2	4.87***	-1.44	-29.4
	(12.5)	(13.7)	(13.1)	(1.36)	(9.46)	(42.5)
ΔTGA_t	0.045***	0.086**	0.041**	0.046	0.22	0.53
	(0.017)	(0.036)	(0.017)	(0.028)	(0.18)	(0.37)
$\Delta SOMA_t$	-0.010	-0.027	-0.0051	-0.023	-0.14	-0.95*
	(0.036)	(0.042)	(0.035)	(0.032)	(0.15)	(0.53)
Constant	-0.21	-0.24	-0.22	-0.035	0.51	6.60
	(0.44)	(0.48)	(0.46)	(0.31)	(1.25)	(5.09)
N	155	157	155	155	150	134
R^2	0.15	0.15	0.18	0.055	0.051	0.11

Notes: This table shows the post-September 2019 regression results of the quarter-end dummies, TGA and SOMA fluctuations on daily changes in various intermediation spreads. The dependent variables are as follows: daily changes in the SOFR–IOR spread (Column 1), daily changes in the GCF repo–IOR spread (Column 2), daily changes in the Triparty (TGCR) repo–IOR spread (Column 3), daily changes in the GCF–TGCR repo spread (Column 4), daily changes spread between the overnight implied dollar rate by swapping the ECB deposit rate and the Fed IOR (Column 5), and daily changes in the spread between the overnight implied dollar rate by swapping the BOJ deposit rate and the Fed IOR (Column 6). The independent variables are as follows: $Qend_t$, a dummy variable indicating the last business day of the quarter; $Qstart_t$ a dummy variable indicating the first business day of the quarter; ΔTGA, daily changes in the TGA balance; $\Delta SOMA$, daily changes in the Fed portfolio holdings of Treasury securities. The sample period is from October 1, 2019 to May 18, 2020. Robust standard errors are reported in the parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.

Table A12: Impact of Quarter-Ends, TGA, and SOMA Fluctuations on Intermediation Activities: Post Sept 2019

	(1) ΔRSV_t	(2) ΔRRP_t	(3) ΔRP_t	(4) $\Delta NRRP_t$	(5) ΔFX_t	(6) $\Delta Deposit_t$	(7) $\Delta TSY_t^{outright}$
$Qend_t$	-43.7***	-10.9	-29.2***	18.3	8.60***	-40.0***	-5.21
	(12.1)	(33.8)	(6.43)	(27.8)	(2.43)	(4.80)	(6.27)
$Qstart_t$	49.0***	-28.7	-24.5***	-4.27	-6.51	16.5	10.5*
	(8.50)	(21.3)	(7.37)	(18.1)	(6.06)	(14.4)	(5.82)
ΔTGA_t	-0.29***	0.11**	0.0096	0.100**	0.070***	-0.053	0.035
	(0.075)	(0.045)	(0.032)	(0.048)	(0.022)	(0.078)	(0.026)
$\Delta SOMA_t$	0.51***	-0.19**	-0.10**	-0.085	-0.019	0.31***	-0.068
	(0.13)	(0.078)	(0.051)	(0.069)	(0.044)	(0.11)	(0.043)
Constant	-0.19	1.77	1.35	0.42	0.029	2.99	0.79
	(2.23)	(1.70)	(1.40)	(1.69)	(0.85)	(2.04)	(0.71)
N	157	157	157	157	157	157	157
R^2	0.30	0.12	0.12	0.060	0.10	0.10	0.061

Notes: This table shows the post-Septmeber 2019 regression results of one-day changes in the TGA account (ΔTGA_t), net SOMA purchase ($\Delta SOMA_t$), and quarter-end ($Qend_t$) and quarter-starts ($Qstart_t$) on daily changes in the U.S. GSIBs intermediation activities. The dependent variables are as follows: changes in reserves (Column 1), changes in dollar reverse repos (Column 2), changes in dollar repos (Column 3), changes in net dollar reverse repos, or the difference between reverse repos and repos in dollars (Column 4), changes in dollar lending in the FX swap market (Column 5), changes in dollar deposits (Column 6), and changes in outright Treasury holdings (Column 7). $Qend_t$ is a dummy variable indicating the last business day of the quarter, and $Qstart_t$ is a dummy variable indicating the first business day of the quarter. The sample period is from October 1, 2019 to May 18, 2020. Robust standard errors are reported in parentheses with significance levels denoted by *p<0.1; **p<0.05; ***p<0.01.