Ample Reserves for Whom?
The Role of Foreign Banks in U.S. Monetary Policy Implementation *

Junko Oguri† Cristoforo Pizzimenti‡

This draft: May 2026

Preliminary & Comments Welcome

Abstract

This paper studies how foreign banks shape reserve demand and the limits of balance-sheet normalization under the Federal Reserve's ample-reserves framework. Although foreign banks account for a modest share of U.S. banking activity, they hold a disproportionate share of reserve balances. Using high-frequency reserve-supply shocks, we show that reserve adjustment is asymmetric across policy phases: foreign banks absorb a large share of reserve inflows during quantitative easing (QE), but do not shed reserves symmetrically during quantitative tightening (QT), shifting adjustment mainly to large domestic banks. We trace this asymmetry to the distinctive institutional features of foreign banks, which face different balance-sheet costs from domestic banks and manage dollar liquidity through global internal capital markets. We develop a model in which uncertainty about foreign banks' reserve-absorption capacity raises the minimum reserve supply required to maintain stable short-term rate control.

* We would like to thank our advisors Gregor Matvos, Efraim Benmelech, Nicolas Crouzet, Martin Eichenbaum, Andrew Metrick, and Matthew Rognlie for their guidance and support. We are grateful to Francesca Barbiero (discussant), Jing Gao (discussant), Paul Huebner (discussant), Stefania D'Amico, Darrell Duffie, Daniel Feinberg, Craig Furfine, Enrique Martínez García, Zhengyang Jiang, Thomas King, Rosie Levy, Benjamin Munyan, Ralf Meisenzahl, Ali Ozdagli, Jonathan Rose, Chase Ross, Sharon Ross, Jung Sakong, Alessio Saretto, Sam Schulhofer-Wohl, Seth Searls, Nitzan Tzur-Ilan, Mark Wynne, Luca Zanotti, Xiaoqing Zhou, and seminar and conference participants at Kellogg Finance, Northwestern Econ, Dallas Fed, Chicago Fed, Waseda University, AFA 2026 (Poster), MFA 2026, BIS–CEPR–Gerzensee–SFI Conference on Financial Intermediation 2026, and Fifth PhD Workshop in Money and Finance at Sveriges Riksbank for helpful discussions and comments. Junko acknowledges the generous support from the Federal Reserve Bank of Dallas, the Federal Reserve Bank of Chicago, and the Bank for International Settlements. We gratefully acknowledge financial support from the 2025 ECB Lamfalussy Research Fellowship.

† Kellogg School of Management, Northwestern University. junko.oguri@kellogg.northwestern.edu

‡ Northwestern University cristoforopizzimenti2025@u.northwestern.edu

"...[the normalization plan] is consciously intended to avoid creating market strains...and will just run quietly in the background... We think this is a workable plan, and it will...be like watching paint dry..." (Yellen, 2017)

"...the ultimate size of our balance sheet will be driven principally by financial institutions' demand for reserves.... Estimates of the level of reserve demand are quite uncertain, but we know that this demand in the post-crisis environment is far larger than before..."
(Powell, 2019)

1 Introduction

For the past two decades, a series of extraordinary events have fundamentally reshaped the conduct of monetary policy. Confronted with the effective lower bound on nominal interest rates, central banks turned to unconventional tools to stabilize markets and support economic activity. Most prominently, many deployed balance sheet policies, including large-scale asset purchases and targeted lending operations, financed by a corresponding expansion of bank reserves on the liability side of central banks' balance sheets. These measures expanded central bank balance sheets to unprecedented levels. In the U.S., the Federal Reserve's balance sheet expanded from about 6 percent of GDP in 2007 to over 33 percent by 2023. Over the same period, reserve balances rose from $5.6 billion in December 2007 to a peak of $4.27 trillion in December 2021 (Figure 1 and 2).

As central banks unwind their balance sheets and proceed with quantitative tightening (QT), an active debate has emerged in both academic and policy circles: What is the optimal long-run size of a central bank balance sheet?[1] Outside of crisis periods, this debate typically reflects a shared preference for balance sheets that are large enough to ensure efficient policy implementation, yet not so large as to constrain future crisis interventions or generate distortions in financial markets, including Treasury markets. Indeed, the Federal Reserve has

[1] Arguments for a larger balance sheet often highlight benefits such as reduced reliance on private-sector maturity transformation (Greenwood et al., 2016) and enhanced liquidity management (Gagnon and Sack, 2014); see Logan (2019); Barr (2026) for a policy perspective. In contrast, arguments for a smaller balance sheet emphasize the need to mitigate risks to central bank net worth and monetary policy independence; for example by Sims (2013) and by Hall and Reis (2013); see Bowman (2025) for a recent policy perspective. A complementary line of work examines composition rather than size (Eren et al., 2024), while Wallace (1981) argued for irrelevance of the composition.

repeatedly emphasized its intention to "hold no more securities than necessary to implement monetary policy efficiently and effectively."[2]

A less explored question is whether institutional constraints prevent central banks from reaching this optimal balance sheet size. While balance sheet normalization is often discussed in terms of asset holdings, we argue that the binding constraint lies on the liability side of the balance sheet—specifically, in banks' demand for reserve balances. Because reserves are central to interest-rate control in the ample-reserves framework, the quantity that banks are willing to hold ultimately limits how far the Federal Reserve can shrink its balance sheet without destabilizing short-term rates. As banks are heterogeneous in their reserve management, this limit depends not only on the aggregate quantity of reserves, but also on how reserves are distributed across institutions.

This paper focuses on the distribution of reserves across banks, rather than on reserves in the aggregate. If banks had similar reserve-demand schedules and reserves could be frictionlessly reallocated through money markets, the aggregate level of reserves would be sufficient for assessing when reserves become scarce. In practice, reserve demand is heterogeneous, reserve holdings are highly concentrated, and money markets are segmented. A small set of institutions therefore plays an outsized role in determining when the aggregate reserve-demand curve becomes steep.

We focus on foreign banks and study how their reserve holdings constrain the Federal Reserve's ability to shrink its balance sheet while maintaining control of short-term interest rates. Although foreign banks represent a relatively small share of U.S. banking activity, they hold a disproportionately large share of reserve balances at the Federal Reserve. Figure 3 plots the shares of total assets, deposits, loans, and reserves held by foreign and domestic banks from 1980 to 2025.[3] While foreign banks consistently account for only about 10 to 25 percent of assets, loans, and deposits, their share of reserves diverges sharply after the Global Financial Crisis. Since 2008, foreign banks' reserve share has at times approached or

[2]See Federal Open Market Committee (2014), which states the Federal Reserve's longer-run intention for securities holdings. See also Board of Governors of the Federal Reserve System (2025) for a historical overview of the FOMC's policy normalization discussions and communications.

[3]As documented by Afonso et al. (2025), reserve balances at foreign banking organization (FBO) branches are, on average, approximately 20 percent lower at quarter-end than on other business days, reflecting balance-sheet adjustments around regulatory reporting dates. For the corresponding reserve shares measured at quarter-end, without window-dressing adjustment, see Figure A1. We interpret these estimates as providing a suggestive lower bound on foreign banks' reserve holdings.

exceeded 50 percent, far above their footprint in other major balance-sheet categories.

We argue that foreign banks' reserve demand is central to the marginal reserve-scarcity problem. Because foreign banks hold a large share of reserve balances, their behavior affects how far QT can proceed before the aggregate reserve-demand curve steepens. The key point is that foreign banks' reserve demand is not governed by domestic money-market conditions alone. It is shaped by regulatory asymmetries, FX-hedged returns, global dollar funding conditions, internal capital markets, and demand for safe dollar assets. As a result, global and institutional conditions outside the Federal Reserve's direct policy and supervisory reach create uncertainty about how far reserves can decline before interest-rate control becomes fragile.

We proceed in three parts. First, we document substantial heterogeneity in reserve demand across bank types and provide causal evidence on which institutions absorb exogenous reserve-supply shocks. Exploiting high-frequency reserve-supply variation generated by fluctuations in the Treasury General Account (TGA), we show that foreign banks are the most elastic margin in overnight interbank funding markets. Foreign banks' federal funds borrowing responds strongly to small changes in overnight funding incentives, whereas domestic-bank borrowing is much less sensitive. On the quantity side, reserve adjustment is asymmetric over the monetary policy regimes. Foreign banks absorb a large share of reserve inflows during quantitative easing (QE), but they do not release reserves symmetrically during quantitative tightening (QT). Instead, the burden of adjustment shifts toward domestic institutions, especially large domestic banks, with the Overnight Reverse Repurchase facility (ONRRP) also absorbing part of the post-2019 adjustment.

Second, we examine why foreign banks' reserve holdings do not simply reverse during QT and exhibit persistent demand. The key institutional distinction is organizational form. Foreign banks operate in the United States through branches and agencies, which are legal extensions of the parent bank; through subsidiaries, which are separately capitalized U.S. entities; or through both. Unlike subsidiaries, branches and agencies are not separately capitalized at the U.S. level and are less directly constrained by U.S. capital and leverage requirements. This gives them greater flexibility to expand and contract branch-level balance sheets. At the same time, branches and agencies are closely integrated with the parent bank's global balance sheet, headquarters liquidity management, and internal capital markets. As a result, reserves held at foreign branches are not financed only through U.S. interbank markets.

They can also be supported by the parent bank's broader dollar-funding strategy, which reallocates liquidity across repo markets, unsecured wholesale funding, and funding provided by headquarters. This makes foreign-branch reserve demand sensitive to global dollar funding conditions and internal capital-market decisions, not only to domestic money-market spreads. Consistent with this mechanism, we show that changes in foreign-branch reserves are matched by adjustments across multiple liability margins, including borrowing from headquarters. We also show that foreign banking organizations hold more reserves when the FX-hedged return to U.S. reserves is higher, and that higher hedged returns are associated with a shift away from branch-based repo funding and toward borrowing from headquarters. These results indicate that foreign banks' reserve demand is shaped by global funding conditions, internal capital markets, and treasury-management decisions partly outside the Federal Reserve's direct policy and supervisory reach.

Third, we develop a simple model of reserve supply under incomplete information that maps these findings into the Federal Reserve's operating problem during balance-sheet normalization. We build on the canonical Poole (1968) model, in which banks hold reserves to insure against payment shocks, and extend it in three directions that are central for the post-crisis monetary system: heterogeneity between domestic and foreign banks, a time-varying balance-sheet capacity margin that governs reserve absorption, and a reserve-supply problem in which the New York Fed's open market operation desk ("the Desk") must choose how many reserves to leave in the banking system before the conditions governing reserve demand are fully observed. In the model, reserve demand varies over time for two reasons: banks' day-to-day liquidity needs fluctuate, and the effective balance-sheet capacity available to absorb reserves at the margin also changes. The second source of variation is especially important for foreign banks, whose willingness to absorb reserves depends on global funding conditions, internal liquidity transfers from headquarters, and reporting-date balance-sheet pressure. Because these conditions are observed by banks but not by the Desk when reserve supply is set, the critical reserve level is stochastic from the Desk's perspective. Greater uncertainty about foreign banks' absorption margin raises the precautionary reserve buffer required for stable interest-rate control. Thus, even if expected reserve demand is unchanged, QT may require a higher minimum level of reserves when the foreign banks' absorption margin becomes less predictable.

Taken together, our findings show that the minimum level of reserves required for smooth policy implementation depends not only on aggregate reserve supply, but also on the identity and balance-sheet constraints of the institutions that hold reserves. Whereas Acharya and Rajan (2022) and Acharya et al. (2023) document that domestic banks' liquidity claims persist as reserves decline, generating liquidity dependence on the central bank, we show that foreign banks also contribute to an increase in the minimum level of reserves required for smooth policy implementation. Foreign banks' reserve holdings are large, persistent, and shaped by global funding conditions and internal capital markets. As a result, foreign banks can affect the effective lower bound of reserve supply even though the relevant margins are only partly tied to U.S. domestic intermediation.

The rest of the paper is structured as follows. Section 2 reviews the related literature. Section 3 provides an overview of the Federal Reserve's balance sheet and the evolution of reserve demand. Section 4 presents the data sources and sample construction. Section 5 documents heterogeneity in reserve demand using TGA shock identification and establishes the cross-sectional QE–QT asymmetry in reserve adjustment. Section 6 examines the institutional drivers of this heterogeneity and presents evidence that foreign-branch reserve persistence is supported by multiple funding margins, including headquarters funding and global FX-hedged reserve returns. Section 7 develops a model of reserve supply under incomplete information. Section 8 concludes.

2 Related Literature

This paper contributes to several strands of the macro-finance literature on reserve demand, global banking, and unconventional monetary policy.

First, the paper is most closely related to the rapidly growing literature on the liability side of central bank balance sheets and the challenges associated with estimating the demand for reserves. Lopez-Salido and Vissing-Jorgensen (2023) use deposit aggregates to identify the point at which reserve demand begins to slope downward. Acharya and Rajan (2022); Acharya et al. (2023) argue that reserve abundance paradoxically increases systemic liquidity risk and explore the "ratchet-up" effect. A broader set of studies examines monetary policy implementation under an ample-reserves regime and the functioning of the federal funds market, including Afonso et al. (2022a,b,c); Bech and Klee (2011); Bianchi and Bigio (2022); Bigio and Sannikov (2021); Darst et al. (2025); Dubois and Rintamäki (2025); Ismail and

Zúñiga (2026); Kashyap and Stein (2012); Keating and Macchiavelli (2017); Lagos and Navarro (2023); Gissler and Narajabad (2025); Smith and Valcarcel (2023). In particular, closely related to our work, Afonso et al. (2023) develop a theoretical framework to analyze the optimal supply of central bank reserves when the central bank faces uncertainty about banks' demand for reserves. Anbil et al. (2025) emphasizes heterogeneity in reserve demand and studies its implications for federal funds market functioning, with particular focus on domestic banks. Our contribution differs from and complements this literature in several dimensions. While existing work primarily focuses on aggregate reserve demand, we emphasize systematic heterogeneity across banks. By decomposing reserve demand by bank type, we show that demand curves and elasticities differ markedly across bank groups and evolve over time. In particular, we document that the reserve demand of foreign banks is both more elastic and more volatile, introducing a source of uncertainty in aggregate reserve demand.

Second, the paper contributes to the literature on global banking and cross-border dollar intermediation. Bräuning and Ivashina (2020) show that global banks respond to cross-country policy rate differentials by reallocating funds across jurisdictions, often at the expense of lending in the home economy. Correa et al. (2020) document how U.S. G-SIBs and foreign banking organizations engage in reserve-draining intermediation in response to dollar funding pressures, with these behaviors shaped by differences in regulatory leverage ratio reporting frameworks. Kim (2025) sets up two-country model and show foreign banks active reserve holdings and interbank market activity leads to reducing welfare for domestic and foreign consumers. A broader literature studies global banking, cross-border capital flows, and arbitrage in dollar funding markets, including Aldasoro et al. (2022); Anderson et al. (2025); Berrospide et al. (2016); Cetorelli and Goldberg (2011); Ivashina et al. (2015); Kalemli-Özcan (2019); Morelli et al. (2022); Niepmann (2023); Niepmann and Shen (2024); Rime et al. (2022). While much of this literature focuses on the lending and funding activities of global banks, we contribute by shifting attention to the reserve holdings of foreign banks operating in the U.S. and by analyzing how these holdings interact with the Federal Reserve's balance sheet policies. In addition, we examine how differences in organizational form—specifically, branches and agencies versus subsidiaries—shape reserve management behavior and participation in U.S. dollar funding markets.

Lastly, the paper contributes to the literature on unconventional monetary policy, with a particular focus on the design and transmission of quantitative tightening (QT). Diamond et al. (2023) use structural estimation to show that an ample-reserves environment can crowd out private lending. Copeland et al. (2025); Yang (2020) emphasizes the role of reserves in supporting payment systems during QT, showing that low or unevenly distributed reserves can lead to payment delays, liquidity hoarding, and stress in short-term funding markets. Borio (2023) argue that the costs associated with floor systems and abundant reserves are often underestimated. Other related contributions include D'Amico and Feldman (2024); d'Avernas et al. (2025); Eisenschmidt et al. (2024); Goldstein et al. (2023); Ihrig and Wolla (2020); D'Amico and Seida (2024); Carlson et al. (2020); Vandeweyer et al. (2024). Our study adds to this literature by emphasizing the heterogeneous costs and incentives banks face when holding reserves, particularly for foreign institutions operating in the U.S. We show that such heterogeneity can lead to uneven responses to balance sheet normalization and may generate uncertainty during the QT process. More broadly, because the Federal Reserve does not coordinate policy rates or balance sheet policies with other central banks, divergence in global monetary conditions may further complicate the implementation and transmission of U.S. monetary policy.

3 Brief Overview of the Federal Reserve's Monetary Policy Implementation Framework and Reserve Market

The surge in reserve supply since the Global Financial Crisis led to a fundamental shift in the Fed's monetary policy framework.[4] The Fed introduced interest on reserves (IOR) in October 2008, marking the transition to a floor system.[5] Under this system, IOR was intended to

[4]Before 2008, the Fed operated under a scarce reserves system, adjusting reserve supply through open market operations to steer the Federal Funds Rate (FFR). Banks, constrained by reserve requirements and liquidity needs, actively managed their balances by borrowing and lending in the federal funds market and using intraday credit at the Fed. Small changes in reserve supply had large effects on interbank rates, placing the supply curve on the sloped part of the reserve demand curve (Figure A2). This system collapsed in late 2008 as reserves flooded the banking system, rendering reserve requirements non-binding; fluctuations in reserve supply no longer moved the FFR, as liquidity had become abundant and supply now intersected the flat part of the demand curve. For further details and historical background, see Ihrig and Wolla (2020); Hughes and Younger (2026).

[5]In 2006, Congress passed a series of regulatory relief measures for banks and other financial institutions. This package, known as the Financial Services Regulatory Relief Act of 2006, included the authorization for the Fed to pay interest on bank reserves. Although this was intended to take effect in 2011, the Fed's response to the GFC expedited the implementation of IOR. The idea of paying interest on reserve holdings had been proposed by economists including Friedman (1959), and the implementation concept was further developed by Goodfriend (2002). For further historical background, see Wall (2017); Borio (2023).

serve as the effective lower bound for the FFR, as banks would have no incentive to lend at rates below the risk-free IOR. The mechanics of this framework, compared to the scarce reserves system, were expected to provide more reliable control over short-term rates (Mester, 2024). By 2019, the Fed formally committed to maintaining an ample reserves regime. In March 2020, the Fed eliminated reserve requirements, setting them to zero.

However, although IOR was intended to act as a floor, the FFR has persistently traded below IOR since its introduction (Figure A3). This deviation stems largely from Government-Sponsored Enterprises (GSEs), which may hold reserves at the Fed but are ineligible to earn interest on reserves. The Federal Home Loan Banks (FHLBs), in particular, face liquidity requirements that encourage them to lend excess balances below IOR, effectively pushing down the FFR (Gissler and Narajabad, 2025). This structural feature of the market has persistently weakened the transmission of IOR to short-term rates, keeping the FFR below IOR and creating challenges for the Fed's monetary policy implementation.[6]

Responding to the leaky floor, the Fed implemented several measures to complement the floor system. First, in 2013, the Fed launched the Overnight Reverse Repurchase Agreement (ONRRP) facility, allowing non-bank entities—such as GSEs and money market mutual funds (MMFs)—to lend overnight to the Fed in exchange for Treasury securities. By providing an alternative investment option to a wider set of counterparties, the ONRRP helped establish a firmer lower bound on short-term rates, mitigating the persistent gap between the FFR and IOR (Figure A4). However, this facility alone was not sufficient to prevent rate spikes in times of stress.

In September 2019, a series of factors triggered severe dislocations in the money market, exposing fragilities in the ample reserves framework (Anbil et al., 2020; Kahn et al., 2023). A corporate tax payment deadline drained liquidity from the banking system, while an unusually large settlement of Treasury securities from prior auctions forced primary dealers and investors to secure short-term financing. At the same time, reserves had been steadily declining due to the Fed's balance sheet normalization, leaving banks less willing to lend in overnight markets. These pressures culminated in a sharp and unexpected spike in repo rates, with overnight borrowing costs surging well above the Fed's target range. The episode underscored the limitations of the floor system in an environment where reserves, though

[6] For further details on the intraday federal funds dynamics, see Appendix A2. and Bech and Klee (2011); Gissler and Narajabad (2025).

still ample in aggregate, were unevenly distributed across institutions.[7]

Uncertainty about reserve demand, together with episodes of money market stress, has become a central consideration in determining the extent of the Federal Reserve's balance sheet normalization. While various tools have helped limit volatility in the FFR, fragilities remain, particularly in the repo market around financial reporting dates like quarter-ends. In September 2024, for instance, the Secured Overnight Financing Rate (SOFR) spiked 21 basis points above its weekly average, reflecting financing pressures. The ongoing QT has further intensified these issues, as private investors absorb a growing supply of Treasuries, often requiring repo financing, while the reduction in Fed-supplied liquidity tightens overall market conditions. Structural constraints—including regulatory requirements, counterparty credit limits, and balance sheet costs—continue to impede the smooth redistribution of liquidity, exacerbating rate volatility.[8] These dynamics may suggest the limits of relying solely on administered rates to control short-term markets, highlighting the interrelationships between reserves, policy tools, and the evolving structure of funding markets (Duygan-Bump and Kahn, 2026).

The appropriate level of reserves for smooth policy implementation remains uncertain, as the Fed struggles to accurately gauge the minimum threshold necessary to prevent market disruptions. In October 2024, the New York Fed introduced the Reserve Demand Elasticity (RDE) indicator to monitor shifts in reserve demand and assess the sensitivity of short-term interest rates to fluctuations in reserves. Constructed using forecast errors from a daily time-varying VAR model of aggregate reserves and federal funds rates, this tool provides a system-wide measure of liquidity conditions (Afonso et al., 2022c). However, it does not account for differences in reserve demand across institutions. The model assumes a single reserve demand curve, implicitly treating all banks as homogeneous. In reality, reserve demand varies significantly with factors such as bank size, regulatory constraints, access to alternative funding markets, and institutional structure. In particular, foreign banks

[7]In response, the Fed introduced the Standing Repo Facility (SRF) for primary dealers in 2021, designed to stabilize short-term funding markets by offering eligible banks and primary dealers access to secured borrowing against high-quality collateral like Treasury securities. The SRF is intended to act as an automatic stabilizer, ensuring that liquidity shortages do not lead to disorderly increases in borrowing costs. By creating a mechanism through which the Fed can directly inject liquidity into the repo market, the SRF was intended to improve rate control and reduce the likelihood of extreme funding pressures disrupting monetary policy implementation.

[8]For further details, see Fed official speeches such as Perli (2024a,b, 2026).

respond to a different set of incentives, including global funding conditions and home-country regulations. By aggregating reserve demand into a single elasticity measure, the RDE risks overlooking key frictions in liquidity distribution, limiting its effectiveness in assessing the true availability of reserves in the banking system.

This measurement challenge is further complicated by the evolving nature of reserve demand, which has forced the Fed to repeatedly revise its estimates of the lowest comfortable level of reserves (LCLOR). For instance, over the past five years, these estimates have steadily increased—from $1.5 trillion in October 2019 to approximately $3 trillion in April 2024 (Nelson, 2024a). Rather than being a fixed threshold, the LCLOR is an evolving concept, reflecting the dynamic nature of reserve demand across different types of institutions. This uncertainty complicates the Fed's ability to forecast the effects of balance sheet normalization. Unlike QE, which injected reserves into a system already operating under clear constraints, QT unfolds in an environment where reserve demand is shifting in unpredictable ways. As the Fed continues to reduce its balance sheet, the interaction between reserve supply, market structure, and institutional heterogeneity presents challenges for both policy transmission and financial stability. To better understand reserve demand, it is important to consider cross-bank heterogeneity rather than relying solely on aggregate measures.

Aggregate reserve levels alone do not fully determine liquidity conditions in the financial system. The distribution of reserves across banks plays a central role in shaping market functioning and interest rate dynamics. We argue that foreign banks play a significant role in the heterogeneity of reserve distribution, introducing an additional layer of uncertainty to monetary policy implementation. Foreign banks operating in the U.S. are not directly regulated or supervised by U.S. authorities in the same way as domestic banks. The majority of foreign banks' reserves are held through branches and agencies (hereafter branches), rather than subsidiaries, and these branches have greater flexibility in their liquidity allocation. As a result, the Federal Reserve has limited control over how foreign banks adjust their reserve holdings.

Beyond the financial stability concerns, the presence of foreign banks in the reserve market could raise political and fiscal considerations. Interest on reserves (IOR) is paid to banks holding reserve balances at the Fed, including foreign institutions.[9] For example, if foreign

[9]For instance, in July 2025, Senator Ted Cruz introduced legislation to eliminate the Federal Reserve's authority to pay interest on bank reserves, citing that foreign banks receive roughly 40–50 percent of aggregate

banks collectively hold around $1.3 trillion in reserves, the level as of January 2025, and IOR remains at 4.4%, foreign banks would earn approximately $58.4 billion in interest payments by year-end, assuming bi-weekly compounding.[10] Since the Fed's net income affects its remittances to the Treasury, these interest payments could raise concerns over the fiscal cost of monetary policy, particularly when reserve balances remain elevated. This dynamic further underscores why foreign banks' reserve behavior is not just a financial stability issue but also a broader policy concern.

In the following sections, we present a series of empirical facts that characterize the reserve behavior of foreign banks, documenting how regulatory structure and global internal capital markets shape their reserve holdings.

4 Data

This section describes the data sources used throughout the paper. We draw on two main types of data: (i) high-frequency data on reserve supply shocks and money market conditions, which enable causal identification of reserve demand elasticities (Sections 5 and 6); and (ii) quarterly bank balance sheet data from regulatory filings, which provide detailed cross-sectional and time-series information on reserve holdings and bank characteristics (Section 6). Appendix A1. provides further details on data collection and cleaning procedures.

4.1 High-Frequency Data: Weekly Balance Sheets and Daily Money Market Conditions

4.1.1 Weekly Bank Balance Sheet Data (H.8)

We use weekly balance sheet data from the Federal Reserve's H.8 Report: Assets and Liabilities of Commercial Banks in the United States. This dataset provides a higher-frequency view of reserve dynamics than the quarterly reports, enabling us to trace behavior around key dates such as quarter-ends and in response to reserve supply shocks. Because reserves are not reported separately in the H.8 data, we use cash assets as a proxy, which closely tracks reserve balances in the post-crisis ample-reserves regime.[11] The H.8 data distinguish between

IOR payments (Cruz, 2025).

[10] Interest payments occur after each maintenance period, typically every 14 days.

[11] See Appendix A1.2 and Appendix Figure A5 for verification that cash assets are an accurate proxy for reserves and for additional data construction details.

large domestic banks, smaller domestic banks, and U.S. branches and agencies of foreign banks, allowing us to trace heterogeneous responses across bank types.

Figure 4 plots reserve holdings from 2008 to 2025 for the three groups. Panel A shows aggregate reserve levels, Panel B shows each group's share of system-wide reserves, and Panel C shows reserve-to-assets ratios. Vertical lines indicate calendar quarter-ends. Two patterns are visible. First, foreign branches hold large cash positions relative to their assets, with reserve-to-assets ratios well above those of domestic banks. Second, foreign branches exhibit pronounced and recurrent drops in cash holdings at quarter-ends, a pattern not observed among domestic banks. We return to these quarter-end balance-sheet adjustments in Section 6.

4.1.2 Other Money Market and Treasury Data

We supplement the bank balance-sheet data with daily money-market rates and Treasury cash-management data. Policy and market rates, including interest on reserves (IOR), the effective Federal Funds Rate (FFR), the federal funds target range, and the Secured Overnight Financing Rate (SOFR), are obtained from FRED, the New York Fed, and Bloomberg. We also use daily federal funds borrowing data from the FR 2420 summary statistics, available beginning in March 2016.

Daily Treasury General Account (TGA) balances are obtained from the U.S. Treasury's Daily Treasury Statement. We also collect Treasury securities issuance data, including auction volumes and maturities, from the Treasury website to refine the measurement of TGA-driven reserve-supply shocks.

4.2 Quarterly Bank Balance Sheet Data

Our quarterly analysis uses bank-level reserve balances from regulatory filings. Reserve balances are reported in FFIEC 031 and 041 filings for domestic banks and foreign-owned subsidiaries, and in FFIEC 002 filings for U.S. branches and agencies of foreign banks.[12] We

[12]Reserve balances are held by depository institutions with master accounts at the Federal Reserve. These institutions include nationally chartered banks, eligible state-chartered banks, and other entities classified under Section 19(b) of the Federal Reserve Act. As of March 2020, the Federal Reserve reduced reserve requirement ratios to zero percent, effectively eliminating reserve mandates for depository institutions. While banks with master accounts continue to hold reserves, these holdings are now discretionary rather than regulatory obligations.

include institutions with positive reserve balances and positive total assets.

For analyses at the banking-organization level, we aggregate individual bank, branch, and agency balance sheets to the top-tier banking organization using FR Y-9C data and institution attributes from the FFIEC. We classify foreign banking organizations by the country of their headquarters and merge the regulatory filings with market data and policy-rate series. The full sample spans 1980Q2 to 2025Q4, the longest period over which data on U.S. branches and agencies of foreign banks are available. Most of the analysis focuses on the post-crisis period from 2009Q1 to 2025Q4, with particular attention to U.S. branches and agencies of foreign banks.

Figure A6 describes balance-sheet composition, and Figures A7 and A8 show jurisdictional heterogeneity of foreign banks. Domestic banks and foreign-owned subsidiaries have broadly similar balance-sheet structures, while foreign branches rely more heavily on wholesale funding, hold larger reserve shares, and report larger internal positions with headquarters.

5 Reserve Demand Heterogeneity

This section documents which institutions adjust at the margin when reserve supply changes. We begin by showing that aggregate reserve balances are related to overnight funding spreads, but that this relationship masks substantial heterogeneity across banks and policy regimes. We then use high-frequency TGA shocks to isolate exogenous reserve-supply variation. The evidence shows that foreign banks are the most spread-sensitive borrowers and absorb a large share of reserve injections during QE. During QT, however, reserve adjustment shifts toward domestic banks and the ONRRP facility. These patterns reveal an asymmetric cross-sectional adjustment margin: the institutions that absorb reserves during balance-sheet expansions are not necessarily the institutions that release them during contractions.

5.1 Funding Spreads and Aggregate Reserve Supply

We begin with the aggregate relationship between reserve supply and overnight funding spreads. Figure 5 plots the spread between the federal funds rate and interest on reserves (FFR–IOR) against aggregate reserve balances at a weekly frequency. Observations are grouped into four policy regimes: QE (January 2009–October 2014), QT (November 2014–October 2019), QE (November 2019–November 2021), and QT (December 2021–December

2025). Across regimes, the figure shows a broadly downward-sloping relationship: as aggregate reserves decline, overnight funding spreads rise relative to IOR. For the post-2019 period, we also report SOFR–IOR as a complementary measure of overnight funding conditions.[13]

This relationship is consistent with spread-based reserve demand. Since the introduction of IOR, the federal funds rate has typically traded below the rate paid on reserves (Figure A3). This creates an incentive for eligible banks to borrow in federal funds or related money markets and hold the proceeds as reserve balances. When the FF–IOR spread becomes more negative, the return to this trade rises; when the spread narrows, the incentive to expand reserve holdings weakens. The relationship also appears nonlinear: at high levels of aggregate reserves, funding spreads become relatively insensitive to additional reserves, consistent with a flatter portion of the reserve-demand curve.

However, the aggregate relationship masks substantial heterogeneity across institutions. Figure 6 disaggregates the spread-reserve relationship by bank type: U.S. branches and agencies of foreign banks, large domestic banks (top 25 in asset size), and small domestic banks. Small domestic banks display little sensitivity to funding spreads or aggregate reserve supply. Large domestic banks and foreign branches respond more strongly, but their slopes differ across QE and QT episodes. These patterns motivate the causal exercises below, which use high-frequency supply shocks to identify which institutions adjust at the margin when reserve supply changes.

5.2 Identifying Exogenous Reserve Supply Shocks Using the TGA Shock

The correlations above are suggestive but do not establish causality. Funding spreads and reserve holdings may be jointly determined, and both may respond to unobserved shocks to money markets or bank balance sheets. To isolate high-frequency variation in reserve supply, we use fluctuations in the Treasury General Account (TGA), the U.S. Treasury's account at the Federal Reserve, as a source of plausibly exogenous movements in aggregate reserve supply.

TGA movements are autonomous factors on the Federal Reserve's balance sheet and

[13] SOFR is a broad measure of overnight Treasury repo rates. We include SOFR–IOR because the repo market has become the largest and most active U.S. money market, with daily trading volume of roughly $3 trillion (Copeland et al., 2025). The SOFR-based evidence is useful for tracking secured funding pressures, but it should be interpreted with caution because repo rates may also respond directly to Treasury collateral supply and other secured-market conditions.

have been used extensively in prior work (e.g., Afonso et al., 2022c; Bräuning, 2017; Correa et al., 2020; Hamilton, 1997). An increase in the TGA drains reserves from the banking system, while a decrease injects reserves, unless offset by changes in overnight reverse repo (ONRRP) usage, which we control for directly. Under the current ample-reserves framework, the Federal Reserve does not routinely sterilize these day-to-day Treasury cash-management flows, allowing TGA movements to pass through to aggregate reserve balances.

TGA shocks are not balance-sheet policy, but they provide a useful laboratory for studying the incidence of reserve-supply changes. Both TGA movements and QE/QT alter the quantity of reserves available to the banking system. The advantage of TGA variation is that it is high-frequency and driven by Treasury cash-management operations, such as tax receipts, benefit payments, and Treasury security settlements, rather than by contemporaneous bank reserve-demand decisions. Banks also do not transact directly with the TGA; instead, they adjust borrowing and reserve positions in response to the funding-market conditions induced by TGA-driven reserve fluctuations. We therefore use TGA shocks to identify which institutions absorb or release reserves at the margin within a policy regime. The exercise should not be interpreted as estimating the full macroeconomic effects of QE or QT; it identifies the cross-sectional incidence of reserve-supply changes at high frequency.

Following Bräuning (2017), we construct TGA shocks by removing predictable variation in daily TGA changes. Specifically, we regress daily changes in the TGA balance on beginning-of-month, end-of-month, beginning-of-quarter, end-of-quarter, and day-of-week fixed effects, and we further control for anticipated Treasury financing flows using information on expected security issuance and maturities. The residual from this regression, shown in Figure 7, is interpreted as the unanticipated component of TGA-driven reserve-supply variation. The table-based TGA-shock sample spans January 2009 through December 2025.

The identifying assumption is that, after removing predictable calendar and issuance-related components, residual TGA movements affect bank borrowing and reserve holdings through their effect on reserve supply and overnight funding conditions. Relevance follows mechanically from the Federal Reserve's balance sheet: reserve-draining TGA shocks reduce aggregate reserves and tighten funding conditions. The main threat to exclusion is that Treasury issuance may affect repo rates directly through collateral supply.[14] We address

[14]Recent policy discussions have emphasized that, in principle, the Federal Reserve could actively offset fluctuations in the Treasury General Account, for example, by adjusting its asset holdings or backing the

this concern by controlling for expected issuance and maturities in the shock construction and by treating SOFR–IOR as complementary evidence rather than as a clean standalone reserve-supply spread.

Using the TGA shocks and daily rate data, we estimate the first-stage relationship:

$$\Delta\left(i^F - i^R\right)_t = \beta_0 + \beta_1 \Delta \text{TGA}_t + \beta_2 \Delta \text{ONRRP}_t + \beta_3 X_{f(t)} + \varepsilon_t, \tag{1}$$

where $\Delta(i^F - i^R)_t$ is the daily change in the funding spread, measured as either FF–IOR or SOFR–IOR; ΔTGA_t is the TGA shock; ΔONRRP_t controls for changes in ONRRP take-up; and $X_{f(t)}$ denotes FOMC-period fixed effects. We exclude quarter-end dates. The FOMC-period fixed effects absorb the policy and macro-financial environment between consecutive FOMC meetings, including administered-rate settings and average reserve conditions. Identification therefore comes from within-period variation in TGA shocks and the associated movements in funding spreads.

Table 1 reports the first-stage estimates. TGA shocks pass through to FF–IOR most strongly in expansionary periods and more weakly in tightening periods. SOFR–IOR shows a similar but less clean pattern, consistent with the fact that repo rates also respond to collateral-market conditions. We therefore use SOFR–IOR as complementary evidence that the results are not specific to the unsecured federal funds market.

Appendix Tables A2 and A3 split TGA shocks into reserve-draining and reserve-injecting components. Reserve drains generate larger and more precise increases in funding spreads than the corresponding spread declines associated with reserve injections. This asymmetry is consistent with state-dependent marginal pricing of reserves: drains are more likely to bind liquidity or balance-sheet constraints, while injections have smaller effects when reserves are already abundant. We treat this evidence as reduced-form support for nonlinear reserve demand.

TGA with short-maturity securities, to insulate reserve balances and money market conditions from Treasury cash-management operations. See Nelson (2024b), Vissing-Jorgensen (2025), and Miran (2025). However, under the current ample-reserves operating framework, such sterilization is not implemented on a routine basis, and predictable Treasury settlements continue to generate high-frequency variation in reserve supply.

5.3 Spread Sensitivity in Overnight Borrowing: Foreign Banks at the Margin

Having established that TGA shocks move overnight funding spreads, we next ask which institutions adjust their borrowing in response. We use the TGA shock as an instrument for spread changes and estimate the effect of these changes on federal funds borrowing by bank type using daily transaction data from the FR 2420 report. Because the foreign–domestic split in FR 2420 begins on March 2, 2016, the disaggregated borrowing evidence pertains to the post-2016 ample-reserves period, including the 2019–2021 balance-sheet expansion and the subsequent tightening period.

The second-stage specification is:

$$\Delta \ln(\text{Borrowing})_{j,t} = \alpha_0 + \alpha_1 \Delta \left(\widehat{i^F - i^R}\right)_t + \alpha_2 \Delta \text{ONRRP}_t + \gamma_{f(t)} + u_{j,t} \tag{2}$$

where $j \in \{\text{All Banks}, \text{Foreign}, \text{Domestic}\}$ indexes bank type, and $\Delta(\widehat{i^F - i^R})_t$ is the predicted spread change from the first stage in (1). All specifications include FOMC-period fixed effects and control for changes in ONRRP take-up.

Table 2 reports the full-sample second-stage results. Foreign-bank borrowing responds strongly and robustly to instrumented changes in spreads. In columns (3)–(4), a 1 bp decrease in FF–IOR or SOFR–IOR is associated with roughly a 7% or 4.5% increase in foreign-bank federal funds borrowing. For domestic banks, by contrast, the estimates are small and not stable across spread measures. We do not find robust evidence of spread sensitivity in domestic borrowing.

Splitting the sample by policy regime in (Table 3) preserves this pattern. The expansionary-phase estimates should be interpreted as evidence for the 2019–2021 balance-sheet expansion, not the 2009–2014 expansion, because the foreign–domestic split is unavailable before 2016. Within the post-2016 sample, foreign-bank borrowing remains the clearest spread-sensitive margin, while domestic-bank estimates remain imprecise and specification-dependent. The SOFR-based disaggregated expansionary estimates are weaker, however, and the corresponding first-stage F-statistic is 4.68; we therefore treat those coefficients as suggestive rather than central to our inference.

5.4 Spread Sensitivity in Reserve Holdings: Foreign Banks at the Margin

The borrowing results identify the active funding margin at daily frequency. We next ask whether the same TGA-induced spread movements translate into changes in reserve holdings. Because reserve holdings are observed in the weekly H.8 data, we estimate the reserve response at a weekly frequency, using Wednesday endpoint spread changes and aggregating daily TGA shocks over the same Wednesday-to-Wednesday window. Appendix Table A1 reports the corresponding weekly first stages.

Using this weekly first stage, we estimate the effect of instrumented spread changes on weekly changes in log reserve holdings. Table 4 reports the full-sample results. The coefficients are negative across all bank groups and both spread measures, indicating that TGA-induced increases in funding spreads reduce reserve holdings on average. The response is largest for foreign banks: a one basis point increase in the instrumented FF–IOR spread is associated with about a 13 percent decline in foreign-bank reserves.[15]

Table 5 shows that this result is driven by QE episodes. In QE, the first stages are strong, the IV estimates are negative and precise, and the foreign-bank response is the most pronounced across bank groups. In QT, by contrast, the weekly first stages are weak. Although the Anderson–Rubin tests reject a zero coefficient in QT, the corresponding confidence sets are disjoint and unbounded, and therefore do not provide informative estimates of the sign or magnitude of the response. We therefore interpret the reserve-holdings IV evidence as primarily a QE result, with foreign banks showing the strongest reserve response to spread movements.

5.5 Reserve Holdings and QE–QT Asymmetry

The IV results above show that TGA-induced spread movements reduce reserve holdings in QE, with foreign banks responding most strongly at the margin. We now examine the quantity-side incidence of the same reserve-supply shocks. Because reserve balances can only be held by institutions with accounts at the Federal Reserve, changes in aggregate reserve supply must be absorbed either by banks or by the overnight reverse repo (ONRRP) facility. Identifying which institutions adjust their reserve positions therefore reveals how

[15] The Anderson–Rubin confidence sets reported in Tables 4 and 5 provide weak-instrument-robust evidence that the full-sample effects are negative, but the stronger identification comes from the QE subsample.

reserve-supply shocks are distributed across the financial system. This exercise allows us to test whether the institutions that absorb reserves during QE are also the institutions that release reserves during QT.

To quantify this adjustment, we regress changes in reserve holdings on TGA-driven reserve-supply shocks. For each bank category i and for the ONRRP facility, we estimate

$$\begin{cases} \Delta \text{Reserves}_{i,t} = \beta_i \, \Delta \text{TGA}_t + \delta_{f(t)} + \varepsilon_{i,t}, \\ \Delta \text{ONRRP}_t = \beta_{\text{ONRRP}} \, \Delta \text{TGA}_t + \delta_{f(t)} + \varepsilon_t. \end{cases} \tag{3}$$

The index i denotes foreign banks, the top 25 domestic banks by asset size, and the rest of domestic banks. The regressions are estimated at a weekly frequency from January 2009 through December 2025, excluding quarter-ends. All specifications include FOMC-period fixed effects.

Table 6 reports the pass-through from TGA-driven reserve-supply shocks to reserve holdings by bank type and policy regime. Because an increase in the TGA drains reserves from the banking system, negative coefficients indicate that a bank group absorbs part of the drain by reducing reserve holdings. The table shows a clear QE–QT asymmetry. In the 2009–2014 expansion, a \$100 billion decline in the TGA is associated with a \$54 billion increase in foreign-branch reserves, compared with \$20 billion at large domestic banks and \$4 billion at small domestic banks. In the 2019–2021 expansion, foreign branches again absorb the largest bank share, while ONRRP also becomes an important absorption margin. During tightening periods, the pattern reverses: large domestic banks absorb the largest reserve drains in both 2014–2019 and 2021–2025, while foreign branches remain responsive but no longer dominate the adjustment. Overall, foreign branches are the main banking-sector absorbers of reserve injections during QE, whereas QT adjustment is more broadly distributed and led by large domestic banks.

We next visualize how the composition of reserve adjustment evolves within and across policy regimes. While the baseline coefficients summarize average pass-through over the full sample, reserve demand need not be stable: shifts in market structure, regulation, and balance sheet constraints can alter banks' capacity and willingness to absorb reserve shocks (Afonso et al., 2022c). Accordingly, we estimate 52-week rolling coefficients, $\hat{\beta}_{j,t}^{(52)}$, from the baseline specification and use them to construct time-varying adjustment shares,

$$\theta_{j,t} \;=\; 100 \times \frac{-\,\hat{\beta}^{(52)}_{j,t}}{\sum_{k\in\{\text{Foreign branches},\,\text{Large domestic},\,\text{Small domestic},\,\text{ONRRP}\}}\left(-\,\hat{\beta}^{(52)}_{k,t}\right)}. \tag{4}$$

The negative sign ensures that institutions absorbing reserve drains receive positive shares. These objects are not elasticities. They are normalized shares of contemporaneous TGA-induced dollar adjustment. Because one category may move opposite to aggregate adjustment, or offset movements in other categories, an individual share can be negative and the set of shares can temporarily exceed 100% in absolute value.

Figure 8 plots the time-varying composition of reserve absorption shares, with vertical dashed lines indicating major policy regime changes. The figure is broadly consistent with three patterns. First, during the 2009–2014 expansionary period, foreign branches absorb the majority of TGA-induced reserve fluctuations, consistent with their high reserve-demand elasticity and active cross-border liquidity management. Second, following the introduction and subsequent expansion of the ONRRP facility after 2014, reserve absorption becomes more distributed across bank types and the ONRRP facility. Third, during tightening periods, the composition shifts toward large domestic institutions and, in parts of the post-2021 tightening period, ONRRP, while foreign branches no longer dominate the marginal adjustment. Small domestic banks play a limited but generally positive role throughout the sample.

Figure 9 provides a complementary stock-level perspective. It plots cumulative balance changes across the two expansion–tightening cycles. Domestic and foreign-bank reserves both rise substantially during QE, but the subsequent QT declines are incomplete, especially in the post-2019 cycle. Foreign-bank reserves rise by about $682 billion during the second expansion but fall by only about $91 billion during the subsequent tightening. By contrast, ONRRP behaves more like a reversible policy margin, rising sharply during the second expansion and falling by a similar amount during QT. These stock patterns are descriptive, but they point in the same direction as the TGA-shock evidence: reserve buildups are not unwound one-for-one during normalization, and the persistence of reserves depends on which institutions absorb them during expansions.

The results in this section show that reserve adjustment is asymmetric across the balance-sheet cycle. Foreign branches are important marginal absorbers of reserve injections during

QE, but reserve drains during QT are absorbed more broadly and often by large domestic banks or ONRRP. Balance-sheet normalization therefore need not reverse the expansion phase: the institutions that absorb reserves when the Federal Reserve expands its balance sheet are not necessarily the institutions that release them when reserves contract. This cross-sectional asymmetry creates a reserve ratchet. When reserves accumulate at institutions that do not release them symmetrically during QT, the Federal Reserve must supply a larger aggregate reserve buffer to maintain smooth policy implementation. Aggregate reserves can therefore appear ample even when the reserves available to the marginal institutions are scarce.

6 Institutional Drivers of Heterogeneous and Asymmetric Reserve Demand

Foreign banks expand reserve holdings elastically during balance-sheet expansions but do not unwind these positions symmetrically during tightening. This section examines why U.S. branches and agencies of foreign banks, in particular, constitute a distinctive reserve-demand margin. The argument has three parts. First, branches and agencies differ from domestic banks and foreign-owned subsidiaries in organizational form and regulatory treatment, which lowers the marginal U.S. balance-sheet cost of reserve accumulation. Second, this institutional advantage is expressed in the post-crisis federal funds market, where FHLBs are the dominant lenders and foreign branches are the primary spread-sensitive borrowers when reserves are abundant. Third, federal funds borrowing is only one component of a broader funding mix: foreign branches also rely on headquarters funding, repo, unsecured wholesale funding, and FX swap markets, so their reserve demand is shaped by global funding conditions, internal capital markets, and treasury-management decisions rather than by the IOR–FFR spread alone. This combination helps explain the asymmetry documented above: foreign branches are elastic reserve absorbers when funding spreads are favorable, but their reserve balances need not be symmetrically released when liquidity becomes scarce. The evidence is primarily descriptive, but it clarifies the institutional mechanisms behind asymmetric reserve absorption across QE and QT episodes and motivates the model in the next section.

6.1 Institutional Features of Foreign Branches and Agencies

Foreign banks have systematically held larger reserve balances than domestic banks since the introduction of interest on reserves (IOR) in late 2008. This gap is not fully explained by size, systemic importance, or observable balance sheet composition.[16] However, a key institutional distinction is the organizational structure. Foreign banks in the United States may operate through branches and agencies, subsidiaries, or a combination of both. Branches and agencies are legal extensions of the parent bank rather than separately capitalized entities, whereas subsidiaries are stand-alone U.S. institutions. This distinction maps directly into the regulatory perimeter and the marginal balance-sheet cost of holding reserves.

Regulatory asymmetries. Branches and agencies face a lighter U.S. prudential burden than subsidiaries and domestic banks. Because they are not separately capitalized U.S. entities, they are not subject at the branch level to the same U.S. capital and leverage requirements that often constrain domestic banks. In contrast, subsidiaries must maintain capital and liquidity buffers consistent with domestic prudential standards. Unlike subsidiaries, they cannot accept FDIC-insured retail deposits, but they also avoid deposit insurance fees and certain capital surcharges.[17] Branches can accept wholesale deposits broadly, while agencies face restrictions on deposits from U.S. citizens. Since July 2016, foreign banking organizations with more than $50 billion in U.S. assets (*excluding* branch assets) have been required to form an Intermediate Holding Company (IHC) under Regulation YY, but this requirement applies to subsidiary operations rather than branches. Large FBOs' U.S. operations can face U.S. liquidity risk-management and internal stress-testing requirements under Regulation YY. Taken together, these regulatory asymmetries lower the marginal balance-sheet cost of holding reserves and help explain why branches and agencies can access the federal funds market more elastically than subsidiaries and domestic banks.

[16] See Appendix Figure A10 for the evolution of foreign banks' reserve holdings relative to domestic banks. Appendix Table A4 reports regressions of reserve holdings on foreign status, G-SIB designation, and their interaction. The foreign indicator remains large and statistically significant after controls and fixed effects.

[17] Insured branches that were accepting domestic retail deposits as of December 19, 1991, were grandfathered. As of June 2025, only four such branches remain in our sample. According to Banegas and Tase (2020), only one of these participates in the federal funds market.

Access to headquarters funding. Critically, branches and agencies can transfer liquidity between their U.S. operations and foreign headquarters (HQ) through internal capital markets, providing flexibility to reallocate dollar liquidity in response to global interest rate differentials and internal funding needs.[18] Figure 10 shows quarterly HQ claims and liabilities by jurisdiction. Before the crisis, branches and agencies accumulated net claims on HQs; since then, they have shifted toward net borrowing from HQs, indicating that HQ funding has become an important source of dollar funding.

We quantify the importance of the organizational form using pre-crisis cross-sectional variation in foreign banks' U.S. presence. Following the logic of Mian and Sufi (2022), for each bank holding company, we exploit the share of U.S. assets operated through branches and agencies in 2007Q1 as a predetermined measure of branch intensity, leveraging the high persistence of branch-versus-subsidiary structures documented by DiSalvo (2019). Specifically, we estimate:

$$\log(\text{Reserves})_{it} = \beta_1 \text{Foreign}_i + \beta_2 \left(\text{Foreign}_i \times \text{BranchRatio}_i^{2007}\right) + \Gamma X_{it} + \alpha_t + \epsilon_{it} \quad (5)$$

where Foreign is an indicator for foreign ownership and $\text{BranchRatio}^{2007}$ is the share of U.S. assets in branch form as of 2007Q1.

Table 7 shows that organizational form is a strong predictor of reserve holdings. A higher pre-crisis branch share is associated with significantly larger reserve holdings among foreign banks, even after controlling for size, capitalization, and quarter fixed effects. In the foreign-bank-only sample, the implied effect of a one-standard-deviation increase in branch intensity is $\exp\left(\hat{\beta}\, \sigma(\text{BranchRatio}^{2007})\right) - 1 \approx 0.40$. Organizational form therefore explains a substantial share of the cross-sectional variation in reserve holdings within the foreign-bank sample.

6.2 Branches and Agencies' Dominance in the Federal Funds Market

Section 5.3 shows that, in the post-2016 FR 2420 data, U.S. branches and agencies of foreign banks are the primary spread-sensitive borrowers in the federal funds market. This fact helps

[18] Branches and agencies are subject to Sections 23A and 23B and Regulation W, but these rules primarily govern transactions among U.S. affiliates and impose few constraints on cross-border liquidity transfers.

explain why foreign branches are an elastic margin of reserve demand when the IOR–FFR arbitrage trade is active.

The post-crisis federal funds market is highly segmented. On the lending side, Federal Home Loan Banks (FHLBs) are the dominant suppliers because they hold accounts at the Federal Reserve but are not eligible to earn interest on reserve balances. Lending overnight in the federal funds market allows them to deploy liquid balances while satisfying liquidity and operational requirements. Other government-sponsored enterprises, such as Fannie Mae and Freddie Mac, largely withdrew from unsecured lending after entering conservatorship in 2008.

On the borrowing side, foreign branches account for most federal funds borrowing (Bech and Klee, 2011; Banegas and Tase, 2020; Anbil et al., 2025). Their organizational structure lowers the marginal U.S. balance-sheet cost of expanding assets: balance-sheet expansion at branches is less directly constrained by U.S. capital and leverage requirements than reserves held at domestic banks or foreign-owned subsidiaries, and branches do not face FDIC insurance assessments associated with insured retail deposit funding. Their credit quality also makes them natural counterparties for FHLBs, while access to headquarters funding allows them to adjust liability composition when spreads are favorable.

As a result, federal funds trading is concentrated on both sides of the market. Figure 11 shows that transactions between FHLBs and foreign bank branches account for roughly 90 percent of federal funds trading volume. A small number of domestic correspondent banks remain active, but their volumes are modest in abundant-reserve periods. Since the effective federal funds rate is calculated as a volume-weighted *median*, the published EFFR reflects the market segment that contains the middle of trading volume. When FHLB-to-foreign-branch trades dominate that segment, the EFFR mainly reflects arbitrage and relationship pricing between FHLBs and foreign branches, rather than the system-wide scarcity value of reserves.[19]

This interpretation changes as reserves become less abundant. The remaining bank-to-bank segment is small, but it is more closely connected to banks' reserve-management needs. Consistent with Anbil et al. (2025), small domestic banks become more relevant borrowers when their liquidity needs rise, and bank lenders' pricing becomes more sensitive as their own reserve buffers decline. Thus, reserve scarcity may first appear in a segmented interbank margin even if the published EFFR remains heavily influenced by FHLB-to-foreign-branch

[19] See Appendix A4. for details on FHLB liquidity management, Fedwire timing, counterparty constraints, and the regulatory treatment of alternative short-term investments.

trades.

Foreign branches are therefore central to the arbitrage margin in federal funds, but they should not be interpreted as an unlimited source of interbank liquidity. Their reserve balances can also serve internal liquidity stress metrics, dollar payment needs, and global treasury objectives. This distinction is important for the asymmetry documented below: foreign branches can absorb reserves elastically when spreads are favorable, but their willingness to release those reserves or lend them onward may be limited when liquidity becomes scarce.

6.3 Reserve Funding Through Multiple Liability Margins

The federal funds evidence identifies an important institutional channel: foreign branches are the natural marginal borrowers in the post-IOR federal funds market. However, this channel cannot be the whole funding margin. The post-crisis FF market is highly segmented and economically small relative to the stock of reserves held by foreign branches; recent FF market size is at most around \$100 billion, while foreign-branch reserve balances are much larger. Moreover, the persistence of foreign-branch reserve positions remains visible even when the IOR–FFR spread narrows. This motivates a broader view in which foreign branches finance reserves through a menu of priced dollar funding margins, rather than through a single overnight unsecured margin.

We first document this broader funding mix using balance-sheet quantities. The purpose of this exercise is accounting and diagnostic. We ask which liability margins move when foreign branches absorb reserve changes, recognizing that liabilities may also respond directly to Treasury collateral supply, money-market-fund reallocations, and reporting-date balance-sheet incentives. Building on the TGA-shock specification in Section 5, we use weekly TGA changes to construct the component of reserve changes associated with plausibly exogenous movements in aggregate reserve supply. For each bank group and liability component j, we estimate

$$\Delta L_{j,t} = \beta_j \Delta \widehat{\text{Reserves}}_t + \alpha_{\tau(t)} + \varepsilon_{j,t}, \tag{6}$$

where the first stage follows equation (3). The fixed effect $\alpha_{\tau(t)}$ is an FOMC-period fixed effect, and quarter-end observations are excluded.

The coefficient β_j is a dollar-for-dollar balance-sheet matching coefficient: it measures how much liability category j changes when the bank group absorbs one dollar of reserve variation associated with TGA movements. The estimates should not be read as a clean causal effect of reserves on liabilities. The exclusion restriction is less credible on the liability side because TGA changes can also affect Treasury collateral, repo conditions, money-fund portfolio allocation, and deposit flows directly. The estimates instead provide diagnostic evidence on which margins are empirically relevant for reserve absorption.

Tables 8 and 9 show that foreign-branch reserve adjustment is not matched by one liability category.[20] TGA-induced reserve movements are associated with changes in wholesale funding and borrowing from headquarters, while large time deposits play a smaller and less stable role. The relevant funding mix also varies across QE and QT episodes. In contrast, the analogous exercise for large domestic banks maps reserve movements more closely into deposits. This comparison is important for interpretation: the distinctive feature of foreign branches is not only that they can borrow in federal funds, but that they can combine wholesale funding with internal dollar liquidity from the global organization.

Quarter-end balance-sheet compression, "window dressing," provides a second diagnostic. Window dressing incentives are especially relevant for foreign banks because many non-U.S. jurisdictions, including the euro area and Japan, calculate leverage ratios using quarter-end snapshots, whereas U.S. and U.K. banks also report quarterly average balance sheets. Figure 12 documents systematic quarter-end compression of reserve balances by foreign branches. A large literature documents related quarter-end compression in repo and other balance-sheet-intensive markets (Anbil and Senyuz, 2018; Anderson et al., 2025; Bech and Klee, 2011; Banegas and Tase, 2020; Keating and Macchiavelli, 2017; Munyan et al., 2017).

For each quarter-end q, let $k = 0$ denote the weekly observation ending on or immediately before the calendar quarter-end. For liability component j, define the pre-quarter-end benchmark

$$\overline{L}_{j,q}^{pre} = \frac{1}{4} \sum_{k=-5}^{-2} L_{j,q,k}, \tag{7}$$

[20]Appendix Tables A5 and A6 report the analogous liability decomposition for large domestic banks.

and the abnormal quarter-end adjustment

$$WD_{j,q} = 100 \times \frac{L_{j,q,0} - \overline{L}^{pre}_{j,q}}{\text{Assets}_{q,-1}}. \tag{8}$$

Negative values of $WD_{j,q}$ indicate that the liability margin is lower at quarter-end relative to its recent pre-quarter-end level, measured in percentage points of assets. Table 10 suggests that the liability margin that compresses at quarter-end varies across episodes. Wholesale funding is the most consistent margin of compression, while HQ funding also declines in some periods, especially during QT1. The evidence is descriptive because the limited sample of weekly data do not always coincide exactly with calendar quarter-end and because subperiod cells contain few events. Nonetheless, the quarter-end evidence and the TGA-shock evidence point to the same mechanism: foreign branches do not finance reserves through a single liability margin.

6.4 Global Funding Margins and Reserve Persistence

The balance-sheet evidence points to a broader funding channel behind foreign-branch reserve demand. Reserve positions move with several liability margins, not only with federal funds borrowing, so the relevant funding price is unlikely to be summarized by the IOR–FFR spread alone. We therefore interpret reserve demand as disciplined by a shadow dollar funding cost faced by the global banking organization. This cost may include unsecured CP/CD funding, repo funding, internal transfers from headquarters, and the cost of obtaining dollars through FX swap markets. Because these margins can be managed at the branch, headquarters, or affiliate level, foreign branches may maintain reserve positions even when the narrow IOR–FFR arbitrage spread narrows.

This interpretation is consistent with internal funds-transfer-pricing practice. Global banks use centralized treasury units to allocate funding and liquidity costs across business lines and jurisdictions (Grant, 2011). For a foreign banking organization, the relevant internal dollar price should therefore reflect unsecured dollar funding costs, balance-sheet costs, currency hedging costs, and the cost of obtaining dollars through repo, CP/CD, and FX swap markets (Rime et al., 2022). We do not observe these internal transfer prices directly. We therefore use observable market funding margins as proxies for components of the shadow dollar funding cost faced by the global banking organization.

The main country-level proxy is the three-month FX-hedged reserve margin. The unhedged reserve-rate differential, $IOR_t^{US} - IOR_{c,t}^{home}$, compares the return on reserve balances in the United States with the reserve remuneration rate in the parent bank's home jurisdiction. For example, for a euro-area parent bank such as Deutsche Bank, this spread compares the Federal Reserve's IOR rate with the ECB deposit facility rate. This raw differential is incomplete because a global bank that reallocates liquidity across currencies also faces the cost of obtaining or hedging dollars in the FX swap market. Following Bräuning and Ivashina (2020), the hedged margin asks whether U.S. reserves remain attractive after accounting for this dollar funding component. We define

$$\text{HedgedMargin}_{c,t}^{3M} = \text{IOR}_t^{\text{US}} - \text{IOR}_{c,t}^{\text{home}} + \rho_{c,t}^{3M}, \tag{9}$$

where $\rho_{c,t}^{3M}$ is the annualized three-month FX-swap-implied dollar funding component, with the sign convention that a higher value raises the hedged return to holding U.S. reserves.[21]

The country-level hedged margin is one component of the shadow funding cost. Global banks may also compare IOR with short-term dollar funding rates, including the federal funds rate, repo rates, and unsecured CP/CD rates. The federal funds margin is important for marginal arbitrage, but the market is too small to explain the full stock of foreign-branch reserve holdings. We therefore use the FX-hedged reserve margin as the main country-level price and examine reserve funding composition below.

The empirical analysis uses quarterly Call Report data for U.S. branches and agencies of foreign banks over 2009Q1–2025Q4. Because dollar funding decisions are often made by global treasury at the consolidated banking-organization level, we aggregate branch and agency balance sheets to the top-tier foreign banking organization. The main BHC-level sample includes organizations with positive U.S. branch and agency assets and positive reserve balances. To match each organization to observable home-country reserve rates and FX swap prices, we restrict the sample to parent jurisdictions or currency areas with reliable

[21] Empirically, $\rho_{c,t}^{3M}$ is constructed from spot and three-month forward exchange rates, together with the relevant home-currency short rate. It is the annualized FX-swap component that converts the home-currency reserve return into a hedged dollar return. Equivalently, it is the deviation between the forward-implied dollar funding cost and the corresponding interest-rate differential, expressed so that a larger $\rho_{c,t}^{3M}$ makes U.S. reserves more attractive on an FX-hedged basis.

rate coverage: the euro area, Japan, the United Kingdom, Canada, Switzerland, Sweden, and Australia. These rate-matched jurisdictions account for 81.8% of total foreign-bank reserve holdings over 2009Q1–2025Q4 on a pooled reserve-dollar basis, and the matched share averages 82.4% across quarters.[22]

We estimate two sets of quarterly specifications. The first relates reserve intensity to the FX-hedged return on U.S. reserves:

$$\frac{\text{Reserves}_{i,t}}{\text{Assets}_{i,t}} = \beta_R \text{HedgedMargin}^{3M}_{c(i),t} + \Gamma' X_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{i,t}, \tag{10}$$

where i indexes the foreign banking organization and $c(i)$ is its parent jurisdiction or currency area. $\text{Reserves}_{i,t}$ denotes reserve balances held at the Federal Reserve, and $\text{Assets}_{i,t}$ denotes total U.S. branch and agency assets. The vector $X_{i,t-1}$ contains lagged bank-level controls, including log assets. The organization fixed effect α_i absorbs time-invariant differences across foreign banks, while the quarter fixed effect λ_t absorbs common U.S. monetary-policy and aggregate reserve-supply conditions. Identification therefore comes from cross-jurisdiction variation in the hedged margin within a quarter.

Figure 13 visualizes the identifying variation at the BHC level. We residualize both reserve intensity and the three-month FX-hedged reserve margin with respect to organization fixed effects, quarter fixed effects, and lagged log assets. Panel A plots a binscatter of the residualized reserve-to-asset ratio against the residualized hedged margin, using 20 equal-count bins; the fitted line is estimated on the underlying residualized observations. Panel B groups the same residualized observations into quintiles of the hedged margin and plots the mean residualized reserve-to-asset ratio in each quintile. Both panels show the same pattern: within a given quarter, foreign banking organizations from jurisdictions where U.S. reserves offer a higher FX-hedged return hold more reserves relative to assets.

Table 11 reports the corresponding regressions. A 25 basis point increase in the three-month hedged margin is associated with roughly a 1.5 percentage point higher reserve-to-asset ratio at both the BHC and branch levels. Because the specification absorbs quarter fixed

[22]While the rate-matched sample accounts for a large share of foreign-branch reserve holdings, it does not cover all economically important reserve holders. For example, First Abu Dhabi Bank's DC branch alone held $61.7 billion in reserves in 2022Q3, equal to 6.0% of total foreign-branch reserve holdings. Chinese foreign branches, in aggregate, reached $71.8 billion in reserves in 2020Q4, equal to 12.0% of total foreign-branch reserve holdings in the 2009Q1–2025Q4 sample.

effects, this result is not identified from common movements in the Federal Reserve's balance sheet, aggregate reserve supply, or the aggregate IOR–FF spread. It instead reflects cross-jurisdiction differences in the hedged return to holding U.S. reserves. We interpret this as evidence that global funding margins shape foreign-branch reserve demand, while recognizing that the hedged margin may also capture home-country stress, monetary-policy regimes, or parent-bank balance-sheet conditions.

The second specification relates changes in the hedged margin to changes in funding composition:

$$\frac{\Delta \text{Funding}^{j}_{i,t}}{\text{Assets}_{i,t-1}} = \beta_j \Delta \text{HedgedMargin}^{3M}_{c(i),t} + \Gamma' X_{i,t-1} + \alpha_i + \lambda_t + \varepsilon^{j}_{i,t}, \tag{11}$$

where $\text{Funding}^{j}_{i,t}$ denotes funding category j. The main table focuses on federal funds borrowing, repo borrowing, and headquarters funding, each measured both gross and net of the corresponding asset-side position. Scaling by assets makes the coefficients comparable across banking organizations of very different size and interpretable as percentage-point changes in balance-sheet intensity. Table 12 reports the BHC-level results, and Appendix Table A7 reports the corresponding branch-level estimates.

The funding results also rely on within-quarter cross-jurisdiction variation. The estimates are not identified from common movements in U.S. monetary policy, aggregate reserve supply, QE–QT regimes, or broad dollar funding cycles; those forces are absorbed by λ_t. At the BHC level, a one-percentage-point increase in the hedged margin is associated with a 2.4 percentage point decline in gross repo borrowing scaled by lag assets and a 4.2 percentage point increase in gross HQ funding. The net-borrowing columns give the same qualitative result: net repo borrowing falls by 1.8 percentage points, while net HQ borrowing rises by 6.6 percentage points. The federal funds coefficients are smaller and statistically imprecise. The branch-level estimates in the appendix are similar. Thus, the funding response is not a broad increase in short-term borrowing. It is a shift away from repo funding and toward headquarters funding, consistent with global treasury reallocating dollar liquidity across external secured funding, internal funding, and reserve positions.

Taken together, the quarterly evidence supports a broader interpretation of foreign-branch reserve persistence. Foreign banking organizations hold more reserves when the FX-hedged return to U.S. reserves is higher, using only cross-jurisdiction variation within the same quarter. At the same time, higher hedged margins are associated with a shift away from repo funding and toward headquarters funding, rather than a broad increase in federal funds borrowing. These patterns indicate that foreign-branch reserve demand is shaped by global funding conditions, internal capital markets, and treasury-management decisions, not by the IOR–FFR spread alone. This evidence motivates the model below, which treats foreign banks' reserve-absorption capacity as an uncertain margin for monetary policy implementation.

7 A Model of Reserve Supply under Incomplete Information

The empirical analysis in Sections 5 and 6 shows that reserve demand is heterogeneous across institutions and that foreign banks play an important role in reserve adjustment at the margin. In particular, foreign banks absorb a large share of reserve inflows during balance-sheet expansions, but do not unwind those positions symmetrically during tightening phases. The evidence in Section 6 further suggests that this behavior is tied to the distinctive organizational form of foreign branches and to the role of internal capital markets in shaping their balance-sheet capacity.

This section develops a simple model that maps these empirical findings into the Federal Reserve's operating problem.[23] The Desk chooses reserve supply before the conditions governing reserve demand are fully observed. As a result, the reserve supply required for stable rate control depends not only on average reserve demand, but also on uncertainty about which institutions will absorb reserves at the margin and how much balance-sheet capacity they will have available. A central implication of the model is that greater uncertainty about foreign banks' reserve-absorption capacity raises the Lowest Comfortable Level of Reserves (LCLOR), that is, the minimum level of reserves consistent with sustaining the ample-reserves regime.

7.1 Bank Reserve Demand

There are two bank types, domestic banks, denoted by D, and U.S. branches of foreign banks, denoted by F. Heterogeneity matters because the two groups need not face the same returns, costs, and risks when holding reserves. The incomplete-information friction arises because

[23] We refer to the Open Market Trading Desk of the Federal Reserve simply as "the Desk" throughout the section.

the Desk chooses aggregate reserve supply before those conditions are fully observed.

At the beginning of day t, the Desk supplies aggregate reserves M. After supply is set, each bank type $j \in \{D, F\}$ observes its own demand conditions and chooses excess reserves $X_j \geq 0$. A bank that holds X_j reserves faces three costs. First, if end-of-day payment flows leave it with positive balances, those balances earn the administered reserve rate rather than the market rate. Second, if payment flows leave it short of reserves, the bank incurs a shortfall cost. Third, large reserve positions consume balance-sheet capacity and become increasingly costly once they exceed an institution-specific effective limit.

Let $\eta_{j,t}$ denote the payment-flow shock and $\delta_{j,t}$ the effective balance-sheet limit for type j. Conditional on realized demand conditions, a bank of type j chooses X_j to minimize

$$\min_{X_j \geq 0} \ \mathbb{E}\Big[(i - i_{\text{IOR}})(X_j + \eta_{j,t})_+ + (i_{\text{DW}} - i + \beta_j)(-X_j - \eta_{j,t})_+ + \chi_j(X_j - \delta_{j,t})_+\Big], \tag{12}$$

where i is the market overnight rate, i_{IOR} is the interest rate on reserves, i_{DW} is the discount-window rate, $\beta_j \geq 0$ is the effective penalty from ending the day short of reserves, and $\chi_j > 0$ governs the marginal balance-sheet cost of reserve positions that exceed the effective limit $\delta_{j,t}$. The notation $(x)_+ := \max\{x, 0\}$ denotes the positive part.

Conditional on the realized demand conditions, we assume

$$\eta_{j,t} \mid \bar{\eta}_{j,t} \sim \mathcal{N}\Big(\bar{\eta}_{j,t},\, \sigma^2_{\eta,j}\Big)\,, \tag{13}$$

$$\delta_{j,t} \mid \bar{\delta}_{j,t} \sim \mathcal{N}\Big(\bar{\delta}_{j,t},\, \sigma^2_{\delta,j}\Big)\,. \tag{14}$$

The Desk does not observe the realized means $(\bar{\eta}_{j,t}, \bar{\delta}_{j,t})$ when it chooses supply. Instead, it observes only their prior distributions,

$$\bar{\eta}_{j,t} \sim \mathcal{N}\Big(\mu_{\eta,j},\, \tau^2_{\eta,j}\Big)\,, \tag{15}$$

$$\bar{\delta}_{j,t} \sim \mathcal{N}\Big(\mu_{\delta,j},\, \tau^2_{\delta,j}\Big)\,, \tag{16}$$

with $\tau_{\eta,j}, \tau_{\delta,j} \geq 0$. The parameter $\tau_{\eta,j}$ captures uncertainty about day-to-day liquidity needs, while $\tau_{\delta,j}$ captures uncertainty about the balance-sheet capacity available for holding large reserve positions. Setting $\tau_{\eta,j} = \tau_{\delta,j} = 0$ nests a fixed-demand benchmark.

Given realized demand conditions, optimal reserve demand satisfies the implicit first-order condition

$$(i_{\text{DW}} - i_{\text{IOR}} + \beta_j)\Phi\left(\frac{-X_j^* - \bar{\eta}_{j,t}}{\sigma_{\eta,j}}\right) = (i - i_{\text{IOR}}) + \chi_j \Phi\left(\frac{X_j^* - \bar{\delta}_{j,t}}{\sigma_{\delta,j}}\right), \tag{17}$$

where $\Phi(\cdot)$ is the standard normal cumulative distribution function. The left-hand side is the marginal benefit of precautionary reserves: a larger reserve position lowers the probability of ending the day short. The right-hand side is the marginal cost of carrying reserves: the opportunity cost relative to market funding plus the expected balance-sheet cost of pushing reserve holdings beyond the effective limit.

This formulation generates time-varying reserve demand even when administered rates are fixed. A more negative $\bar{\eta}_{j,t}$ raises precautionary demand because the bank anticipates larger payment outflows. A larger $\bar{\delta}_{j,t}$ raises demand because the bank can absorb reserves at the margin with less balance-sheet strain. In the application to foreign branches, movements in $\bar{\delta}_{F,t}$ summarize the effective balance-sheet capacity created or withdrawn by global funding conditions, reporting incentives, and internal capital-market constraints.

The structure of the demand side builds on Poole (1968), where banks hold reserves to insure against stochastic payment outflows, trading off the opportunity cost of idle balances against the risk of a shortfall that triggers penalty borrowing. However, it expands Poole (1968)'s framework in two ways: (i) it differentiates between domestic and foreign banks; and (ii) it introduces a stochastic balance-sheet capacity constraint, $\delta_{j,t}$, that captures the key trade-offs affecting reserve demand in the ample-reserves regime where $i < i_{\text{IOR}}$ and holding reserves financed in the market can generate profits rather than costs.

Figure 14 shows an illustration of the inverse demand curves for both types of banks and the aggregate.

7.2 Aggregate Demand and Market Clearing

Let

$$\boldsymbol{\theta}_t := (\bar{\eta}_{D,t}, \bar{\delta}_{D,t}, \bar{\eta}_{F,t}, \bar{\delta}_{F,t})$$

collect the latent demand conditions. Aggregate reserve demand is

$$M_{\text{agg}}(i;\boldsymbol{\theta}_t) = X_D^*(i;\bar{\eta}_{D,t},\bar{\delta}_{D,t}) + X_F^*(i;\bar{\eta}_{F,t},\bar{\delta}_{F,t}). \tag{18}$$

For a given realization of $\boldsymbol{\theta}_t$, this schedule summarizes the quantity of reserves the banking system wishes to hold at each overnight rate.

Let $\varepsilon_t \sim \mathcal{N}(0,\sigma_\varepsilon^2)$ denote an aggregate reserve drain that captures Treasury General Account fluctuations and other payment-system noise. Market clearing implies

$$M_{\text{agg}}(i_t;\boldsymbol{\theta}_t) = M - \varepsilon_t, \tag{19}$$

so the clearing rate can be written as

$$i_t = g(M - \varepsilon_t;\boldsymbol{\theta}_t), \tag{20}$$

where $g(\cdot;\boldsymbol{\theta}_t)$ is the inverse demand function associated with the realized demand curve.

Assumption 7.1. The inverse demand function g satisfies:

(i) $g'(M) < 0$ for all relevant M (strictly decreasing);

(ii) $\lim_{M\to\infty} g(M) = i_{\text{floor}}$, where i_{floor} is a reduced-form asymptotic floor.

The microfoundation provides a natural justification for both conditions, but the identity of the bank type that pins i_{floor} depends on the parameter values as well as realization of the random variables determining the bank's demand for reserves.[24]

A key concern for the Desk is the risk that the market rate exceeds a tolerable spike threshold. Let

$$\bar{i} := i_{\text{target}} + \bar{s}, \qquad \bar{s} > 0,$$

where i_{target} is the policy target and $\bar{s}$ is the maximum tolerated overshoot[25]. For a given

[24]Under the current assumption on the banks' problem, each type-j demand goes to infinity as $i \to i_{\text{IOR}} - \chi_j$, so the aggregate floor takes the form $i_{\text{floor}} = \max_j(i_{\text{IOR}} - \chi_j)$.

[25]For example, $i_{\text{target}} = i_{\text{IOR}}$.

realization of $\boldsymbol{\theta}_t$, define the critical reserve level

$$M_{\text{crit}}(\boldsymbol{\theta}_t) := M_{\text{agg}}(\bar{i}; \boldsymbol{\theta}_t). \tag{21}$$

This is the reserve supply at which the market rate exactly reaches the spike threshold under the realized demand conditions. When $M_{\text{crit}}(\boldsymbol{\theta}_t)$ is high, rate control is more fragile because a larger reserve supply is required to keep the overnight rate below $\bar{i}$.

A rate spike occurs when $i_t > \bar{i}$, hence using the market clearing equation and the fact that $g(\cdot; \boldsymbol{\theta}_t)$ is decreasing in its first argument:

$$i_t > \bar{i} \iff M - \varepsilon_t < M_{\text{crit}}(\boldsymbol{\theta}_t) \iff \varepsilon_t > M - M_{\text{crit}}(\boldsymbol{\theta}_t).$$

The corresponding spike probability is therefore

$$\Gamma(M) = \Pr(i_t > \bar{i}) = \mathbb{E}_{\boldsymbol{\theta}}\left[1 - \Phi\left(\frac{M - M_{\text{crit}}(\boldsymbol{\theta}_t)}{\sigma_\varepsilon}\right)\right]. \tag{22}$$

All of the demand-side uncertainty relevant for rate control is summarized by the distribution of $M_{\text{crit}}(\boldsymbol{\theta}_t)$.

7.3 The Desk's Reserve-Supply Problem

We assume the FOMC sets both the target short-term rate $\bar{i}$ and the desired size of its balance sheet, funded through a quantity $\bar{M}$ of reserves.[26] Based on the FOMC decision and before observing either $\boldsymbol{\theta}_t$ or ε_t, the Desk chooses the smallest reserve supply for which the spike probability is acceptable and reserves are enough to finance the desired level of the balance sheet:

$$M^* = \min\left\{M : \Gamma(M) \leq \kappa \text{ and } M \geq \bar{M}\right\}. \tag{23}$$

where $\kappa \in (0, 1)$ is the rate-control tolerance—the maximum probability of a rate spike that the Desk is willing to accept. This formulation gives LCLOR a precise operational definition:

[26]The desired size of the Federal Reserve's balance sheet is partly aimed at influencing longer-term yields. Here, we do not model how monetary policy decisions are made or their effectiveness; we simply take $\bar{i}$ and $\bar{M}$ as exogenous.

the smallest balance sheet consistent with keeping rate spikes sufficiently unlikely, i.e. solving:

$$M' = \min\{M \geq 0 : \Gamma(M) \leq \kappa\}, \tag{24}$$

Notice that M', i.e. the LCLOR, corresponds to M^* when $M' \geq \bar{M}$, which is the case when the desired balance sheet size is low enough that reserves might become scarce. This case can arise during tightening phases. Conversely, when $M' < \bar{M}$, the economy is in a QE-like phase and simply $M^* = \bar{M}$.[27] Hence we have:

$$M^* = \max\{M', \bar{M}\}. \tag{25}$$

This formulation is intentionally conservative. The Desk does not fine-tune supply to the expected rate; instead, it chooses the smallest reserve supply that makes rate spikes sufficiently unlikely. That structure is well suited to the operating problem studied in this paper, where the primary concern is not average rate deviations but loss of control in the upper tail of the rate distribution.

The solution of the Desk's problem can be found with two steps: (i) find M' and (ii) take $M^* = \max\{M', \bar{M}\}$. Given the assumption of independence and normal distribution for $\boldsymbol{\theta}_t$ and ε_t and Assumption 7.1, $\Gamma(\cdot)$ is continuous and strictly decreasing in M with $\Gamma(M) \to 0$ as $M \to \infty$. Therefore, a unique M' such that $\Gamma(M') = \kappa$. exists provided $\kappa < \Gamma(0)$.[28]

Figure 15 shows an illustration of $\Gamma(\cdot)$ and the optimal choices of M^* under an expansionary phase, when $\bar{M}$ is large and $M^* = \bar{M} > M'$, and under a tightening phase, when $\bar{M}$ is small and $M^* = M' > \bar{M}$.

7.4 Closed-form approximation

As discussed in Section 7.3, to solve for the optimal supply of reserves M^* it is necessary to find M' such that $\Gamma(M') = \kappa$ for κ small enough. The function $\Gamma(\cdot)$ can be numerically evaluated using Monte Carlo simulations of $\boldsymbol{\theta}_t$ and ε_t. While we can use this approach for a more precise solution, we can also use a first-order Taylor expansion to derive simple and

[27]This simplification does not mean that the Desk's problem is unimportant during QE; it allows us to focus on the role of foreign banks in determining the LCLOR.

[28]Any tolerance in the empirically relevant range (a few percent) satisfies this condition.

interpretable analytical solutions. All components of $\boldsymbol{\theta}_t$ are independent normals, so a first-order Taylor expansion of $M_{\text{crit}}(\boldsymbol{\theta}_t)$ around the prior means $\boldsymbol{\mu}$ yields a normally distributed approximation for M_{crit}, which in turn allows $\Gamma(M)$ to be computed in closed form without Monte Carlo simulation.

For each bank type j, we can expand $X_j^*(i;\, \bar{\eta}_{j,t}, \bar{\delta}_{j,t})$ around $(\mu_{\eta,j}, \mu_{\delta,j})$:

$$X_j^*\left(i;\, \bar{\eta}_{j,t}, \bar{\delta}_{j,t}\right) \approx X_j^*(i;\, \mu_{\eta,j}, \mu_{\delta,j}) + \frac{\partial X_j^*}{\partial \bar{\eta}_j}(\bar{\eta}_{j,t} - \mu_{\eta,j}) + \frac{\partial X_j^*}{\partial \bar{\delta}_j}\left(\bar{\delta}_{j,t} - \mu_{\delta,j}\right), \tag{26}$$

where all partial derivatives are evaluated at the prior means. These sensitivities are obtained by implicit differentiation of Equation 17. Differentiating with respect to $\bar{\eta}_j$ and $\bar{\delta}_j$, and denoting the common denominator

$$\mathcal{D}_j \equiv \frac{i_{\text{DW}} - i_{\text{IOR}} + \beta_j}{\sigma_{\eta,j}}\, \phi\left(\frac{-X_j^* - \mu_{\eta,j}}{\sigma_{\eta,j}}\right) + \frac{\chi_j}{\sigma_{\delta,j}}\, \phi\left(\frac{X_j^* - \mu_{\delta,j}}{\sigma_{\delta,j}}\right) > 0, \tag{27}$$

where $\phi(\cdot)$ is the probability distribution function of a standard normal distribution, one obtains[29]:

$$\frac{\partial X_j^*}{\partial \bar{\eta}_j} = -\frac{1}{\mathcal{D}_j} \cdot \frac{i_{\text{DW}} - i_{\text{IOR}} + \beta_j}{\sigma_{\eta,j}}\, \phi\left(\frac{-X_j^* - \mu_{\eta,j}}{\sigma_{\eta,j}}\right), \tag{28}$$

$$\frac{\partial X_j^*}{\partial \bar{\delta}_j} = \frac{1}{\mathcal{D}_j} \cdot \frac{\chi_j}{\sigma_{\delta,j}}\, \phi\left(\frac{X_j^* - \mu_{\delta,j}}{\sigma_{\delta,j}}\right). \tag{29}$$

Remark 7.2. The signs of these derivatives have a simple economic interpretation. A more negative value of $\bar{\eta}_j$ corresponds to larger expected payment outflows and therefore raises precautionary reserve demand. A higher value of $\bar{\delta}_j$ corresponds to greater effective balance-sheet capacity to absorb reserves at the margin and therefore also raises reserve demand. The relative magnitudes depend on which force is more important for a given bank type: when payment risk dominates, demand responds more strongly to $\bar{\eta}_j$; when balance-sheet capacity is the binding margin, demand responds more strongly to $\bar{\delta}_j$.

Under the linear approximation (26), evaluated at the spike threshold $\bar{i}$, the critical reserve

[29] Note that $\mathcal{D}_j$ is precisely the denominator that appears in $\partial X_j^*/\partial i$, so no additional solver calls are needed beyond those already required to evaluate the demand curve and its interest-rate derivative.

level is:

$$M_{\text{crit}}(\boldsymbol{\theta}_t) \approx \bar{M}_{\text{crit}} + \sum_{j\in\{D,F\}} \left[\frac{\partial X_j^*}{\partial \bar{\eta}_j} (\bar{\eta}_{j,t} - \mu_{\eta,j}) + \frac{\partial X_j^*}{\partial \bar{\delta}_j} \left(\bar{\delta}_{j,t} - \mu_{\delta,j} \right) \right], \tag{30}$$

where $\bar{M}_{\text{crit}} \equiv M_{\text{agg}}(\bar{i};\, \boldsymbol{\mu})$ is the critical level evaluated at the prior means.

Since $\bar{\eta}_{j,t}$ and $\bar{\delta}_{j,t}$ are mutually independent normals, $M_{\text{crit}}(\boldsymbol{\theta}_t)$ is approximately normally distributed:

$$M_{\text{crit}}(\boldsymbol{\theta}_t) \;\sim\; \mathcal{N}\Big(\bar{M}_{\text{crit}},\; V_{\text{crit}}\Big), \tag{31}$$

with variance:

$$V_{\text{crit}} \equiv \sum_{j\in\{D,F\}} \left[\left(\frac{\partial X_j^*}{\partial \bar{\eta}_j} \right)^2 \tau_{\eta,j}^2 + \left(\frac{\partial X_j^*}{\partial \bar{\delta}_j} \right)^2 \tau_{\delta,j}^2 \right]. \tag{32}$$

Since $\varepsilon_t \sim \mathcal{N}(0, \sigma_\varepsilon^2)$ is independent of $\boldsymbol{\theta}_t$, the difference $M - M_{\text{crit}}(\boldsymbol{\theta}_t) - \varepsilon_t$ is approximately normal with mean $M - \bar{M}_{\text{crit}}$ and variance $\sigma_\varepsilon^2 + V_{\text{crit}}$. Equation (22) therefore reduces to:

$$\Gamma(M) \approx 1 - \Phi\left(\frac{M - \bar{M}_{\text{crit}}}{\sqrt{\sigma_\varepsilon^2 + V_{\text{crit}}}} \right). \tag{33}$$

This is a single normal CDF evaluation requiring no simulation. Demand uncertainty enters only through V_{crit}, which inflates the effective standard deviation from σ_ε to $\sqrt{\sigma_\varepsilon^2 + V_{\text{crit}}}$.

Inverting $\Gamma(M') = \kappa$ using (33) gives an explicit expression for the LCLOR:

$$M' \approx \bar{M}_{\text{crit}} + \Phi^{-1}(1-\kappa)\,\sqrt{\sigma_\varepsilon^2 + V_{\text{crit}}}. \tag{34}$$

The LCLOR thus decomposes into two terms: the expected critical reserve level $\bar{M}_{\text{crit}}$, and a precautionary buffer $\Phi^{-1}(1-\kappa)\sqrt{\sigma_\varepsilon^2 + V_{\text{crit}}}$ that rises with total drain volatility. The latter reflects both supply-side disturbances, through σ_ε^2, and demand-side uncertainty, through V_{crit}.

7.5 Implications

Equation (34) makes the model's central policy implication precise: even if expected reserve demand is unchanged, greater uncertainty about the *distribution* of marginal reserve demand raises the reserve supply needed for stable rate control. In the paper's application this uncertainty is concentrated in foreign branches' effective balance-sheet capacity, summarised by $\tau_{\delta,F}$, which governs the spread of $\bar{\delta}_{F,t}$ and hence the volatility of V_{crit}.

When $\tau_{\delta,F}$ increases, the Desk becomes less certain about how much reserves foreign branches demand at the margin. The distribution of $M_{\text{crit}}(\boldsymbol{\theta}_t)$ becomes more dispersed, so the probability of an overnight rate spike is higher at any given reserve supply. To keep upper-tail rate risk below the tolerance κ, the Desk must hold a larger precautionary buffer.

This mechanism is especially relevant during quantitative tightening (QT), when the Federal Reserve seeks to reduce its balance sheet consistent with effective rate control. As reserves become scarcer, the Desk operates closer to the LCLOR constraint, so uncertainty about how much of the remaining reserve supply foreign branches will absorb at the margin becomes increasingly consequential. A higher $\tau_{\delta,F}$ directly raises the precautionary buffer $\Phi^{-1}(1-\kappa)\sqrt{\sigma_\varepsilon^2 + V_{\text{crit}}}$ and therefore the LCLOR itself, limiting the Fed's capacity to shrink its balance sheet without sacrificing rate-control objectives.

The recent QT episodes illustrate why this uncertainty could be revealed at exactly the wrong moment. Periods of stress in global funding markets, reflected, for example, in flight-to-safety behaviors of financial institutions worldwide and especially elevated net-due-from-headquarters balances, can sharply affect foreign branches' effective balance-sheet capacity, while simultaneously making that capacity harder to forecast. When such episodes coincide with an active tightening phase, the implied increase in $\tau_{\delta,F}$ raises the LCLOR precisely when the Desk is attempting to reduce reserve supply, closing the operational space of the Desk that is not predictable from aggregate reserve quantities alone.

More broadly, the model clarifies why aggregate reserve quantities are not sufficient statistics for implementation risk. The same aggregate level of reserves can be associated with very different rate-control risk depending on how uncertain the cross-sectional distribution of marginal reserve demand is, a dimension that is invisible in aggregate data but central to the Desk's operational problem.

8 Conclusion

This paper studies how foreign banks shape reserve demand and the limits of balance-sheet normalization under the Federal Reserve's ample-reserves framework. Although foreign banks account for a modest share of U.S. banking activity, they hold a disproportionate share of reserve balances. Using high-frequency reserve-supply shocks, we show that reserve adjustment is asymmetric across policy phases: foreign banks absorb a large share of reserve inflows during QE, but do not shed reserves symmetrically during QT. Instead, adjustment shifts mainly toward large domestic banks.

We trace this asymmetry to the institutional structure of foreign banks. Branches and agencies operate as extensions of global banking organizations, face different marginal balance-sheet costs, and can reallocate dollar liquidity through internal capital markets. The evidence suggests that foreign-branch reserve persistence is not explained by the IOR–FFR spread alone. Reserve holdings are associated with multiple liability margins, including wholesale funding and headquarters funding, and are higher when the FX-hedged return to holding U.S. reserves is higher.

These findings speak to a broader policy question: what determines reserve scarcity under an ample-reserves regime? In our model, the Desk chooses reserve supply under incomplete information, and uncertainty about foreign banks' reserve-absorption capacity raises the minimum reserve supply required for stable short-term rate control. Aggregate reserve quantities alone are therefore not sufficient statistics for implementation. The cross-sectional distribution of reserves, and the global nature of the institutions that hold them, also shape how far the Federal Reserve can normalize its balance sheet without disrupting money markets.

Balance-sheet normalization is constrained not only by aggregate liquidity needs, but also by who holds reserves and how flexibly they can adjust them. Because foreign banks' reserve demand is linked to internal capital markets and global funding conditions, reserve scarcity under an ample-reserves regime has an international dimension beyond domestic money markets.

References

Viral V Acharya and Raghuram Rajan. Liquidity, liquidity everywhere, not a drop to use–why flooding banks with central bank reserves may not expand liquidity. Technical report, National Bureau of Economic Research, 2022.

Viral V Acharya, Rahul S Chauhan, Raghuram Rajan, and Sascha Steffen. Liquidity dependence and the waxing and waning of central bank balance sheets. Technical report, National Bureau of Economic Research, 2023.

Gara Afonso, Marco Cipriani, and Gabriele La Spada. Banks' Balance-Sheet Costs, Monetary Policy, and the ON RRP. *SSRN Electronic Journal*, 2022a. ISSN 1556-5068. doi: 10.2139/ssrn.4308896. URL https://www.ssrn.com/abstract=4308896.

Gara Afonso, Darrell Duffie, Lorenzo Rigon, and Hyun Song Shin. How abundant are reserves? evidence from the wholesale payment system. Technical report, National Bureau of Economic Research, 2022b.

Gara Afonso, Domenico Giannone, Gabriele La Spada, and John C Williams. Scarce, abundant, or ample? a time-varying model of the reserve demand curve. Technical report, Staff report, 2022c.

Gara Afonso, Gabriele La Spada, Thomas M Mertens, and John C Williams. The optimal supply of central bank reserves under uncertainty. Staff Report 1077, Federal Reserve Bank of New York, 2023.

Gara Afonso, Marco Cipriani, JC Martinez, and Matthew Plosser. Reserves and where to find them. https://libertystreeteconomics.newyorkfed.org/2025/06/reserves-and-where-to-find-them/, June 2025. URL https://libertystreeteconomics.newyorkfed.org/2025/06/reserves-and-where-to-find-them/. Liberty Street Economics, Federal Reserve Bank of New York.

Iñaki Aldasoro, Torsten Ehlers, and Egemen Eren. Global banks, dollar funding, and regulation. *Journal of International Economics*, 137:103609, 2022.

Sriya Anbil and Zeynep Senyuz. The regulatory and monetary policy nexus in the repo market. *Working paper*, 2018.

Sriya Anbil, Alyssa Anderson, and Zeynep Senyuz. What happened in money markets in september 2019? Feds notes, Board of Governors of the Federal Reserve System, Washington, DC, February 2020. URL https://doi.org/10.17016/2380-7172.2527.

Sriya Anbil, Sebastian Infante, and Zeynep Senyuz. A tale of demand and supply for central bank reserves. *Working Paper*, 2025.

Alyssa Anderson, Wenxin Du, and Bernd Schlusche. Arbitrage capital of global banks. *The Journal of Finance*, 80(5):2591–2638, 2025.

Ayelen Banegas and Manjola Tase. Reserve balances, the federal funds market and arbitrage in the new regulatory framework. *Journal of Banking & Finance*, 118:105893, 2020.

Michael S. Barr. Efficient and effective central banking: Beyond the balance sheet. Speech, Board of Governors of the Federal Reserve System, New York, NY, May 2026. URL https://www.federalreserve.gov/newsevents/speech/barr20260514a.htm. Speech at the Money Marketeers of New York University.

Basel Committee on Banking Supervision. Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools. Technical report, Bank for International Settlements, 2013. URL https://www.bis.org/publ/bcbs238.htm. Retrieved from Bank for International Settlements.

Basel Committee on Banking Supervision. Basel III leverage ratio framework and disclosure requirements. Technical report, Bank for International Settlements, 2014. URL https://www.bis.org/publ/bcbs270.htm. Retrieved from Bank for International Settlements.

Basel Committee on Banking Supervision. Revisions to the Basel III leverage ratio framework. Technical report, Bank for International Settlements, 2017a. URL https://www.bis.org/bcbs/publ/d365.htm. Retrieved from Bank for International Settlements.

Basel Committee on Banking Supervision. Finalising Basel III - In brief. Technical report, Bank for International Settlements, 2017b. URL https://www.bis.org/bcbs/publ/d424_inbrief.pdf. Retrieved from Bank for International Settlements.

Morten L Bech and Elizabeth Klee. The mechanics of a graceful exit: Interest on reserves and segmentation in the federal funds market. *Journal of Monetary Economics*, 58(5): 415–431, 2011.

Efraim Benmelech. An empirical analysis of the fed's term auction facility. Technical report, National Bureau of Economic Research, 2012.

Jose Berrospide, Ricardo Correa, Linda Goldberg, and Friederike Niepmann. International banking and cross-border effects of regulation: Lessons from the united states. Technical report, National Bureau of Economic Research, 2016.

Javier Bianchi and Saki Bigio. Banks, liquidity management, and monetary policy. *Econometrica*, 90(1):391–454, 2022.

Saki Bigio and Yuliy Sannikov. A model of credit, money, interest, and prices. Technical report, National Bureau of Economic Research, 2021.

Board of Governors of the Federal Reserve System. History of the fomc's policy normalization discussions and communications, 2025. URL https://www.federalreserve.gov/monetarypolicy/policy-normalization-discussions-communications-history.htm. Accessed January 2026; documents evolution of FOMC policy normalization discussions and communications.

Claudio Borio. Getting up from the floor. *SUERF Policy Notes*, 2023.

David Bowman. Historical proxies for the secured overnight financing rate, July 2019. URL https://doi.org/10.17016/2380-7172.2386.

Michelle W. Bowman. Thoughts on monetary policy decisionmaking and challenges ahead. Speech at the Forecasters Club of New York Luncheon, New York, NY, 2025. URL https://www.federalreserve.gov/newsevents/speech/bowman20250926a.htm. Vice Chair for Supervision.

Falk Bräuning. The liquidity effect of the federal reserve's balance sheet reduction on short-term interest rates. Current Policy Perspectives 18-1, Federal Reserve Bank of Boston, 2017.

Falk Bräuning and Victoria Ivashina. Monetary policy and global banking. *The Journal of Finance*, 75(6):3055–3095, 2020.

Mark A Carlson, Stefania D'Amico, Cristina Fuentes-Albero, Bernd Schlusche, and Paul R Wood. Issues in the use of the balance sheet tool. *FEDS Working Paper*, 2020.

Nicola Cetorelli and Linda S Goldberg. Global banks and international shock transmission: Evidence from the crisis. *IMF Economic review*, 59(1):41–76, 2011.

Adam Copeland, Darrell Duffie, and Yilin Yang. Reserves were not so ample after all. *The Quarterly Journal of Economics*, 140(1):239–281, 2025.

Ricardo Correa, Wenxin Du, and Gordon Y Liao. Us banks and global liquidity. Technical report, National Bureau of Economic Research, 2020.

Sergio Correia, Stephan Luck, and Emil Verner. Failing banks. *Available at SSRN 4650834*, 2024.

Ted Cruz. Sens. cruz, scott lead bill to stop federal reserve from paying interest on bank reserves. Press Release, U.S. Senate, July 2025. URL https://www.cruz.senate.gov/newsroom/press-releases/sens-cruz-scott-lead-bill-to-stop-federal-reserve-from-paying-interest-on-bank-reserves. Fiscal Accountability for Interest on Reserves (FAIR) Act.

Stefania D'Amico and Corey Feldman. Balance sheet policy uncertainty and its aggregate implications. *FRB of Chicago Working Paper*, 2024.

Matthew Darst, Sotirios Kokas, Alexandros Kontonikas, José-Luis Peydró, and Alexandros Vardoulakis. QE, bank liquidity risk management, and non-bank funding: Evidence from US administrative data. *FEDS Working Paper*, 2025.

Adrien d'Avernas, Damon Petersen, and Quentin Vandeweyer. The central bank's balance sheet and treasury market disruptions. *ECB Working Paper*, 2025.

William F Diamond, Zhengyang Jiang, and Yiming Ma. The reserve supply channel of unconventional monetary policy. Technical report, National Bureau of Economic Research, 2023.

James DiSalvo. How foreign banks changed after dodd–frank. *Federal Reserve Bank of Philadelphia Economic Insights (USA)*, 3:1–6, 2019.

Itamar Drechsler, Alexi Savov, and Philipp Schnabl. The deposits channel of monetary policy. *The Quarterly Journal of Economics*, 132(4):1819–1876, 2017.

Itamar Drechsler, Alexi Savov, and Philipp Schnabl. Banking on deposits: Maturity transformation without interest rate risk. *The Journal of Finance*, 76(3):1091–1143, 2021.

Basile Dubois and Paul Rintamäki. Banking under large excess reserves. *Working paper*, 2025.

Burcu Duygan-Bump and R. Jay Kahn. The central bank balance-sheet trilemma. *FEDS Notes*, January 2026. doi: 10.17016/2380-7172.3979. URL `https://doi.org/10.17016/2380-7172.3979`.

Stefania D'Amico and Tim Seida. Unexpected supply effects of quantitative easing and tightening. *The Economic Journal*, 134(658):579–613, 2024.

Jens Eisenschmidt, Yiming Ma, and Anthony Lee Zhang. Monetary policy transmission in segmented markets. *Journal of Financial Economics*, 151:103738, 2024.

Egemen Eren, Timothy Jackson, and Giovanni Lombardo. Optimal central bank balance sheets. *Working paper*, 2024.

Federal Open Market Committee. Policy normalization principles and plans, September 2014. URL `https://www.federalreserve.gov/monetarypolicy/files/FOMC_PolicyNormalization.pdf`. Adopted effective September 16, 2014.

José Fillat, Arthur Smith, and Stefania Garetto. To branch or not to branch? a quantitative evaluation of the consequences of global banks' organization. In *2018 Meeting Papers*, number 1079 in Meeting Papers. Society for Economic Dynamics, 2018.

Milton Friedman. *A Program for Monetary Stability*. Fordham University Press, New York, 1959.

Joseph E Gagnon and Brian Sack. *Monetary policy with abundant liquidity: a new operating framework for the Federal Reserve*. Peterson Institute for International Economics, 2014.

Stefan Gissler and Borghan Narajabad. Intraday liquidity management and the value of flexibility. *Available at SSRN 5609030*, oct 2025. URL `https://ssrn.com/abstract=5609030`.

Itay Goldstein, Ming Yang, and Yao Zeng. Payments, reserves, and financial fragility. *Available at SSRN 4547329*, 2023.

Marvin Goodfriend. Interest on reserves and monetary policy. *Economic Policy Review*, 8(1), 2002.

Joel Grant. *Liquidity transfer pricing: a guide to better practice*. Financial Stability Institute [and] Bank for International Settlements, 2011.

Robin Greenwood, Samuel G Hanson, Jeremy C Stein, et al. The federal reserve's balance sheet as a financial-stability tool. *Innovative Federal Reserve Policies During the Great Financial Crisis*, pages 63–124, 2016.

Robert E Hall and Ricardo Reis. Maintaining central-bank solvency under new-style central banking. *Hoover Institution, Stanford University, and Columbia University*, 2013.

James D Hamilton. Measuring the liquidity effect. *The American Economic Review*, pages 80–97, 1997.

Chris Hughes and Josh Younger. The price of the floor: Quantifying the cost of ample reserves in u.s. monetary policy implementation. Technical report, The Brookings Institution, February 2026. URL `https://www.brookings.edu/wp-content/uploads/2026/02/Hughes-Younger-report_Feb.-2026.pdf`. Accessed: 2026-03-24.

Jane E Ihrig and Scott Wolla. Let's close the gap: Revising teaching materials to reflect how the federal reserve implements monetary policy. *FEDS Working Paper*, 2020.

Ali Haider Ismail and Diego Zúñiga. Welfare implications of reserve regimes. Working paper, Working paper, jan 2026. URL `https://ahismail.net/files/ismail-zuniga-welfare.pdf`.

Victoria Ivashina, David S Scharfstein, and Jeremy C Stein. Dollar funding and the lending behavior of global banks. *The Quarterly Journal of Economics*, 130(3):1241–1281, 2015.

R Jay Kahn, Matthew McCormick, Vy Nguyen, Mark Paddrik, and H Peyton Young. Anatomy of the repo rate spikes in september 2019. *Journal of Financial Crises*, 5(4):1–25, 2023.

Sebnem Kalemli-Özcan. Us monetary policy and international risk spillovers. Technical report, National Bureau of Economic Research, 2019.

Anil K Kashyap and Jeremy C Stein. What do a million observations on banks say about the transmission of monetary policy? *American Economic Review*, 90(3):407–428, 2000.

Anil K Kashyap and Jeremy C Stein. The optimal conduct of monetary policy with interest on reserves. *American Economic Journal: Macroeconomics*, 4(1):266–282, 2012.

Thomas Keating and Marco Macchiavelli. Interest on reserves and arbitrage in post-crisis money markets. *FEDS Working Paper*, 2017.

Bradley Keoun. Foreign banks used fed secret lifeline most at crisis peak. *Bloomberg Business*, April 2011. URL `http://www.bloomberg.com/news/articles/2011-04-01/foreignbanks-tapped-fed-s-lifeline-most-as-bernanke-kept-borrowers-secret`.

Duhyeong Kim. Interbank markets, foreign banks, and monetary policy under a floor system. Available at SSRN, December 2025. URL `https://ssrn.com/abstract=4922179`.

Ricardo Lagos and Gastón Navarro. Monetary policy operations: Theory, evidence, and tools for quantitative analysis. Technical report, National Bureau of Economic Research, 2023.

Lorie K. Logan. Observations on implementing monetary policy in an ample-reserves regime. Technical report, Federal Reserve Bank of New York, April 2019. URL `https://www.newyorkfed.org/newsevents/speeches/2019/log190417`. Speech delivered on April 17, 2019.

David Lopez-Salido and Annette Vissing-Jorgensen. Reserve demand, interest rate control, and quantitative tightening. *Interest Rate Control, and Quantitative Tightening (February 27, 2023)*, 2023.

Loretta J Mester. The Fed's Ample Reserves Monetary Policy Operating Framework: It Isn't as Simple as It Looks. *Speech*, 2024.

Atif Mian and Amir Sufi. Credit supply and housing speculation. *The Review of Financial Studies*, 35(2):680–719, 2022.

Stephen I. Miran. Regulatory dominance of the federal reserve's balance sheet. Speech, November 2025. URL https://www.federalreserve.gov/newsevents/speech/miran20251119a.htm. Speech delivered November 19, 2025.

Juan M Morelli, Pablo Ottonello, and Diego J Perez. Global banks and systemic debt crises. *Econometrica*, 90(2):749–798, 2022.

Benjamin Munyan et al. *Regulatory arbitrage in repo markets*. SSRN, 2017.

Bill Nelson. From the floor back to the corridor: Why the choice of monetary policy implementation framework matters, September 2024a. URL https://bpi.com/from-the-floor-back-to-the-corridor-why-the-choice-of-monetary-policy-implementation-framework-matters/. Bank Policy Institute.

Bill Nelson. How the federal reserve got so huge, and why and how it can shrink. Technical Report Staff Working Paper 2024-1, Bank Policy Institute, February 2024b. URL https://bpi.com/wp-content/uploads/2024/02/How-the-Federal-Reserve-Got-So-Huge-and-Why-and-How-It-Can-Shrink.pdf. Staff Working Paper, February 7, 2024.

Friederike Niepmann. Banking across borders with heterogeneous banks. *Journal of International Economics*, 142:103748, 2023.

Friederike Niepmann and Leslie Sheng Shen. Geopolitical risk and global banking. *Available at SSRN*, 2024.

Roberto Perli. Balance sheet normalization: Monitoring reserve conditions and understanding repo market pressures. Technical report, Federal Reserve Bank of New York, 2024a.

Roberto Perli. Facing quarter-end pressures: Understanding the repo market and federal reserve tools. Technical report, Federal Reserve Bank of New York, 2024b.

Roberto Perli. Reflections on the early days of reserve management purchases and the maintenance of ample reserves. Speech, Federal Reserve Bank of New York, mar 2026. URL https://www.newyorkfed.org/newsevents/speeches/2026/per260326. Remarks before the Money Marketeers of New York University, New York City.

William Poole. Commercial bank reserve management in a stochastic model: implications for monetary policy. *The Journal of finance*, 23(5):769–791, 1968.

Dagfinn Rime, Andreas Schrimpf, and Olav Syrstad. Covered interest parity arbitrage. *The Review of Financial Studies*, 35(11):5185–5227, 2022.

Paul Santoro. The evolution of treasury cash management during the financial crisis. *Current Issues in Economics and Finance*, 18(3), 2012.

Christopher A Sims. Paper money. *American Economic Review*, 103(2):563–584, 2013.

A Lee Smith and Victor J Valcarcel. The financial market effects of unwinding the federal reserve's balance sheet. *Journal of Economic Dynamics and Control*, 146:104582, 2023.

Quentin Vandeweyer, Adrien d'Avernas, Antoine Hubert de Fraisse, and Liming Ning. The fiscal cost of quantitative easing. *Available at SSRN 5314990*, 2024.

Annette Vissing-Jorgensen. Fluctuations in the treasury general account and their effect on the fed's balance sheet. Feds notes, Board of Governors of the Federal Reserve System, August 2025. URL `https://doi.org/10.17016/2380-7172.3873`. FEDS Notes, August 6, 2025.

Larry Wall. Interest on reserves. *Notes from the Vault*, 2017.

Neil Wallace. A modigliani-miller theorem for open-market operations. *The American Economic Review*, 71(3):267–274, 1981.

Yilin David Yang. What quantity of reserves is sufficient? *Available at SSRN 3721785*, 2020.

Figures

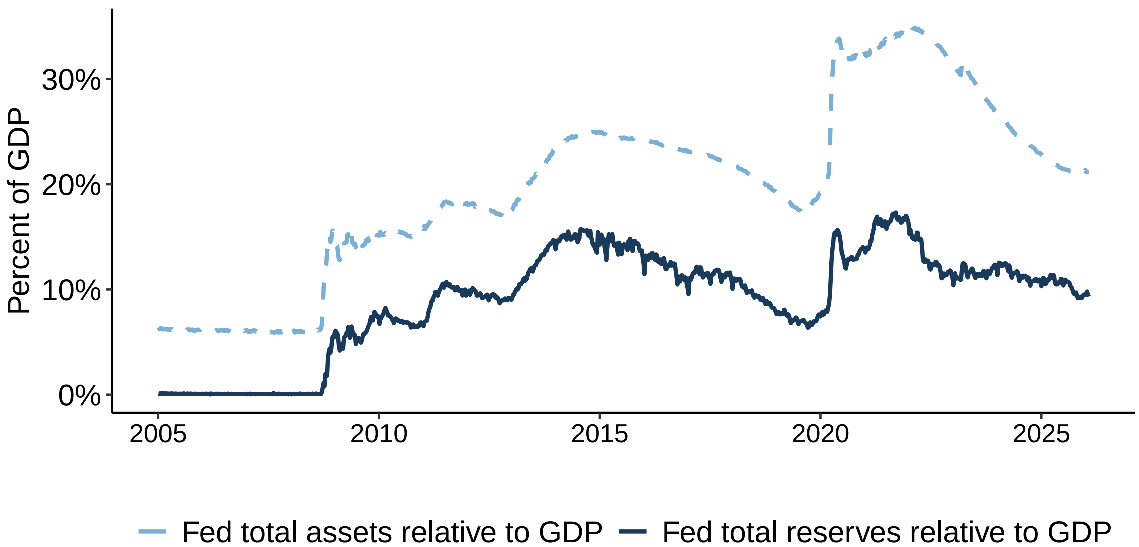

Figure 1: Federal Reserve Balance Sheet Relative to GDP. Weekly ratios of total Federal Reserve assets (WALCL) and reserve balances (WRESBAL) to U.S. GDP. GDP is quarterly and linearly interpolated to weekly frequency. Source: Federal Reserve Board H.4.1 Factors Affecting Reserve Balances and FRED.

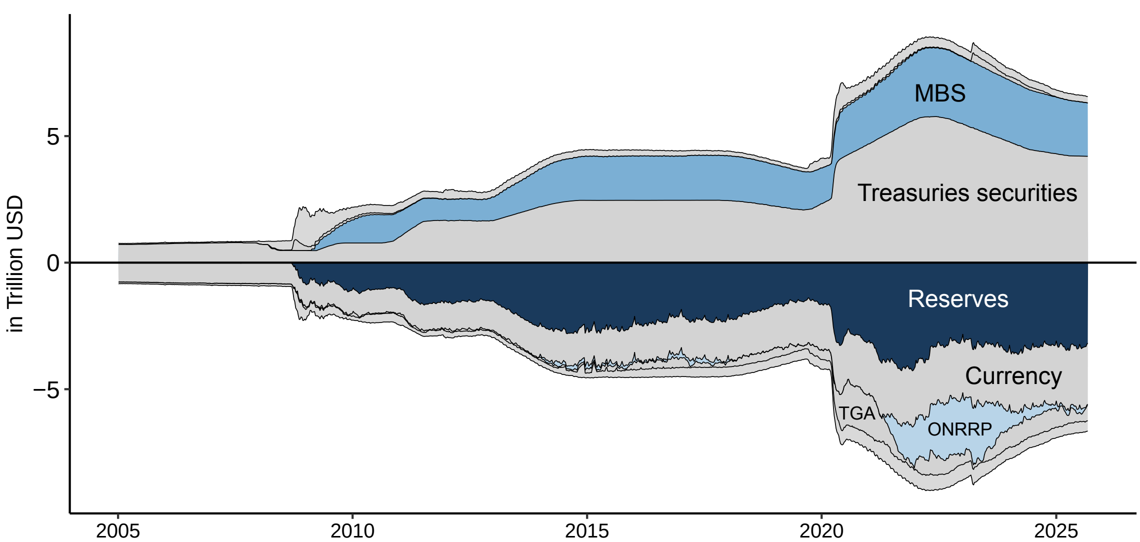

Figure 2: Federal Reserve Balance Sheet Breakdown. Composition of the Federal Reserve's balance sheet from 2005 to the present, highlighting the key components used in this paper. Source: Federal Reserve Board H.4.1 Factors Affecting Reserve Balances.

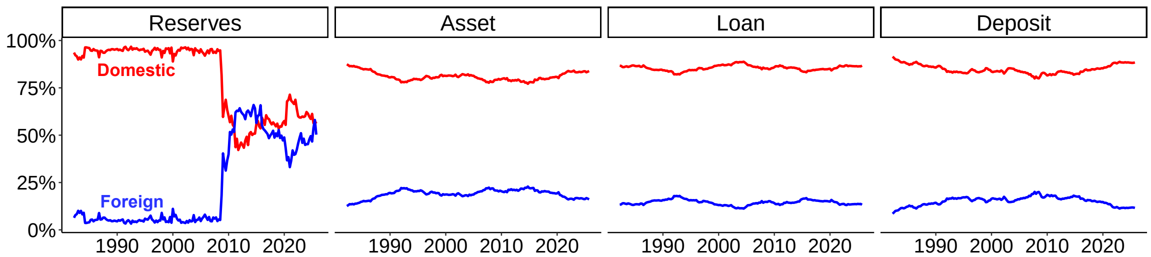

Figure 3: Share of Balance Sheet Components: Domestic Banks and Foreign Banks This figure shows the assets, loans, deposits, and reserves of the domestic banks and foreign banks (the aggregate sum of subsidiaries and branches and agencies) from 1980Q2 to 2025Q4 based on Call Report filings. The plots are adjusted for window-dressing. For non window dressing adjusted plot, see Figure A1. Source: FFIEC 002, 031, 041 reports

Figure 4: Reserve Holdings by Bank Type This figure plots the evolution of reserve balances (proxied by cash holdings) among banks from 2008 to 2025, distinguishing between domestic large banks (Top 25 banks by asset size), domestic small banks, and U.S. branches of foreign banks. Panel A shows the total level of reserve holdings (in billions of dollars). Panel B displays the share of total U.S. banking system reserve held by each bank type. Panel C presents the ratio of reserve to total assets. Vertical dotted lines indicate calendar year-ends. Source: Federal Reserve's H.8 release.

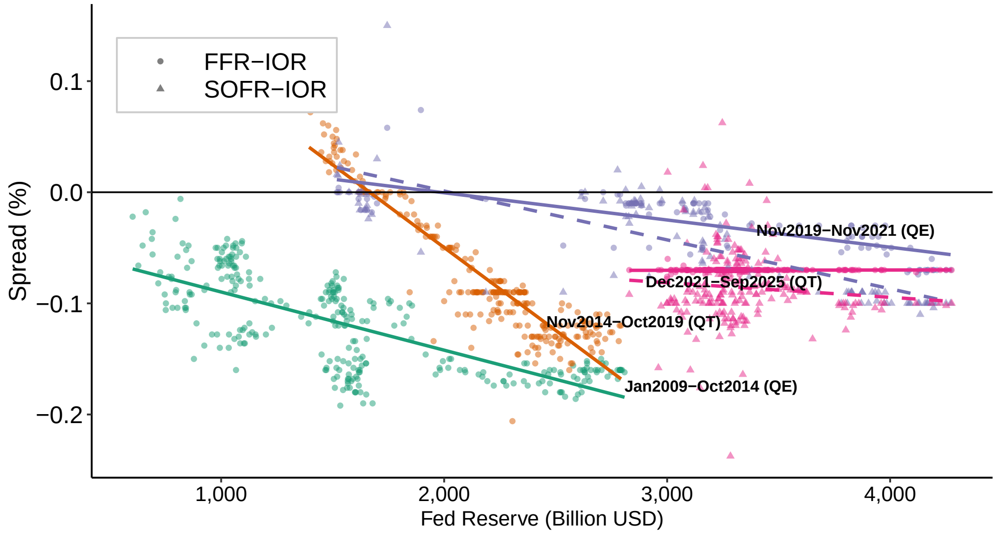

Figure 5: Funding Spreads and Aggregate Reserve Balances This figure plots the spread between the Federal Funds Rate (FFR) and interest on reserves (IOR) against aggregate reserve balances at the Federal Reserve, measured at weekly frequency. Observations are grouped into four monetary policy regimes: QE (January 2009 to October 2014), QT (November 2014 to October 2019), QE (November 2019 to November 2021), and QT (December 2021 to December 2025). Solid lines show FFR-IOR spreads; dashed lines show SOFR-IOR spreads for post-November 2019 periods. Each point represents a weekly observation; fitted lines are estimated by OLS within each regime. Source: FRED (DFF, IORB, IOER, SOFR, WRESBAL)

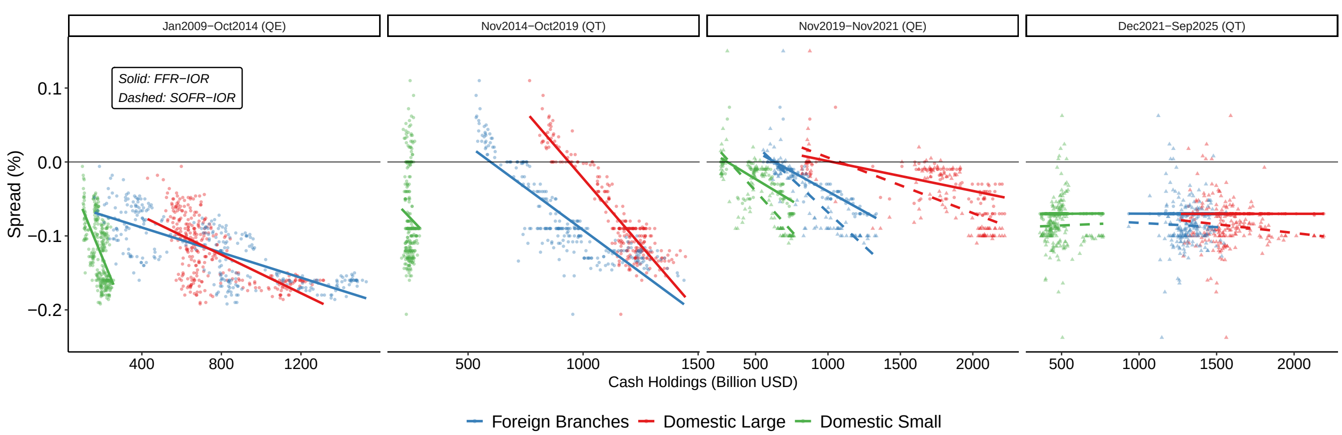

Figure 6: Reserve Holdings and Funding Spreads by Bank Type This figure plots reserve holdings against the FFR-IOR spread for three bank types: foreign branches (blue), large domestic banks (red), and small domestic banks (green). Each panel corresponds to a monetary policy regime. Solid lines represent FFR-IOR relationships; dashed lines represent SOFR-IOR relationships (available for post-2019 periods only). Reserve holdings are measured weekly from the Federal Reserve H.8 release, proxied by cash holdings. Source: FRED (H.8 cash assets by bank type, DFF, SOFR, IORB, IOER).

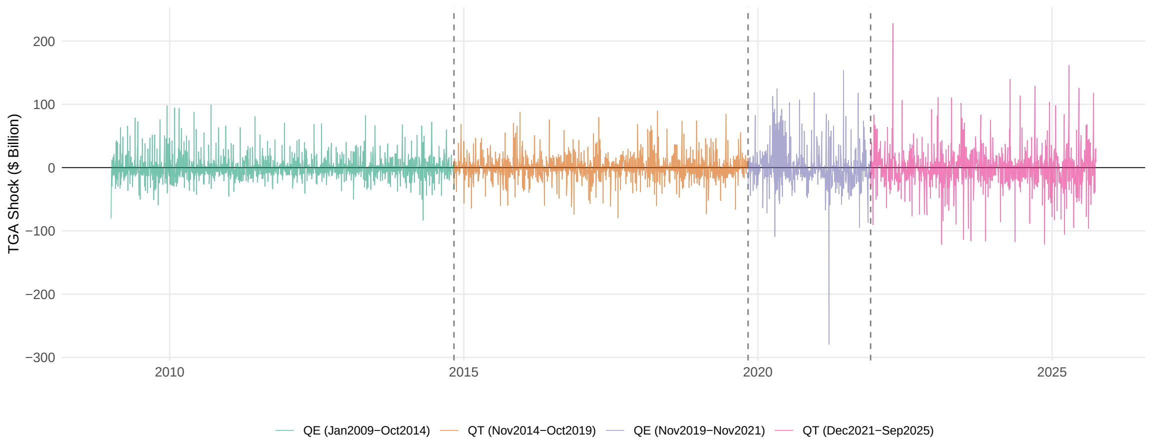

Figure 7: Daily Treasury General Account (TGA) Shocks This figure plots the daily unanticipated TGA shock, constructed as the residual from regressing daily changes in the TGA balance on calendar fixed effects (beginning/end of month, beginning/end of quarter, day of week) and anticipated Treasury issuance flows. Positive values represent reserve drains; negative values represent reserve injections. Vertical dashed lines indicate regime transitions. Colors denote monetary policy phases: QE (January 2009 to October 2014), QT (November 2014 to October 2019), QE (November 2019 to November 2021), and QT (December 2021 to December 2025). Source: U.S. Treasury Daily Treasury Statement.

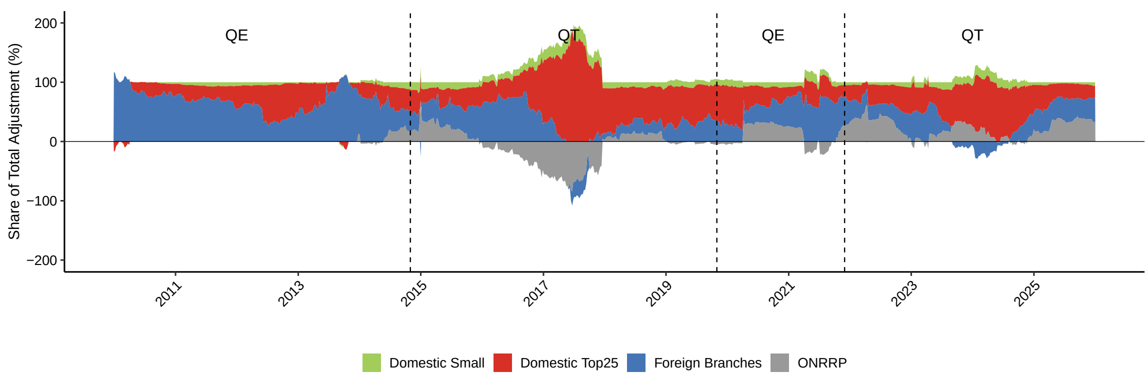

Figure 8: Composition of Reserve Adjustment to TGA Shocks over Time. This figure plots rolling adjustment shares, not elasticities, based on 52-week rolling regressions of changes in banks' reserve holdings (proxied by cash assets) on TGA shocks. Each share is constructed from the corresponding rolling coefficient and normalized by the sum across categories, so it describes the composition of contemporaneous TGA-induced dollar adjustment. Shares can be negative or exceed 100% when one category offsets the response of others. Vertical dashed lines mark key policy regime transitions: the end of QE in 2014, the onset of balance sheet normalization in 2019, and the start of the 2021 QE episode. Values that exceed 200% or -200% are trimmed for readability. The underlying regression specification follows Table 6.

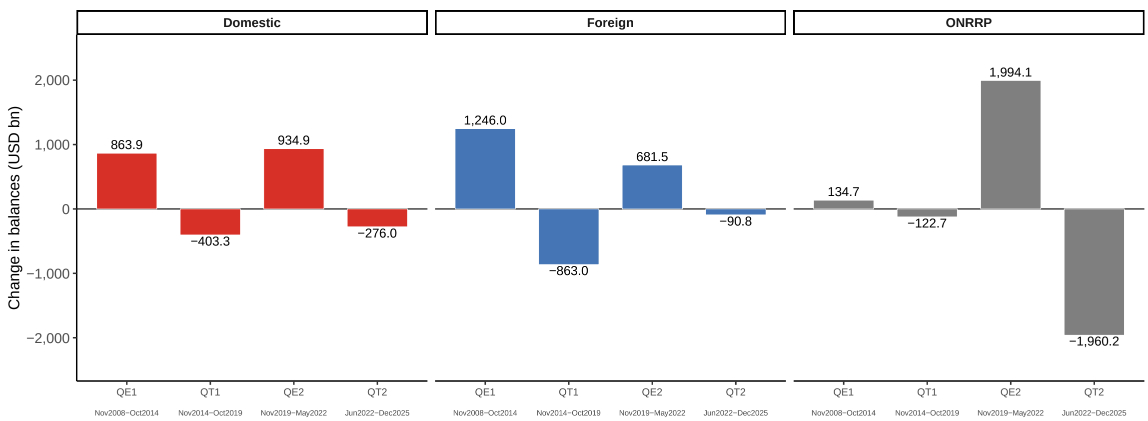

Figure 9: Changes in reserve holdings and ONRRP across QE and QT episodes. This figure plots the change in weekly Wednesday observations between the first and last available week in each episode. Domestic is the sum of H.8 Domestic Large (Top25) and Domestic Small; Foreign is H.8 Foreign-related institutions; ONRRP is aggregate overnight reverse repo take-up aligned to the same weekly Wednesday dates. To remove spurious early observations unrelated to the standing ONRRP facility, ONRRP is set to zero before 2013-02-13. Episode coverage is QE1 (2008-11-25 to 2014-10-31, actual weekly observations 2008-11-26 to 2014-10-29), QT1 (2014-11-01 to 2019-10-31, actual 2014-11-05 to 2019-10-30), QE2 (2019-11-01 to 2022-05-31, actual 2019-11-06 to 2022-05-25), and QT2 (2022-06-01 to 2025-12-24). QT2 is ended on 2025-12-24 rather than 2025-12-31 to avoid quarter-end and year-end window-dressing effects: foreign H.8 cash is USD 1129.7 bn on 2025-12-24, falls to USD 1040.9 bn on 2025-12-31, and rebounds to USD 1118.9 bn on 2026-01-07.

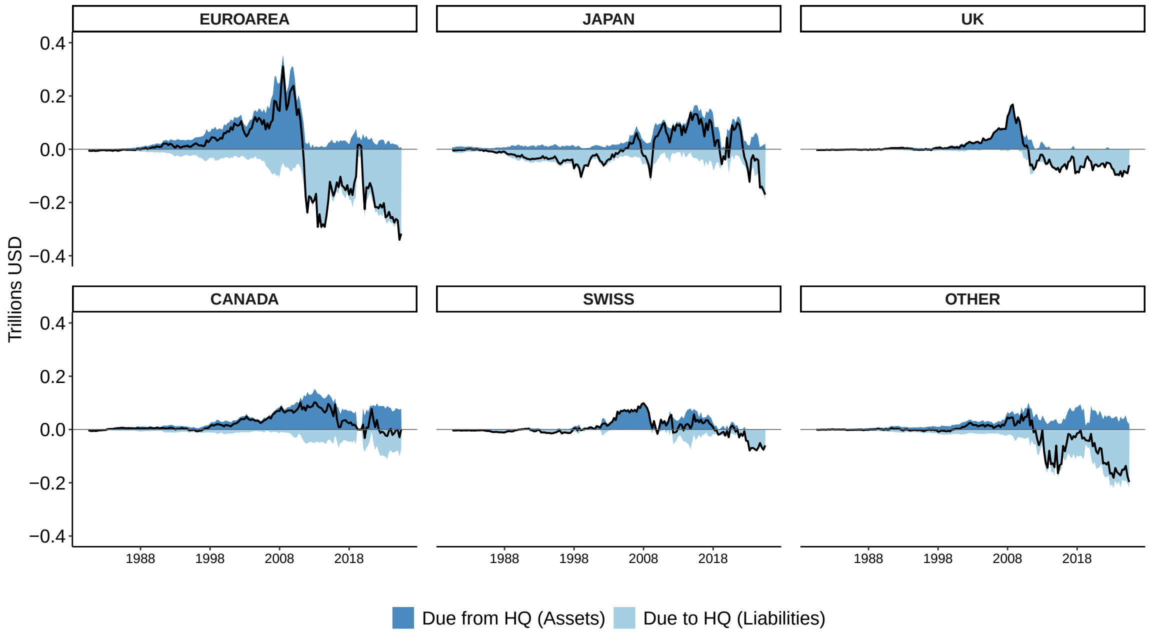

Figure 10: Headquarters (HQ) Funding Flows of Foreign Bank Branches This figure illustrates the intra-group funding flows between U.S. branches of foreign banks and their headquarters (HQ), disaggregated by jurisdiction. Positive values indicate lending from branches to HQ, while negative values represent borrowing from HQ to fund branch operations. The black solid line indicated the net balances. Source: FFIEC 002 reports

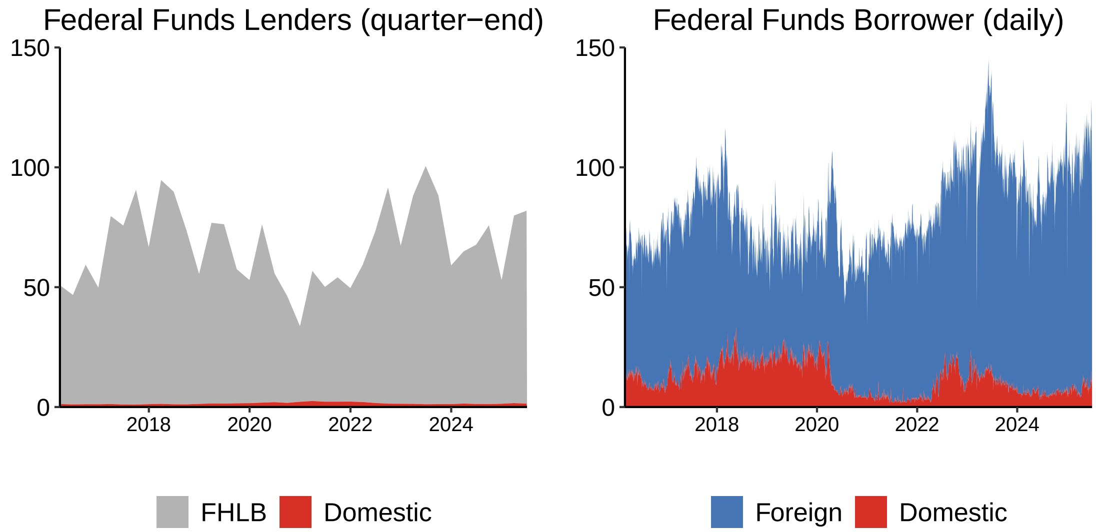

Figure 11: Federal Funds Market Dynamics. This figure shows the institutional composition of the post-2016 federal funds market. The left panel plots federal funds lending volumes by lender type at quarter-end, distinguishing Federal Home Loan Banks (FHLBs) from domestic banks. The right panel plots daily federal funds borrowing volumes by borrower type, distinguishing U.S. branches and agencies of foreign banks from domestic banks. Volumes are measured in billions of dollars. The figure illustrates the concentration of federal funds activity in an FHLB-to-foreign-branch segment: FHLBs are the dominant lenders, while foreign branches account for most borrowing. Source: FFIEC 002 reports, Federal Reserve Bank of New York, and FHLB data.

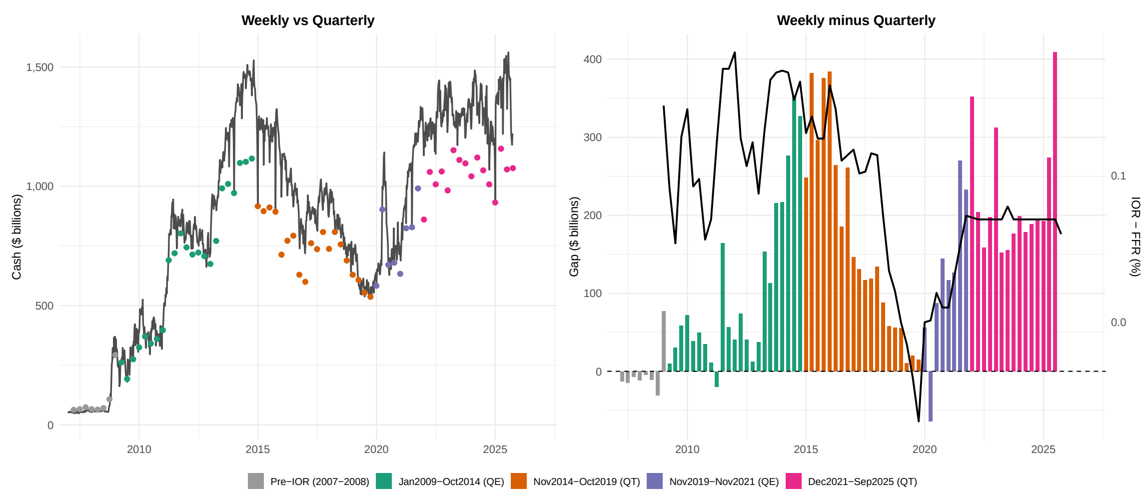

Figure 12: Window Dressing Gap Over Time: Foreign Bank Branches This figure plots the window dressing gap for U.S. branches of foreign banks, defined as the difference between weekly cash holdings (from the H.8 release, measured the week before quarter-end) and quarter-end cash balances (from FFIEC 002 filings). Panel A shows the window dressing amount in billions of dollars; Panel B shows the window dressing as a percentage of pre-quarter-end cash. Vertical dotted lines indicate regime transitions. Two patterns emerge: systematic quarter-end compression is largely absent before the introduction of interest on reserves in 2008, and the magnitude of the window dressing gap declines during quantitative tightening, particularly around 2019. Source: FFIEC 002 reports and Federal Reserve H.8 release.

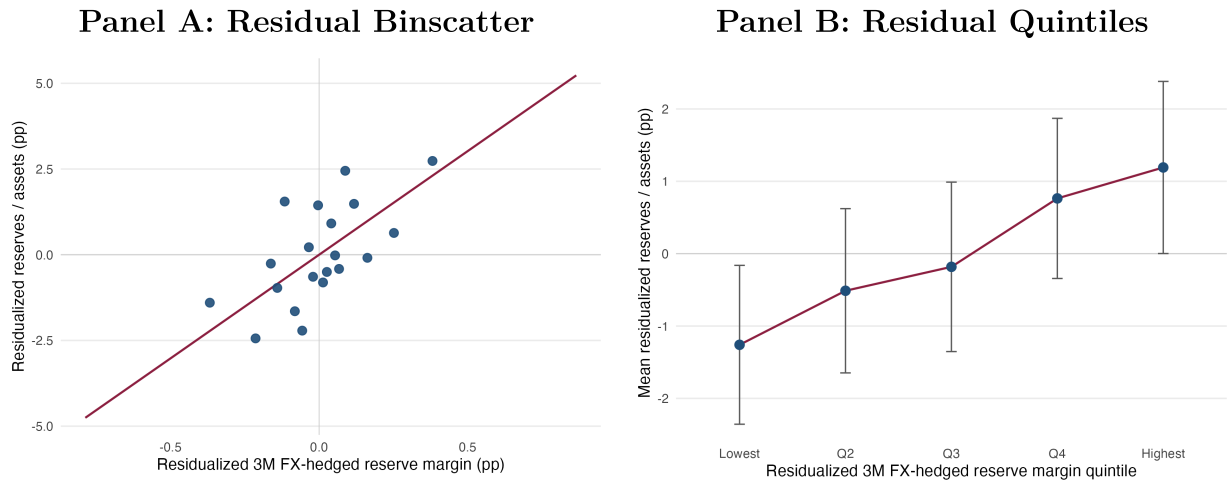

Figure 13: FX-Hedged Reserve Margin and Reserve Intensity. This figure visualizes the within-quarter relationship between reserve intensity and the three-month FX-hedged reserve margin at the BHC level. The BHC panel aggregates U.S. branches and agencies to the top foreign banking organization. In both panels, reserve intensity and the hedged margin are residualized with respect to banking-organization fixed effects, quarter fixed effects, and lagged log assets. Panel A plots a residual binscatter: each point is one of 20 equal-count bins of the residualized hedged margin, and the fitted line is estimated on the underlying residualized observations. Panel B groups the same residualized observations into quintiles of the residualized hedged margin and plots the mean residualized reserve-to-asset ratio in each quintile, with 95 percent confidence intervals. The x-axis in Panel A is measured in pp, and the y-axis in both panels is measured in pp of assets. The figure illustrates that, after absorbing common quarter effects, foreign banking organizations facing a higher FX-hedged return to holding U.S. reserves hold higher reserve balances relative to assets. Source: FFIEC 002 reports and authors' calculations.

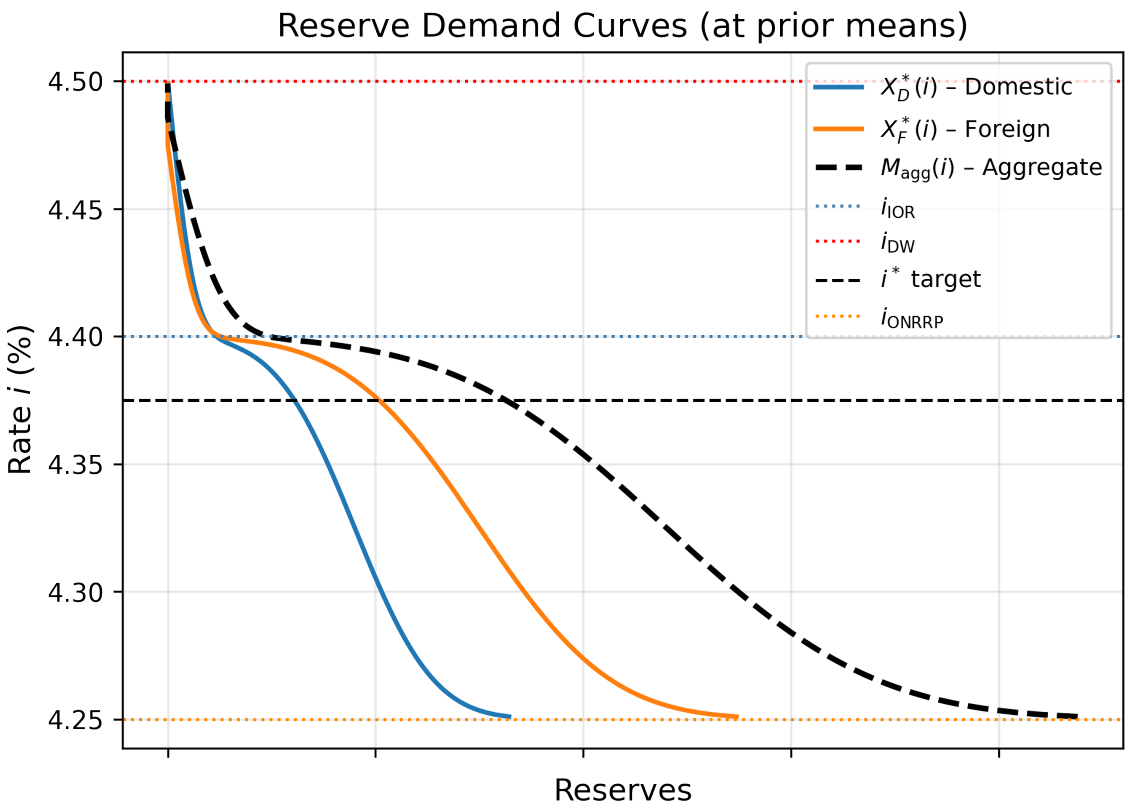

Figure 14: Reserve Demand Curves. This figure plots reserve demand as a function of the overnight rate. The solid lines show optimal reserve holdings of domestic and foreign banks, $X_D^*(i)$ and $X_F^*(i)$, and the dashed line shows aggregate demand $M_{\text{agg}}(i) = X_D^*(i) + X_F^*(i)$. All curves are evaluated at the prior means of the demand shifters. Horizontal lines indicate administered rates, including the interest on reserve balances (IOR), the discount window rate, and the ON RRP rate.

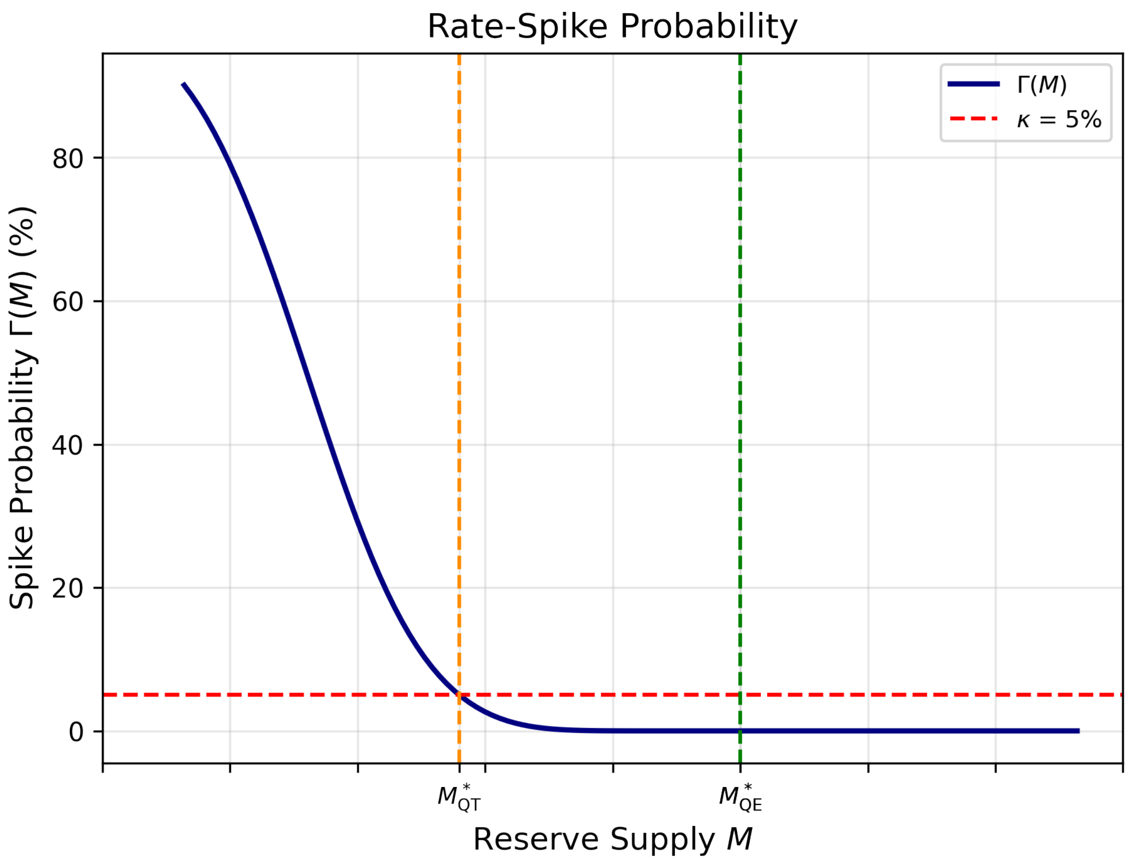

Figure 15: Rate-Spike Probability and Optimal Reserve Supply. This figure plots the probability of a rate spike, $\Gamma(M)$, as a function of aggregate reserve supply M, computed using Monte Carlo integration over uncertainty in reserve demand. The horizontal line denotes the policy tolerance parameter κ. Vertical lines indicate the optimal reserve supply M^* under alternative balance sheet regimes. The figure shows that the probability of a rate spike is decreasing in reserve supply and illustrates how demand uncertainty determines the minimum level of reserves required to satisfy the central bank's rate control objective.

9 Tables

Table 1

First Stage: TGA Shock and Overnight Spreads

This exploratory table estimates first-stage regressions of daily changes in overnight spreads on TGA shocks using the active-market-day panel, excluding all calendar quarter-end dates. The full-sample coverage in Panels A and B runs from 2009-01-05 to 2025-12-30. The QE sample pools 2009-01-02 to 2014-10-31 and 2019-11-01 to 2021-11-30; the QT sample pools 2014-11-01 to 2019-10-31 and 2021-12-01 to 2025-12-31. Panel B uses a historical SOFR proxy relative to IOR, where the SOFR level is linearly interpolated on five holiday-gap dates. The first ΔSOFR− IOR remain missing on the two splice-boundary dates (2014-08-22 and 2018-04-03), so Panel B uses two fewer observations than Panel A in each specification. The coefficient on ΔTGA represents the basis point change in the spread per $100 billion increase in TGA. Columns (1)–(3) use the full sample with progressively more controls. Columns (4) and (5) split the sample into QE and QT periods.

Panel A: FFR-IOR

	Δ(FFR − IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	0.3331***	0.3202***	0.1837	0.6761***	-0.1533
	(0.0878)	(0.1228)	(0.1223)	(0.1807)	(0.1706)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	4,010	4,010	4,010	1,879	2,131
R^2	0.004	0.037	0.137	0.111	0.169

Panel B: SOFR-IOR

	Δ(SOFR − IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	1.7515***	1.8070***	1.8165***	2.4236***	1.3407***
	(0.2171)	(0.3318)	(0.3337)	(0.4945)	(0.4667)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	4,008	4,008	4,008	1,878	2,130
R^2	0.016	0.024	0.024	0.049	0.020

Table 2

Second Stage: Money Market Spread and Fed Funds Borrowing

This table reports second-stage IV estimates of the effect of overnight funding spreads on daily federal funds borrowing volumes for the full sample only. The dependent variable is the daily log change in borrowing volume, shown under the common header Δ(Fed Funds Borrowing). The excluded instrument is the TGA shock. Odd-numbered columns use instrumented $\Delta\widehat{\text{FF-IOR}}$, and even-numbered columns use instrumented $\Delta\widehat{\text{SOFR-IOR}}$ from an extended historical SOFR series constructed from the historical SOFR proxy before April 2018 and official SOFR thereafter. All specifications include ΔONRRP as an exogenous control, exclude calendar quarter-end observations, include FOMC-period fixed effects, and report standard errors clustered by FOMC period. Columns (1)–(2) use aggregate total Fed Funds borrowing in the banking sector and span 2009-01-01 through 2025-12-31. Columns (3)–(6) use foreign and domestic borrowing breakdowns, which begin on 2016-03-01 and end on 2025-12-31. The sample row summarizes the estimation window for each column. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Full Sample

	Δ log (Fed Funds Borrowing)					
	All Banks		Foreign		Domestic	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\widehat{\text{FF-IOR}}$	-0.0584***		-0.0715***		-0.0192	
	(0.0112)		(0.0158)		(0.0139)	
$\Delta\widehat{\text{SOFR-IOR}}$		-0.0222***		-0.0456***		0.0237*
		(0.0043)		(0.0113)		(0.0129)
FOMC Period FE	✓	✓	✓	✓	✓	✓
Δ ONRRP Control	✓	✓	✓	✓	✓	✓
Sample	Full	Full	Full (2016-)	Full (2016-)	Full (2016-)	Full (2016-)
Observations	4,010	4,003	2,290	2,288	2,290	2,288
F-stats	240.40	88.86	137.83	24.28	137.83	24.28

Table 3

Second Stage: Money Market Spread and Fed Funds Borrowing

This table reports second-stage IV estimates of the effect of overnight funding spreads on daily federal funds borrowing volumes for QE and QT subsamples. The dependent variable is the daily log change in borrowing volume, shown under the common header Δ(Fed Funds Borrowing). The excluded instrument is the TGA shock. Odd-numbered columns use instrumented $\Delta\widehat{\text{FF-IOR}}$, and even-numbered columns use instrumented $\Delta\widehat{\text{SOFR-IOR}}$ from an extended historical SOFR series constructed from the historical SOFR proxy before April 2018 and official SOFR thereafter. All specifications include ΔONRRP as an exogenous control, exclude calendar quarter-end observations, include FOMC-period fixed effects, and report standard errors clustered by FOMC period. Columns (1)–(2) use aggregate total Fed Funds borrowing in the banking sector and span 2009-01-01 through 2025-12-31. Columns (3)–(6) use foreign and domestic borrowing breakdowns, which begin on 2016-03-02 and end on 2025-12-31. For columns (3)–(6), the expansionary subsample therefore effectively begins on 2019-11-01, so the disaggregated expansionary estimates refer to the 2019–2021 balance-sheet expansion rather than the 2009–2014 expansion. The sample row summarizes the estimation window for each column. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel A: QE Periods

	Δ log (Fed Funds Borrowing)					
	All Banks		Foreign		Domestic	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\widehat{\text{FF-IOR}}$	-0.0413*		-0.1110***		-0.1500	
	(0.0226)		(0.0260)		(0.1035)	
$\Delta\widehat{\text{SOFR-IOR}}$		-0.0131***		-0.0351		0.0575
		(0.0045)		(0.0217)		(0.0362)
FOMC Period FE	✓	✓	✓	✓	✓	✓
Δ ONRRP Control	✓	✓	✓	✓	✓	✓
Sample	QE	QE	QE (2016-)	QE (2016-)	QE (2016-)	QE (2016-)
Observations	1,879	1,876	475	475	475	475
F-stats	32.03	77.51	15.28	4.68	15.28	4.68

Panel B: QT Periods

	Δ log (Fed Funds Borrowing)					
	All Banks		Foreign		Domestic	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\widehat{\text{FF-IOR}}$	-0.0503***		-0.0672***		-0.0101	
	(0.0104)		(0.0161)		(0.0117)	
$\Delta\widehat{\text{SOFR-IOR}}$		-0.0339***		-0.0494***		0.0141
		(0.0090)		(0.0138)		(0.0137)
FOMC Period FE	✓	✓	✓	✓	✓	✓
Δ ONRRP Control	✓	✓	✓	✓	✓	✓
Sample	QT	QT	QT (2016-)	QT (2016-)	QT (2016-)	QT (2016-)
Observations	2,131	2,127	1,815	1,813	1,815	1,813
F-stats	197.50	27.38	121.70	19.41	121.70	19.41

Table 4

Second Stage: Money Market Spread and Reserve Holding

This table reports full-sample weekly second-stage IV estimates using the weekly TGA shock as the excluded instrument. The dependent variable is the weekly change in log reserves. The endogenous regressor is the weekly endpoint spread change. All columns include weekly ΔONRRP and FOMC-period fixed effects. F-stats are first-stage IV F-statistics for the excluded instrument. AR p-values test a zero second-stage coefficient, and AR 95% confidence sets invert weak-IV robust Anderson-Rubin tests; entries of the form $\leq a; \geq b$ denote $(-\infty, a] \cup [b, \infty)$. Standard errors, clustered by FOMC period, are in parentheses.

	Δ log(Reserves)					
	All Banks		Foreign		Domestic	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\widehat{\text{FFR} - \text{IOR}}$	-0.1003***		-0.1372***		-0.0835**	
	(0.0388)		(0.0509)		(0.0356)	
$\Delta\widehat{\text{SOFR} - \text{IOR}}$		-0.0215***		-0.0294***		-0.0178**
		(0.0074)		(0.0093)		(0.0072)
FOMC Period FE	✓	✓	✓	✓	✓	✓
ΔONRRP Control	✓	✓	✓	✓	✓	✓
Sample	Full	Full	Full	Full	Full	Full
Observations	877	875	877	875	877	875
F-stats	7.31	10.28	7.31	10.28	7.31	10.28
AR p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
AR 95% set	$[-.723, -.055]$	$[-.093, -.012]$	$[-.917, -.075]$	$[-.115, -.017]$	$[-.643, -.041]$	$[-.086, -.009]$

Table 5

Second-Stage IV Estimates by QE/QT Period: Weekly TGA Shock

This table repeats the weekly second-stage IV estimates separately for QE and QT periods. Panel A pools QE1 and QE2; Panel B pools QT1 and QT2. The dependent variable is the weekly change in log reserves. All columns include weekly ΔONRRP and FOMC-period fixed effects. F-stats are first-stage IV F-statistics for the excluded instrument. AR p-values test a zero second-stage coefficient, and AR 95% confidence sets invert weak-IV robust Anderson-Rubin tests; entries of the form $\leq a; \geq b$ denote $(-\infty, a] \cup [b, \infty)$. Standard errors are clustered by FOMC period.

Panel A: QE Periods

	Δ log(Reserves)					
	All Banks		Foreign		Domestic	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\widehat{\text{FFR} - \text{IOR}}$	-0.0483***		-0.0956***		-0.0266**	
	(0.0134)		(0.0229)		(0.0120)	
$\Delta\widehat{\text{SOFR} - \text{IOR}}$		-0.0190***		-0.0376***		-0.0105**
		(0.0052)		(0.0087)		(0.0049)
FOMC Period FE	✓	✓	✓	✓	✓	✓
ΔONRRP Control	✓	✓	✓	✓	✓	✓
Sample	QE	QE	QE	QE	QE	QE
Observations	405	404	405	404	405	404
F-stats	19.80	16.30	19.80	16.30	19.80	16.30
AR p-value	< 0.001	< 0.001	< 0.001	< 0.001	0.002	0.002
AR 95% set	$[-.132, -.029]$	$[-.051, -.012]$	$[-.228, -.060]$	$[-.086, -.024]$	$[-.096, -.008]$	$[-.039, -.003]$

Panel B: QT Periods

	Δ log(Reserves)					
	All Banks		Foreign		Domestic	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\widehat{\text{FFR} - \text{IOR}}$	-0.4439		-0.4042		-0.4623	
	(0.9666)		(0.8860)		(1.0065)	
$\Delta\widehat{\text{SOFR} - \text{IOR}}$		-0.0246		-0.0225*		-0.0255
		(0.0155)		(0.0134)		(0.0171)
FOMC Period FE	✓	✓	✓	✓	✓	✓
ΔONRRP Control	✓	✓	✓	✓	✓	✓
Sample	QT	QT	QT	QT	QT	QT
Observations	472	471	472	471	472	471
F-stats	0.17	2.65	0.17	2.65	0.17	2.65
AR p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
AR 95% set	$\leq -.077; \geq .116$	$\leq -.010; \geq .061$	$\leq -.062; \geq .100$	$\leq -.009; \geq .047$	$\leq -.079; \geq .118$	$\leq -.010; \geq .067$

Table 6

TGA Shock Absorption by Bank Type and Monetary Policy Regime

This table reports coefficient estimates from weekly regressions estimated separately by bank type and monetary policy regime after excluding quarter-end sample dates. The dependent variable in columns (1) and (5) is the weekly change in reserve holdings of foreign bank branches; columns (2) and (6) use large domestic banks (top 25); columns (3) and (7) use small domestic banks; columns (4) and (8) use ON RRP take-up. Panel A covers the first QE/QT cycle (2009–2019); Panel B covers the second cycle (2019–2025). All specifications include FOMC period fixed effects, and standard errors are clustered by FOMC period. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	QE Periods				QT Periods			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: First QE/QT Cycle							
	QE1: Jan 2009 – Oct 2014				QT1: Nov 2014 – Oct 2019			
ΔTGA ($100bn)	-54.3518***	-19.7013**	-3.7823***	-2.1238	-31.6050***	-51.0992***	-9.3442***	8.8793
	(7.8539)	(8.2654)	(1.0769)	(1.8911)	(10.0981)	(7.9073)	(1.7848)	(7.0688)
Observations	301	301	301	301	259	259	259	259
R^2	0.22	0.14	0.15	0.05	0.16	0.27	0.22	0.04
	Panel B: Second QE/QT Cycle							
	QE2: Nov 2019 – Nov 2021				QT2: Dec 2021 – Dec 2025			
ΔTGA ($100bn)	-22.9926***	-18.5075	-5.4936	-26.4115**	-21.6990***	-35.9174***	-6.2748***	-17.7387***
	(7.0408)	(12.3444)	(3.3749)	(12.0281)	(6.6579)	(7.7144)	(1.6970)	(6.5956)
Observations	105	105	105	105	213	213	213	213
R^2	0.34	0.43	0.26	0.21	0.11	0.23	0.24	0.17
Dep. Variable	Foreign	Large Domestic	Small Domestic	ONRRP	Foreign	Large Domestic	Small Domestic	ONRRP

Table 7

2007 Branch Ratio in Foreign Banks and Reserve Holdings

This table reports regressions of log reserves on foreign-bank status and the 2007 branch-to-asset ratio: $\log(\text{Reserves})_{it} = \beta_1 \text{Foreign}_i + \beta_2(\text{Foreign}_i \times \text{BranchRatio}_i^{2007}) + \Gamma X_{it} + \alpha_t + \epsilon_{it}$, where Foreign_i is an indicator equal to one if the bank is foreign-owned, and $\text{BranchRatio}_i^{2007}$ is the share of U.S. assets held in branch form as of 2007Q1. Specifications (1)–(3) use the full sample of banks, while specification (4) restricts to foreign banks only. All regressions control for log assets and log equity capital, and include quarter fixed effects. Using column (4), the implied effect of a one-standard-deviation increase in branch intensity is $\exp\big(\hat{\beta}\,\sigma(\text{BranchRatio}^{2007})\big) - 1 \approx 0.40$, where $\sigma(\text{BranchRatio}^{2007})$ denotes the sample standard deviation of the 2007 branch ratio in the foreign-bank estimation sample. Standard errors are clustered at the BHC level. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	log(Reserves)			
	(1)	(2)	(3)	(4)
Foreign (F)	2.200***		2.126***	
	(0.2006)		(0.2010)	
$\text{BranchShare}_i^{2007}$		4.124***	2.001***	1.248***
		(0.2526)	(0.2687)	(0.1880)
Time FE	✓	✓	✓	✓
Balance Sheet Ctrl	✓	✓	✓	✓
Sample	All	All	All	Foreign
Observations	299,213	299,213	299,213	2,357
R^2	0.44	0.43	0.44	0.85

Table 8

Liabilities Adjustment Given Reserve Change
Foreign Banks

This table reports two-stage least-squares estimates for foreign-related institutions using weekly H.8 level changes in billions of dollars from 2009 to 2025. The endogenous regressor is weekly Δ reserves, instrumented with the raw Wednesday-to-Wednesday TGA shock measured in units of 100 billion dollars. All specifications include FOMC-period fixed effects and cluster standard errors by FOMC period. Quarter-end sample dates are excluded, matching the raw TGA absorption table. Large time deposits are LTDFRIW027NBOG, other deposits are ODSFRIW027NBOG, HQ funding is measured as max(NDFFRIW027NBOG, 0), and wholesale funding is measured as H8B3094NFRD divided by 1,000 to convert millions to billions. Wholesale funding includes federal funds purchased, securities sold under agreements to repurchase, and other borrowed money. ***, **, and * denote significance at the 1%, 5%, and 10% levels.

	Δ large time deposits (1)	Δ other deposits (2)	Δ HQ funding (3)	Δ wholesale funding (4)
$\Delta\widehat{Reserves}$	0.0603**	0.0315	0.4272***	0.2713***
	(0.0269)	(0.0278)	(0.0619)	(0.0519)
First stage: ΔTGA ($100bn)	-29.1197***	-29.1197***	-29.1197***	-29.1197***
Observations	878	878	878	878
F-stats	46.68	46.68	46.68	46.68

Table 9

Liabilities Adjustment Given Reserve Change: QE and QT Periods
Foreign Banks

This table reports two-stage least-squares estimates for foreign-related institutions using weekly H.8 level changes in billions of dollars from 2009 to 2025. The endogenous regressor is weekly Δ reserves, instrumented with the raw Wednesday-to-Wednesday TGA shock measured in units of 100 billion dollars. All specifications include FOMC-period fixed effects and cluster standard errors by FOMC period. Quarter-end sample dates are excluded, matching the raw TGA absorption table. Large time deposits are LTDFRIW027NBOG, other deposits are ODSFRIW027NBOG, HQ funding is measured as max(NDFFRIW027NBOG, 0), and wholesale funding is measured as H8B3094NFRD divided by 1,000 to convert millions to billions. Wholesale funding includes federal funds purchased, securities sold under agreements to repurchase, and other borrowed money. ***, **, and * denote significance at the 1%, 5%, and 10% levels.

	QE Periods				QT Periods			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: First QE/QT Cycle							
	QE1: Jan 2009 – Oct 2014				QT1: Nov 2014 – Oct 2019			
$\Delta\widehat{Reserves}$	0.0810**	0.0038	0.2482***	0.0926**	0.0447	0.1024*	0.5099***	0.4029***
	(0.0385)	(0.0099)	(0.0787)	(0.0436)	(0.0493)	(0.0612)	(0.1305)	(0.1078)
Observations	301	301	301	301	259	259	259	259
F-stats	47.89	47.89	47.89	47.89	9.80	9.80	9.80	9.80
	Panel B: Second QE/QT Cycle							
	QE2: Nov 2019 – Nov 2021				QT2: Dec 2021 – Dec 2025			
$\Delta\widehat{Reserves}$	0.0973***	0.1053	0.2478	0.4065**	0.0315	-0.0119	0.6285***	0.3050***
	(0.0299)	(0.0670)	(0.1730)	(0.1869)	(0.0636)	(0.0669)	(0.1029)	(0.1075)
Observations	105	105	105	105	213	213	213	213
F-stats	10.66	10.66	10.66	10.66	10.64	10.64	10.64	10.64
Dep. Variable	Δ large time deposits	Δ other deposits	Δ HQ funding	Δ wholesale funding	Δ large time deposits	Δ other deposits	Δ HQ funding	Δ wholesale funding

Table 10

Foreign Bank Quarter-End Liability Adjustment

Cells report the mean quarter-end abnormal liability movement in percentage points of foreign-bank assets, with standard errors in parentheses on the second line. Compact period coverage is shown under the column headings. Stars test whether the mean abnormal movement differs from zero across quarter-end events. The abnormal movement is the H.8 liability level at $k = 0$ minus the average over $k = -5, -4, -3, -2$, scaled by total assets at $k = -1$. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Component	Full	QE1	QT1	QE2	QT2
	2009–25	Jan09–Oct14	Nov14–Oct19	Nov19–Nov21	Dec21–Dec25
Large Time Deposits	-0.20	0.34	-0.35*	-0.98**	-0.37**
	(0.13)	(0.27)	(0.18)	(0.41)	(0.16)
Other Deposits	-0.20**	0.07	-0.18	-0.55	-0.43***
	(0.08)	(0.05)	(0.13)	(0.49)	(0.12)
Wholesale Funding	-1.68***	-1.01***	-2.74***	-2.08	-1.17***
	(0.23)	(0.32)	(0.34)	(1.28)	(0.26)
HQ Funding	-0.72**	-0.74**	-2.06***	1.57	-0.19
	(0.32)	(0.28)	(0.71)	(1.39)	(0.43)
Other Liabilities	0.10	0.10	-0.04	-0.05	0.32**
	(0.06)	(0.13)	(0.08)	(0.19)	(0.12)
Observations	68	23	20	8	17

Table 11

Reserve Intensity and the FX-Hedged Reserve Margin

This table reports quarterly regressions of reserve/assets on the three-month FX-hedged reserve margin. The BHC column aggregates U.S. branches and agencies to the top foreign banking organization; the branch column uses the branch-level panel. All specifications include unit fixed effects, quarter fixed effects, and lagged log assets. The coefficient is measured per one-percentage-point increase in the hedged margin. Standard errors are clustered by unit and quarter. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	BHC	Branch
3M FX-hedged reserve margin	6.045**	5.911**
	(2.733)	(2.396)
Unit FE	✓	✓
Time FE	✓	✓
Balance Sheet Ctrl	✓	✓
Observations	4,064	4,770
R^2	0.557	0.572

Table 12

Global Funding Margins and Funding Composition

This table reports BHC-level regressions of quarterly changes in foreign-bank funding components on the change in the three-month FX-hedged reserve margin. Columns (1)–(3) use gross funding changes; columns (4)–(6) use net funding changes, where net positions subtract the corresponding asset-side exposure before taking changes. Outcomes are scaled by lagged assets and measured in percentage points. The regressor is measured in one-percentage-point units. All specifications include BHC fixed effects, quarter fixed effects, and lagged log assets. Standard errors are clustered by BHC and quarter. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Δ Gross			Δ Net		
	FedFunds	Repo	HQ Funding	FedFunds	Repo	HQ Funding
Δ 3M hedged IOR spread	-0.515	-2.388***	4.167***	-0.232	-1.796***	6.616***
	(0.395)	(0.808)	(1.182)	(0.435)	(0.443)	(2.376)
Time FE	✓	✓	✓	✓	✓	✓
Balance Sheet Ctrl	✓	✓	✓	✓	✓	✓
Observations	4,052	4,052	4,052	4,052	4,052	4,052
R^2	0.038	0.036	0.067	0.034	0.028	0.054

Appendix

A1. Data Details

A1.1 Quarterly Bank-BHC Panel Data

To construct the quarterly panel dataset, we obtain Call Report data and Y-9C Reports from the National Information Center (NIC) and the Federal Reserve Bank of Chicago. FFIEC 031 and 041, the Call Report data for U.S. commercial banks and foreign bank subsidiaries, provide detailed balance sheet and income statement information.[30] FFIEC 002, 'Report of Assets and Liabilities of U.S. Branches and Agencies of Foreign Banks,' provides balance sheet data for foreign branches and agencies. The Y-9C reports contain similar data at the bank holding company (BHC) level. The Call Report data are available from 1976Q1 for domestic banks and foreign bank subsidiaries, while data on foreign bank branches begin in 1980Q2. While balance sheet variables on foreign branches and agencies are similar to those for domestic banks, there are differences in RSSD variables and some contents. For instance, they do not contain income statement and capital accounts, although they provide information on flows with their headquarters.[31] Y-9C reports are available starting in 1986Q2. To maintain consistency in our sample, we exclude reporters of FR 2886a (New York Investment Companies) and FR 2886b (Edge Act and Agreement Corporations) from our foreign samples and concentrate on branches and agencies and subsidiaries.

We link bank-level data to their respective BHCs using the following approach. When available, we rely on RSSD9347 and RSSD9348 to match RSSD9001 (individual bank IDs) to their parent holding companies. In cases where these identifiers are missing or inconsistent over time, we supplement the linkage using the Relationship Data provided by the NIC. We also refer to 'Events & Changes' on the FDIC website to account for some large mergers and liquidations. For foreign banking organization (FBO) samples after December 2008, we also rely on the Federal Reserve's Structure and Share Data for mapping. For banks headquartered in Australia, Canada, the Eurozone, Japan, Sweden, Switzerland, and the U.K., we manually check and refine these assignments to ensure accurate representation at the top-tier level.

[30] Typical economic analyses of Call Report data primarily use FFIEC 031, 041, and 051 reports. We exclude FFIEC 051 due to its focus on small banks. Designed for institutions with total assets under $5 billion, the FFIEC 051 report does not separately report reserve holdings, instead aggregating them with other cash assets, preventing us from observing reserve holdings. Additionally, smaller banks are less likely to engage in active reserve management, making them less relevant for studying reserve dynamics. To ensure accurate measurement of reserves and focus on institutions with significant reserve activity, we restrict our sample to FFIEC 031 and 041 filers.

[31] Previous literature that has used FFIEC 002 includes Aldasoro et al. (2022); Cetorelli and Goldberg (2011); Fillat et al. (2018).

To classify foreign banking organizations by country and type, we follow Aldasoro et al. (2022), using RSSD9331 and RSSD9209.[32] When these variables are missing, we impute the country classification based on the bank's most recent filings or refer to the Federal Reserve's Structure and Share Data for verification. If a bank is headquartered in Austria, Belgium, Croatia, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia, or Spain, we classify it as 'Euroarea'. To identify G-SIBs and domestic U.S. banks subject to relevant regulations, we refer to data from the Financial Stability Board (FSB), the Federal Reserve Board, and other regulatory agencies. We then compile regulatory ratios from manually collected Basel III Pillar 3 Disclosure Reports and supplement this information with Bloomberg data before merging it into our dataset.

We construct our key variables—including reserves, assets, and balance sheet components—from Call Report data while ensuring consistency over time. For domestic banks and foreign subsidiaries, we adopt methodologies outlined in Kashyap and Stein (2000); Drechsler et al. (2017, 2021); Correia et al. (2024). Where applicable, we adhere to definitions used in these sources to maintain continuity. However, for foreign banks and more recent data, we develop new variable definitions to account for changes in FFIEC 002 reports. In our main analysis, we compute variables at both the BHC-merged level and the standalone bank level, ensuring robustness in our empirical results. We omit samples that report non-positive reserves or assets. When calculating the shares of reserve holdings in Figure 3, we compare the holdings of domestic and foreign banks, aggregating subsidiaries and branches and agencies, and exclude reserve holdings of other entities. In other words, we do not include deposit categories such as 'Term deposits held by depository institutions,' 'U.S. Treasury, General Account,' 'U.S. Treasury, Supplementary Financing Account,' 'Foreign official accounts,' and 'Other deposits' in the H.4.1 report for our share analysis.

Our primary outcome is reserve holdings, which are held by depository institutions with a master account at the Federal Reserve. These institutions include nationally chartered banks, eligible state-chartered banks, and other entities classified under Section 19(b) of the Federal Reserve Act. In March 2020, reserve requirement ratios were reduced to zero, so reserve holdings in the post-2020 period reflect banks' discretionary liquidity management rather than statutory reserve mandates.

In analyses involving cross-jurisdiction reserve-remuneration spreads, we focus on foreign banks headquartered in jurisdictions for which we can construct a consistent home-country central-bank remuneration rate: the euro area, Japan, the United Kingdom, Canada, Sweden,

[32] We are deeply grateful to the authors for their invaluable guidance on classification methodologies and assistance.

Switzerland, and Australia. These rate-matched jurisdictions account for 81.8% of total foreign-bank reserve holdings over 2009Q1–2025Q4 on a pooled reserve-dollar basis, and the matched share averages 82.4% across quarters.

For each jurisdiction, we collect the relevant home-country reserve-remuneration or central-bank deposit rate and define the international reserve-rate spread as $IOR_t^{US} - IOR_{c,t}^{home}$. Figure A9 plots this spread across countries and shows substantial variation over the sample period. The home-country benchmark $IOR_{c,t}^{home}$ is intended to capture the marginal administered return that a bank can earn on balances held at its home central bank. For tiered remuneration systems, we use the marginal or non-exempt rate rather than a bank-specific average rate across tiers. Thus, for the euro area we use the ECB deposit facility rate, including the non-exempt tier during the two-tier period; for Japan we use the Bank of Japan policy-rate balance rate; and for Switzerland we use the SNB sight-deposit remuneration rate applicable above the exemption threshold. For the United Kingdom we use Bank Rate, for Canada the Bank of Canada deposit or settlement-balance remuneration benchmark, for Sweden the Riksbank standing deposit facility rate, and for Australia the RBA Exchange Settlement balance remuneration rate.

We also construct the three-month FX hedge component, $\rho_{c,t}^{3m}$, from spot exchange rates and three-month FX forward/swap quotes. The object captures the annualized exchange-rate cost or benefit of synthetically converting a home-currency position into a hedged U.S. dollar position over a three-month horizon. Let $S_{c,t}$ denote the spot exchange rate and $F_{c,t}^{3m}$ the outright three-month forward rate, expressed in a consistent foreign-currency-per-U.S.-dollar convention. We compute

$$\rho_{c,t}^{3m} = 100 \times \frac{A_c}{D_{c,t}^{3m}} \left[\log F_{c,t}^{3m} - \log S_{c,t} \right],$$

where $D_{c,t}^{3m}$ is the number of days to maturity of the forward contract and A_c is the relevant annualization convention. We use actual days to maturity when available; otherwise we use a standard 90-day three-month maturity. The annualization convention is 365 days for Canada, the United Kingdom, Australia, and Sweden, and 360 days for the euro area, Japan, and Switzerland.[33]

For currencies quoted in U.S. dollars per foreign currency, such as the euro, pound sterling, and Australian dollar, we invert the quote convention before applying the formula, equivalently using $\log S_{c,t} - \log F_{c,t}^{3m}$. The resulting $\rho_{c,t}^{3m}$ is measured in annualized percentage points. Under our sign convention, a positive value raises the FX-hedged return on U.S. reserves relative to the unhedged spread $IOR_t^{US} - IOR_{c,t}^{home}$, while a negative value lowers it.

[33]We are deeply grateful to Chase Ross and Sharon Ross for sharing their insights in variable construction.

The three-month FX-hedged reserve spread is therefore

$$HedgedSpread_{c,t}^{3m} = IOR_t^{US} - IOR_{c,t}^{home} + \rho_{c,t}^{3m}.$$

A1.2 TGA Shock Related Data

For our analysis of supply shocks on short-term interest rates, we construct key variables from multiple sources. Daily Treasury General Account (TGA) balances are obtained from the Treasury website and Haver Analytics. Policy rates and market interest rates—including the Federal Funds Rate (FFR), the effective lower bound, and the Interest on Reserves (IOR)—are sourced from the Federal Reserve Bank of St. Louis (FRED). The general collateral (GC) repo rate and LIBOR rate come from Bloomberg.

Although Treasury cash balances have always affected reserve supply, their quantitative importance increased substantially after the Global Financial Crisis. Prior to 2008, the Treasury managed most of its cash through the Treasury Tax and Loan (TT&L) program, which placed funds with private depository institutions. Following the introduction of interest on reserves in late 2008, this arrangement became less efficient, and the Treasury gradually shifted cash management to the TGA, effectively ending the TT&L program by 2012 (Santoro, 2012). As a result, post-crisis fluctuations in the TGA are large and frequent, making the TGA the dominant autonomous driver of reserve supply over our sample period.

To account for seasonal fluctuations in TGA shocks, we follow the cleaning procedure in Bräuning (2017). Specifically, we regress TGA changes on beginning-of-month, end-of-month, beginning-of-quarter, end-of-quarter, and day-of-week (Monday to Friday) fixed effects to isolate supply-driven fluctuations. To further refine this adjustment, we incorporate the expected maturity dates and volumes of Treasury bonds, extracting the residuals as a measure of supply shocks using net issuance data from the Treasury website. To align with bank balance sheet reporting schedules, we aggregate daily TGA balances and Overnight Reverse Repurchase Agreement (ONRRP) balances into weekly averages. The aggregation period runs from Thursday to Wednesday, matching the weekly bank cash holding data from the H.8 report.

We rely on the FR 2420 for daily transaction data on federal funds purchased, Eurodollar transactions, and certificates of deposit. The breakdown of bank type in these data is available only from March 1, 2016. Our primary data source for weekly bank balance sheet information is the H.8 Report, Assets and Liabilities of Commercial Banks in the United States, published by the Federal Reserve Board. The H.8 data, compiled from FR 2644 weekly reporting banks, provide an aggregate view of commercial bank assets and liabilities, allowing us to track trends in bank reserves. We use non-seasonally adjusted Wednesday values. Our sample period spans from January 1, 2009, to July 31, 2024, except for the short-term liabilities analysis, which spans from March 1, 2016, to July 31, 2024.

The classification of foreign banks in this section differs from our bank panel analysis. In the H.8 report, foreign-related institutions refer specifically to branches and agencies of foreign banks, as well as Edge Act and agreement corporations, but exclude foreign subsidiaries as well as International Banking Facilities (IBFs). As a result, the foreign banks examined in the supply shock section primarily capture the reserve holdings of foreign branches, not subsidiaries.[34]

Since reserves are not directly reported in the H.8 data, we use cash assets as a proxy variable. The H.8 cash holding category includes vault cash, cash items in process of collection, balances due from depository institutions, and reserves. While this measure closely tracks reserves, it differs from the Call Report definition, which also includes balances due from foreign central banks and foreign financial institutions.[35]

We verify that the deviation between H.8 cash assets and actual reserve balances is minimal following the introduction of Interest on Reserves (IOR). Figure A5 left panel compares Call Report aggregate cash balances, Call Report aggregate reserves, H.4.1 reported Fed reserves, and H.8 bank cash holdings. Before the Global Financial Crisis in 2008, the discrepancy between cash assets reported in H.8 (purple line) and reserves at the Fed (light blue line) was substantial, but post-GFC, the two measures converge. Notably, weekly cash and reserve balances dip around quarter-ends, consistent with window-dressing, where banks adjust their balance sheets for regulatory reporting purposes. This suggests that weekly data are better suited to capture banks' reserve management behavior and arbitrage sensitivity. Similarly, Figure A5 right panel shows that foreign-related banks' cash holdings in the H.8 data closely align with the reserve holdings of foreign branches reported in Call Report FFIEC 002 at quarter-end, while diverging at non-quarter-end periods, where H.8 cash holdings appear larger.

The H.8 dataset further classifies domestic banks into large domestically chartered banks, and small domestically chartered banks. Large domestically chartered banks refer to the top 25 banks ranked by domestic assets as of the most recent Call Report. These institutions include all U.S. Global Systemically Important Banks (G-SIBs) as well as most Category II to IV banks, which are subject to heightened prudential standards. For instance, in 2019Q1, the top 25 banks by total assets included all Category II to IV banks, making

[34] Edge Act and agreement corporations hold a negligible share of reserves.

[35] The Call Report (FFIEC 031, 041, 002) defines cash to include balances due from foreign financial institutions (RCON0070). While a more precise measure of Call Report cash (excluding foreign balances) can be constructed, this breakdown is only reported by banks with total assets exceeding $300 million, limiting full comparability.

them a distinct regulatory group. Small domestically chartered banks consist of all other domestic banks reporting FR 2644 data. Since FR 2644 reporting is voluntary, the H.8 sample—approximately 850 institutions—is smaller than the full Call Report sample.

A1.3 Construction of Historical SOFR series

We construct a time-consistent SOFR series by combining available data sources across periods. When the official or historical SOFR series is available, we use the reported observations directly. For the period August 2014 through March 2018, we use the historical SOFR series constructed from transaction-level repo data published by the New York Fed. For earlier periods, we splice in the New York Fed's primary dealer Treasury general collateral (GC) repo survey rate. This survey-based rate differs from SOFR along several dimensions. In particular, it is a volume-weighted mean based on a narrower set of transactions, whereas SOFR is a volume-weighted median constructed from a broader set of transaction-level data. Despite these differences, the survey rate provides a reasonable proxy for pre-SOFR repo market conditions (Bowman, 2019). Finally, for a small number of holiday-related gaps (April 2, 2010; April 6, 2012; December 26, 2014; April 3, 2015; and April 2, 2018), we linearly interpolate the level of the historical SOFR series to maintain continuity.

A1.4 Liability Variables Used in the Decomposition

We construct liability-side observables from weekly H.8 series for foreign-related institutions. The exact series are: net due to related foreign offices (NDFFRIW027NBOG), large time deposits (LTDFRIW027NBOG), other deposits (ODSFRIW027NBOG), borrowing (H8B3094NFRD), other liabilities (H8B3095NFRD), total assets (TLAFRIW027NBOG), and cash assets (CASFRIW027NBOG) which is used as a proxy of reserves. Because H8B3094NFRD is reported in millions, we divide it by 1000 to express it in billions, consistent with the other H.8 series. All liability components are normalized by total assets and log-transformed, except net due to related foreign offices, which is transformed using the inverse hyperbolic sine (IHS) because it can take negative values.

A2. Discussion on Intraday Liquidity

A potential determinant of reserve demand that we do not explicitly test in our analysis is intraday liquidity management. While intraday demands on reserves drive the distribution of transactions within the day across each settlement service (Copeland et al., 2025; Yang, 2020), we argue that their impact on foreign banks, particularly on branches, is limited due to regulatory and structural differences. For U.S. banks, the Dodd-Frank Act and SR 14-1 have increased the need to hold reserves to meet both overnight and intraday liquidity obligations. For foreign banks, the situation is different. Only IHCs (subsidiaries) are subject to similar U.S. supervision and regulation. Therefore, branches of foreign banks have been exempt and thus are not directly affected by these constraints. Large foreign banks are subject to LCR and other Basel III requirements; however, branches are not required to hold separate liquidity.

Meanwhile, foreign bank subsidiaries and branches operating in the United States have access to the Federal Reserve's daylight overdraft and discount window under the same eligibility criteria and terms as domestic depository institutions. Foreign banks with multiple subsidiaries and branches may access the discount window in more than one Federal Reserve District. In most emergency liquidity facilities, foreign banks generally receive treatment equivalent to that of domestic banks.[36]

For this reason, we believe that intraday liquidity requirements have limited impact on foreign banks' reserve demand. While domestic banks must actively manage reserves to meet intraday liquidity needs, foreign branches—unconstrained by U.S. liquidity requirements—rely more on parent-bank funding and the Federal Reserve's daylight overdraft facilities to meet short-term payment obligations. This structural distinction means that intraday liquidity considerations are less likely to be a primary driver of reserve holdings among foreign branches.

Additionally, the lack of granular daily data prevents a more precise examination of how intraday liquidity considerations might influence foreign banks' reserve management. Given that our analysis focuses on quarterly reserve adjustments in response to interest rate spreads, incorporating intraday dynamics would require a more detailed transaction-level dataset that is not publicly available. While intraday liquidity management is undoubtedly an important aspect of reserve behavior for some institutions, we find that its relevance for foreign banks—especially branches—is likely secondary to broader funding and arbitrage incentives.

A3. Relevant Regulations: Leverage Ratio and Liquidity Coverage Ratio

A3.1 Basel III standards

Basel III is a global regulatory framework developed by the Basel Committee on Banking Supervision (BCBS) to strengthen the resilience of internationally active banks. Introduced in response to the 2008 financial crisis, Basel III enhances capital adequacy, introduces stricter

[36] During the Global Financial Crisis, foreign banks made extensive use of the discount window and other emergency liquidity facilities. In October 2008, foreign banks accounted for at least 70% of outstanding discount window borrowing (Keoun, 2011). Benmelech (2012) finds that over 50% of Term Auction Facility (TAF) funds were borrowed by foreign banks.

liquidity requirements, and limits excessive leverage to reduce systemic risk. The framework builds on Basel I and Basel II by raising minimum capital requirements, implementing the Liquidity Coverage Ratio (LCR) and Net Stable Funding Ratio (NSFR), and incorporating a non-risk-based leverage ratio to serve as a backstop to risk-weighted capital measures. Basel III applies to banks operating across jurisdictions, with national regulators responsible for its phased implementation and enforcement.

Leverage Ratio: The Basel III leverage ratio framework has evolved over time to strengthen the resilience of the global banking system by constraining excessive leverage. Before its introduction, there was no globally standardized leverage ratio, as bank capital regulation primarily relied on risk-weighted capital requirements. However, the Global Financial Crisis (GFC) exposed weaknesses in this approach, revealing that risk-weighted asset (RWA) calculations often understated actual risk exposures. The leverage ratio was introduced as a supplementary, non-risk-based measure to serve as a backstop against potentially miscalculated RWAs. Between 2009 and 2013, no formal requirements were in place as discussions around the framework were still ongoing. In January 2014, the Basel Committee on Banking Supervision (BCBS) introduced the Basel III leverage ratio framework and disclosure requirements, setting a minimum Tier 1 leverage ratio of 3% and mandating public disclosure to enhance market discipline. This marked the beginning of a parallel run period, allowing banks to report their leverage ratios without mandatory compliance (Basel Committee on Banking Supervision, 2014). In 2017, the BCBS refined the leverage ratio by revising the definition of exposure, incorporating insights from the parallel run to ensure the leverage ratio functioned as an effective backstop to risk-based capital requirements (Basel Committee on Banking Supervision, 2017a).

By January 2018, the leverage ratio transitioned from a reporting requirement to a binding Pillar 1 capital standard, requiring banks to maintain a minimum leverage ratio of 3% (Basel Committee on Banking Supervision, 2014). This transition was based on the original 2014 framework but incorporated the revised exposure definitions introduced in 2017. The 2017 revisions also introduced a leverage ratio buffer for Global Systemically Important Banks (G-SIBs), requiring them to hold an additional leverage ratio buffer equal to 50% of their risk-weighted higher loss absorbency requirement. Originally scheduled for implementation in January 2022, the redefinition of the exposure and the G-SIB leverage ratio buffer was postponed to January 2024 to provide banks with additional time to adapt to the new requirements (Basel Committee on Banking Supervision, 2017b).

Liquidity Coverage Ratio: Prior to the Global Financial Crisis (GFC), there was no globally standardized liquidity requirement. While the importance of liquidity risk was recognized, its measurement and regulation remained fragmented across jurisdictions, reflecting the structural differences in national financial markets. Basel II largely overlooked liquidity risk, focusing instead on capital adequacy. However, the crisis exposed significant weaknesses in banks' liquidity positions, highlighting the need for an internationally coordinated approach.

In December 2010, the Basel Committee on Banking Supervision (BCBS) introduced the Liquidity Coverage Ratio (LCR) as part of Basel III, requiring banks to hold sufficient high-quality liquid assets (HQLA) to withstand a 30-day period of severe liquidity stress. The LCR was initially scheduled for full implementation by January 1, 2015, but following concerns over its impact on financial markets and credit supply, the BCBS revised the framework in January 2013. The revisions adjusted the definitions of HQLA and net cash outflows while introducing a phase-in schedule, starting at 60% in 2015 and increasing annually to reach 100% by 2019 (Basel Committee on Banking Supervision, 2013).

With the full implementation of the LCR in 2019, banks are required to maintain a minimum 100% LCR under normal conditions, ensuring that short-term liquidity risk is adequately managed. During stress periods, banks are permitted to draw down their liquidity buffers, recognizing the role of HQLA in mitigating shocks rather than serving as a static regulatory minimum. This evolution marks a shift in Basel regulation, expanding its scope beyond capital adequacy to explicitly incorporate liquidity as a pillar of financial stability.

A3.2 US

The Basel III framework allows member countries a degree of national discretion in its implementation, enabling jurisdictions to tailor standards to their domestic banking systems. For this reason, the implementation schedule and the scope differ between the Basel III and the US standards.

Leverage Ratio: Leverage ratio requirements have long been integral to US banking regulation, predating international standards such as Basel III. While the definition of the numerator differs (Basel III being stricter), US banks have been historically subject to a minimum Tier 1 leverage ratio of 4%, with a 5% threshold for well-capitalized status since 1985.

In 2014, US regulators introduced the Supplementary Leverage Ratio (SLR) as part of the Basel III reforms, a year ahead of the Basel Committee's 2015 timeline. The SLR requires large, internationally active banks to maintain a minimum Tier 1 capital of 3% of their total leverage exposure, which includes both on-balance-sheet assets and certain off-balance-sheet exposures, which is consistent with Basel III definition. The US implementation did not include a phase-in period; banks were expected to comply with the SLR requirements upon the rule's effective date.

To further enhance the resilience of systemically important banks, US regulators implemented the Enhanced Supplementary Leverage Ratio (eSLR) in 2014. This rule mandates US G-SIBs to maintain an additional buffer of 2% at the BHC level, raising the minimum SLR requirement to 5%. At the depository institution level, these banks are required to maintain a 6% SLR to be considered "well-capitalized."

In 2018, the Economic Growth, Regulatory Relief, and Consumer Protection Act (EGRRCPA) was enacted, mandating adjustments to the SLR for specific banking organizations.[37] This led banks under $250 billion total assets to be excluded from the SLR requirement. The final rule implementing this change became effective on April 1, 2020, aiming to more accurately reflect the leverage exposure of these specialized institutions.

In April 2020, responding to the outbreak of COVID-19, the Federal Reserve announced a temporary change to the Supplementary Leverage Ratio (SLR) requirements for large banks, intending to ease strains in the Treasury market and promote lending to households and businesses. This modification allowed banks to exclude U.S. Treasury securities and reserves at the Fed from the SLR calculation. This relief measure expired on March 31, 2021, at which point the previous SLR requirements were reinstated.[38]

Liquidity Coverage Ratio: In September 2014, US federal banking agencies finalized a rule implementing the Liquidity Coverage Ratio (LCR) for large and internationally active banking organizations. This rule established a standardized minimum liquidity requirement, mandating that these institutions hold sufficient high-quality liquid assets (HQLA) to cover projected net cash outflows over a 30-day stress period. The US LCR rule closely aligns with the Basel Committee on Banking Supervision's LCR standard but incorporates certain adjustments to address the specific characteristics of the US financial system.

A notable distinction between the US and Basel III LCR implementation lies in the phase-in schedules. The Basel III framework introduced the LCR starting at 60% on January 1, 2015, with annual increments of 10 percentage points, reaching 100% by January 1, 2019. In contrast, the US adopted a more accelerated timeline: institutions were required to maintain an LCR of 80% by January 1, 2015, increasing to 90% by January 1, 2016, and achieving full compliance at 100% by January 1, 2017.

[37] Furthermore, Section 402 of the EGRRCPA requires federal banking agencies to amend their capital regulations to allow custodial banks to exclude certain central bank deposits from the SLR calculation. This provision primarily benefits institutions predominantly engaged in custody, safekeeping, and asset servicing activities, such as The Bank of New York Mellon, Northern Trust Corporation, and State Street Corporation.

[38] Jurisdictions varied in their treatment of reserve exemptions in leverage ratio calculations. For instance, the ECB and Japan temporarily excluded reserves, while the UK had already permanently excluded them since 2016. Canada and Switzerland also implemented temporary exemptions, whereas the US reinstated its original SLR framework after March 2021.

A4. Institutional Details of the Federal Funds Market

In the post-crisis ample reserves regime, the federal funds market has become highly segmented and institutionally constrained. Although the Federal Funds Rate (FFR) remains the Federal Reserve's primary operating target, it is no longer determined through broad-based trading among a wide range of depository institutions. Instead, as shown in Figure 11, the effective FFR is shaped by bilateral bargaining between a narrow set of participants: the Federal Home Loan Banks (FHLBs) on the lending side and branches of foreign banking organizations on the borrowing side. Understanding how the FF market evolved into this oligopoly-oligopsony structure requires highlighting two key factors: regulatory constraints and the intraday liquidity needs of the federal funds market participants.

On the lending side, the FHLBs have emerged as the dominant suppliers of federal funds. Like other GSEs, the FHLBs are ineligible to earn interest on reserve balances held at the Federal Reserve, which gives them a strong incentive to lend cash at rates below the interest on reserve balances (IOR). However, only the FHLBs remain active in the federal funds market. This is because Fannie Mae and Freddie Mac, which were placed into conservatorship in September 2008, curtailed and ultimately ceased participation in unsecured lending markets following supervisory guidance issued in the early 2010s.[39] As a result, the FHLBs are now the sole GSEs supplying liquidity to the federal funds market.

The FHLBs' participation in the federal funds market is shaped by both regulatory requirements and operational needs. Each of the 11 regional FHLB manages its own investment portfolio and liquidity position. To fund their activities, FHLBs issue debt through the Office of Finance and extend advances to member institutions. Critically, they must maintain sufficient intraday liquidity to meet debt service obligations, which are typically due around 12:00 p.m. ET. Among available short-term instruments, overnight federal funds lending is uniquely well-suited to this requirement. These transactions operate through the Fedwire Funds Service, which opens at 9:00 p.m. ET on the prior business day (T–1) and closes at 7:00 p.m. ET on the settlement day (T), offering a wide window for access.[40] More importantly, overnight fed funds loans are typically repaid by 9:00 a.m. on T+1, allowing the FHLBs to redeploy cash ahead of their mid-day funding obligations on the next day.

Federal funds also receive favorable regulatory treatment. Under contingent liquidity requirements, FHLBs must hold a minimum stock of liquid assets. Interest-bearing deposits

[39] Fannie Mae and Freddie Mac are permitted to place overnight cash in the Federal Reserve's ONRRP facility, which is a secured transaction.

[40] The Fedwire Funds Service closing time was extended from 6:30 p.m. to 7:00 p.m. ET on March 8, 2021.

at commercial banks are subject to unsecured credit exposure limits, whereas placements in the federal funds market are exempted from these constraints.[41] These features make federal funds lending not only operationally flexible but also regulatory-efficient, reinforcing its role as the FHLBs' preferred short-term investment vehicle.

Other short-term investment options available to the FHLBs are operationally or institutionally constrained in ways that limit their usefulness for intraday liquidity management. Interest bearing bank deposits, for example, are subject to strict internal single-name counterparty limits, which restrict unsecured exposure to individual institutions and make it difficult to deploy large volumes of cash. Although these placements may offer comparable returns to fed funds, they are typically less scalable under current regulatory risk frameworks. The ONRRP facility offers a risk-free overnight investment option, but its timing is misaligned with FHLBs' operational requirements. The ONRRP auction window only opens between 12:45 p.m. to 1:15 p.m. ET, and the transaction settles on a T+1 basis at 3:30 p.m. ET. This means that cash placed in the facility is unavailable on the same day, limiting its usefulness for mid-day liquidity obligations. Similarly, tri-party repo transactions unwind late around 3:30 p.m. ET. As a result, while these instruments may serve a role in broader liquidity management, they are not viable substitutes for federal funds.

On the borrowing side, foreign bank branches account for the majority of activity in the federal funds market. Several regulatory and structural features contribute to this oligopsonistic outcome. First, foreign bank branches are exempted from paying the FDIC deposit insurance assessment, which domestic banks must pay on their total liabilities, including fed funds borrowed. This exemption makes overnight borrowing less costly for foreign banks than for their domestic counterparts.

Second, many large domestic banks face binding constraints under the Supplementary Leverage Ratio (SLR) or enhanced SLR (eSLR), which raise the marginal cost of balance sheet expansion—especially when borrowing reserves. In contrast, branches of foreign banks are not subject to these leverage requirements at the branch level, allowing them to take on reserves without facing regulatory balance-sheet costs.[42] This differential treatment creates a structural asymmetry in reserve demand, with foreign banks acting as more elastic borrowers in the overnight unsecured market.

In addition to these regulatory advantages, foreign bank branches are more likely to meet the credit standards required to access FHLB funding. The FHLBs impose internal

[41] This treatment was updated in January 2025, when the FHFA revised the liquidity framework for FHLBs: `https://www.fhfa.gov/news/news-release/fhfa-announces-final-rule-expanding-access-to-liquidity-for-the-federal-home-loan-bank-system`

[42] These exemptions apply to branches of FBOs. The consolidated parent may still be subject to leverage constraints, but these are often less strict compared to the Dodd-Frank framework in the U.S.

counterparty rating requirements for fed funds lending, typically at or above investment grade, and, in practice, many smaller domestic banks lack formal credit ratings or prefer to borrow term advances rather than engage in the overnight market.[43] In contrast, the foreign banks with branches in the U.S. are global institutions that tend to have more robust credit ratings, making them eligible counterparties for FHLB transactions.

This concentrated market structure has important implications for how the FFR is determined. In a frictionless environment with perfect competition among foreign banks, the FHLBs would be able to extract rates close to the borrowers' reservation price at IOR. In practice, however, the effective FFR in our sample period is often below IOR (Figure A3). This spread reflects a bargaining process: while the FHLBs are constrained by operational needs and regulatory limits on short-term investment options, foreign bank branches retain enough pricing power to secure funding at a discount.[44] As a result, the FFR is not a market-clearing rate in the classical sense, but the negotiated outcome of bilateral interaction between a very small number of lenders and borrowers. It reflects the internal incentives and constraints of these institutions rather than system-wide marginal valuations of reserves. Moreover, this structure is fragile because it depends on the continued participation of both FHLBs as reliable lenders and foreign bank branches as eligible, low-cost borrowers. Any disruption on either side could materially affect the level and behavior of the FFR. For example, FHLB short-term investment rule revisions or divergence in global monetary policies could significantly alter participation and change bargaining dynamics.

[43] Foreign banks are not members of FHLBs and thus do not have access to secured advances from FHLBs.
[44] For underlying bargaining process in the federal funds market, see Bech and Klee (2011).

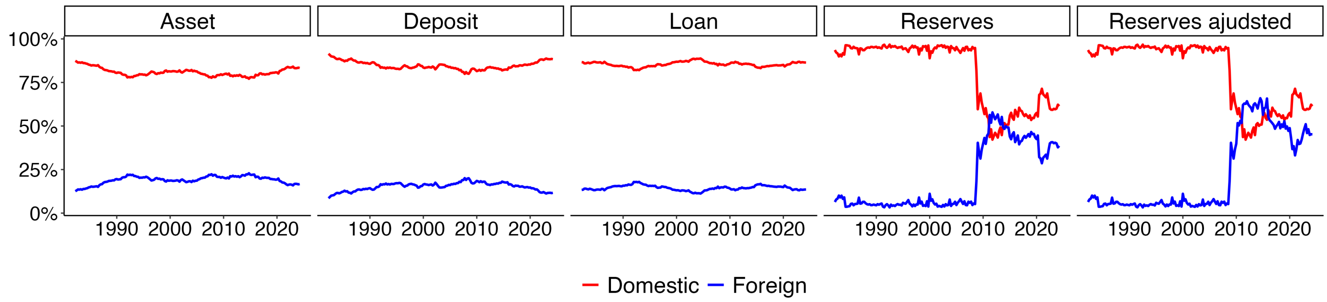

Figure A1: Share of Balance Sheet Components: Domestic Banks and Foreign Banks This figure shows the assets, loans, deposits, and reserves of the domestic banks and foreign banks (the aggregate sum of subsidiaries and branches and agencies) from 1980Q2 to 2024Q3. The "Reserves" show share based on Call Report quarterly-end reportings where "Reserves adjusted" show the reserve holdings based after adjusting for window dressing. Specifically, we replace quarter-end reserve reports of foreign branches and agencies with their daily cash balances from the H.8 release, carrying forward the most recent non-quarter-end value for March 31, June 30, September 30, and December 31. This adjustment removes artificial dips and yields a smoother, more accurate measure of foreign branches' true reserve holdings. No adjustment is applied to foreign bank subsidiaries or to domestic banks. Source: FFIEC 002, 031, 041 reports, Federal Reserve H.8 release.

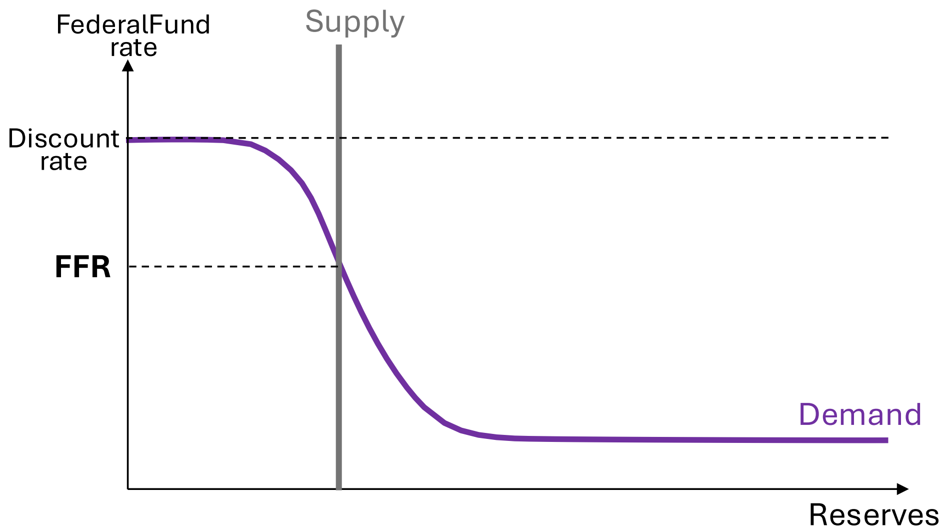

Figure A2: Illustration of Scarce Reserves System

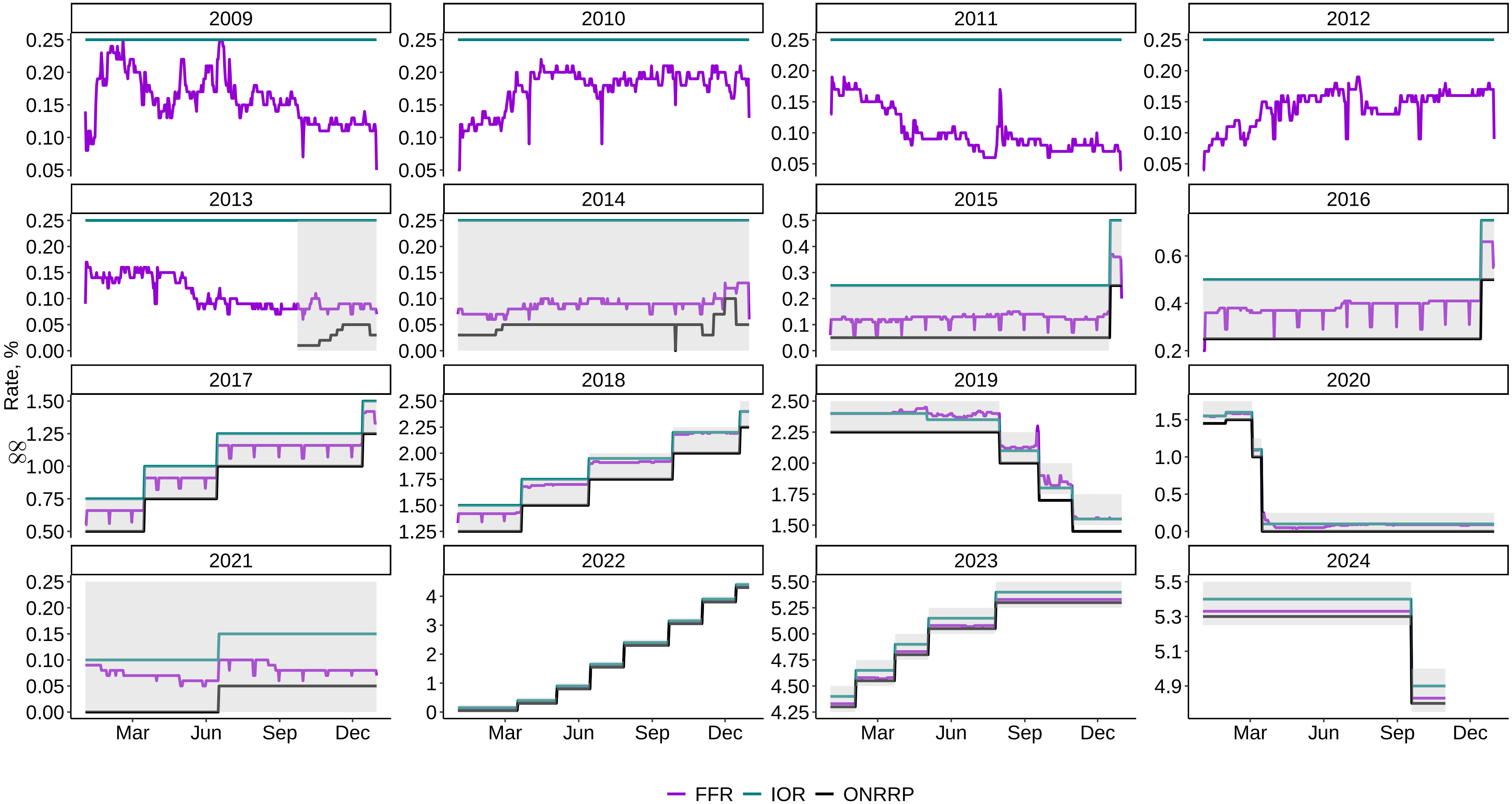

Figure A3: Federal Funds Rate (FFR), Interest on Reserves (IOR), Overnight Reverse Repurchase Agreements Award Rate (ONRRP), and the Federal Funds Target Range (2009-2024) The Federal Funds Target Range shaded in gray. Source: FRED

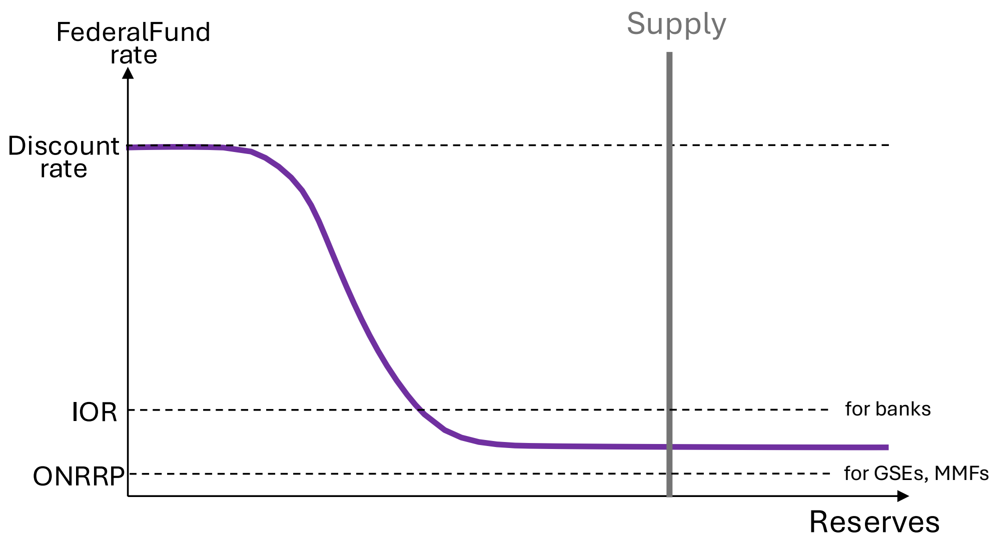

Figure A4: Illustration of Introduction of ONRRP

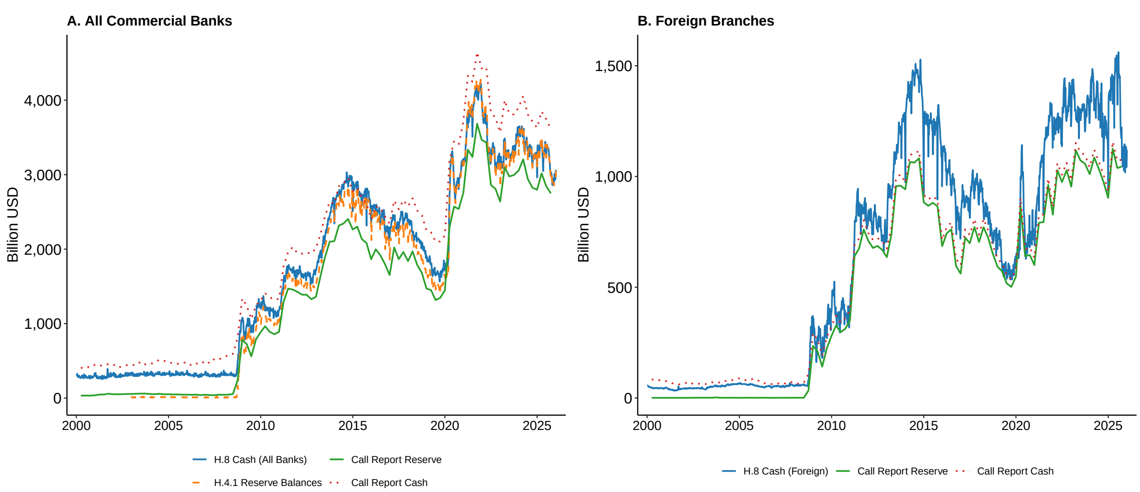

Figure A5: Cash and reserve data source and frequency comparison Source: FFIEC 002, 031, 041 reports, Assets and Liabilities of Commercial Banks in the United States (H.8), Federal Reserve Balance Sheet: Factors Affecting Reserve Balances (H.4.1)

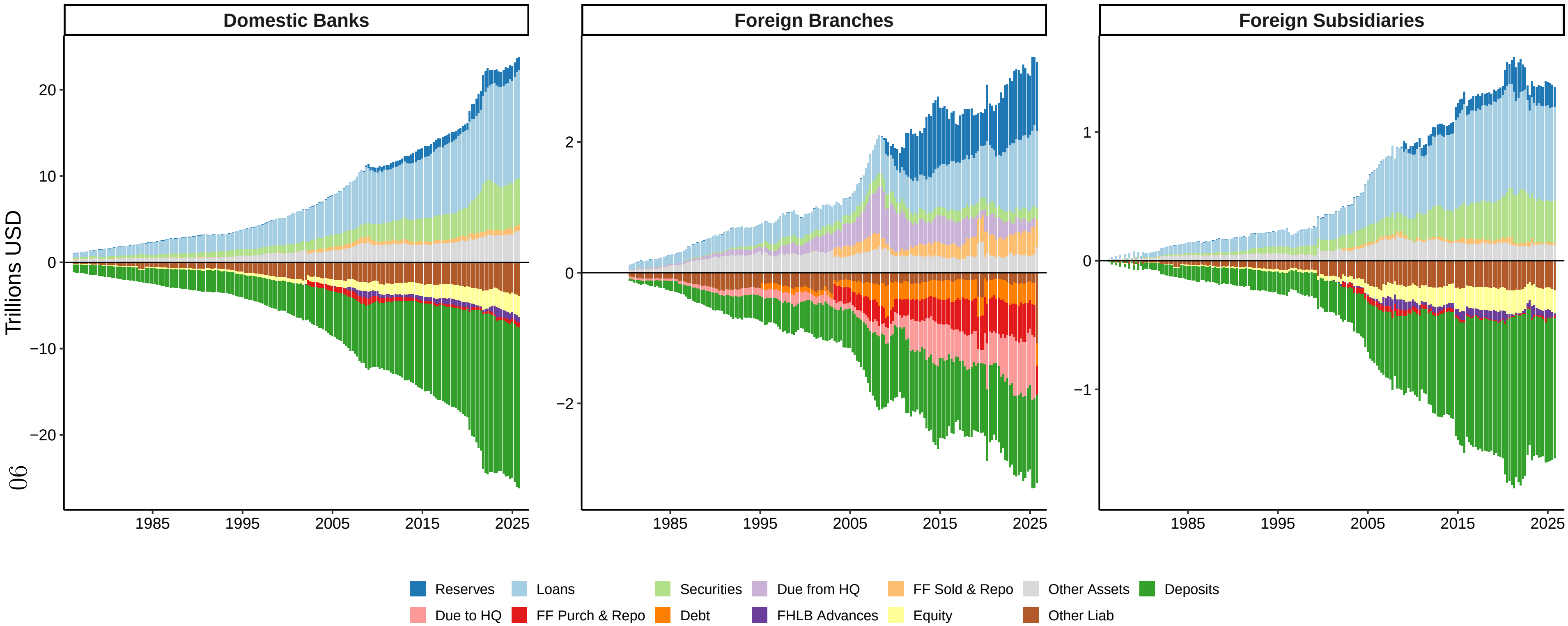

Figure A6: Balance Sheet Breakdown Source: FFIEC 002, 031, 041 reports, FR Y-9C reports

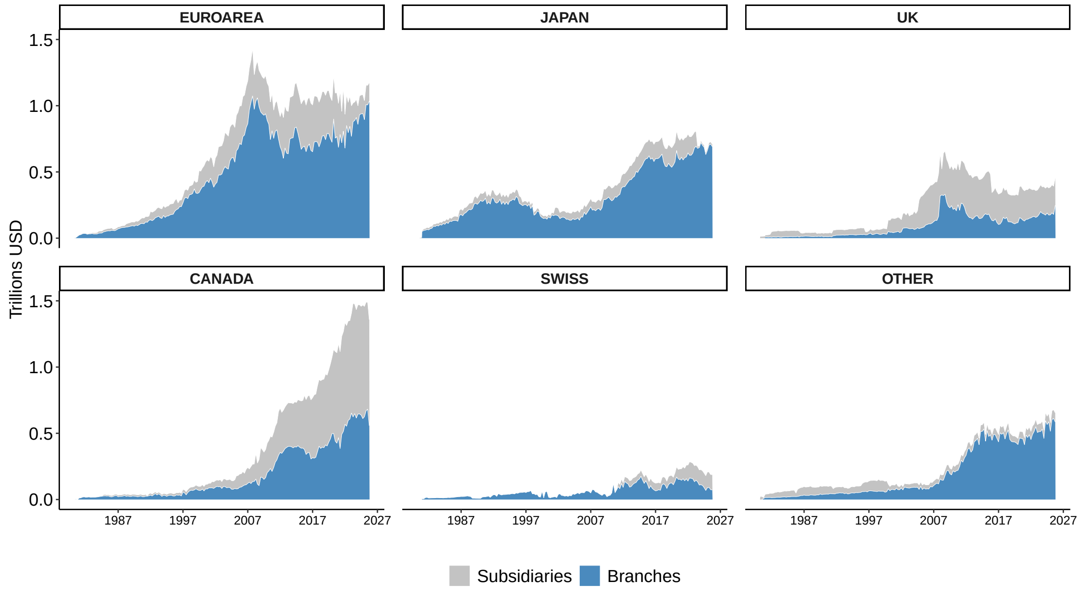

Figure A7: Asset Composition of Foreign Banks by Jurisdiction This figure displays the total assets of foreign banks in the U.S., disaggregated by jurisdiction and organizational structure. Each panel shows the time series of total assets for banks headquartered in a given jurisdiction, broken down into branches (gray) and subsidiaries (blue). Source: FFIEC 002, 031, 041 reports

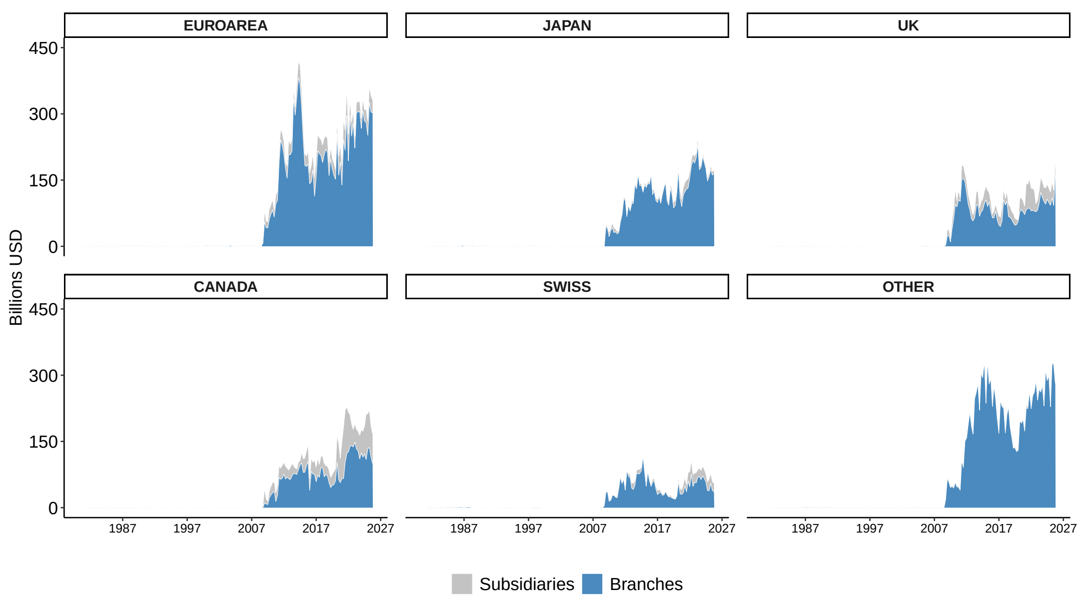

Figure A8: Reserves Composition of Foreign Banks by Jurisdiction This figure displays the total reserves of foreign banks in the U.S., disaggregated by jurisdiction and organizational structure. Each panel shows the time series of total reserves for banks headquartered in a given jurisdiction, broken down into branches (gray) and subsidiaries (blue). Source: FFIEC 002, 031, 041 reports

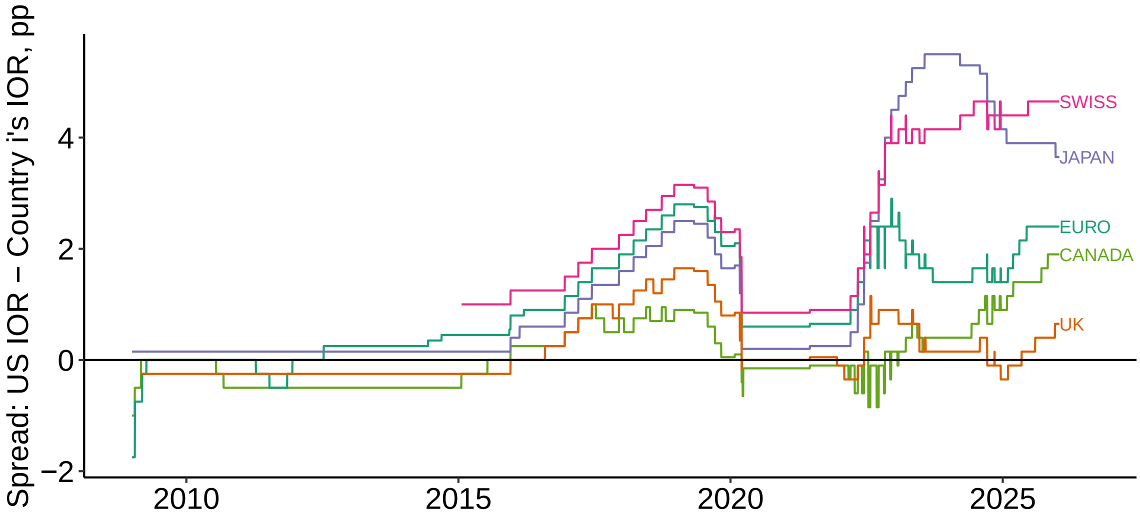

Figure A9: International Reserves Rate Spreads for Foreign Banks This figure displays the daily interest rate spread between the US interest on reserves (IOR) and the corresponding reserve interest rates in selected foreign jurisdictions. For the US, we use the interest rate on excess reserves (IOER) until July 28, 2021, after which we use the interest rate on reserve balances (IORB). For Japan, following the introduction of the three-tier reserve system in January 2016, we use the allocation to the policy rate balance as the relevant rate, representing the lowest interest rate applied to reserves held at the Bank of Japan. This rate was –0.1% through March 2024 and was raised to 0.1% thereafter. For the Euro area, we use the deposit facility rate, while for the UK, we use the Bank Rate. For Switzerland, we use the interest rate on sight deposits above the policy threshold, starting from January 22, 2015. Data sources: Bank of Canada, Bank of England, Bank of Japan, European Central Bank, Federal Reserve Board, and Swiss National Bank.

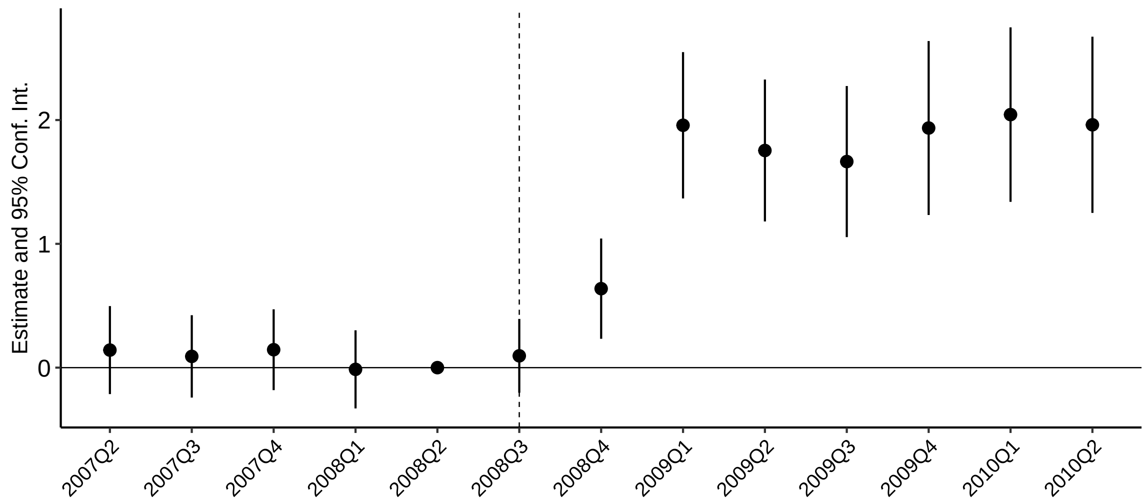

Figure A10: Event study around 2008Q3 This figure presents an event study analysis of the reserve holdings of bank holding companies (BHCs) around 2008Q3 of equation $Y_{it} = \sum_{k \neq 0} \gamma_k \cdot \mathbb{1}\{T_i = k\} + \beta X_{it} + \alpha_i + \delta_t + \epsilon_{it}$, where Y_{it} denotes the log of reserves held by bank holding company i at time t. The event, which corresponds to the third quarter of 2008, is normalized to $k = 0$, and $\mathbb{1}\{T_i = k\}$ is an indicator for periods k relative to this event. The coefficients γ_k capture the differential reserve accumulation of foreign banks relative to domestic banks before and after the event. The model includes BHC fixed effects (α_i), and time fixed effects (δ_t), which control for macroeconomic shocks common to all banks. Additionally, we control for bank-specific characteristics (X_{it}), such as the lagged value of total assets, which account for differences in bank size and balance sheet structure. The horizontal axis represents time in quarters relative to this event, while the vertical axis shows the estimated effect on log reserve holdings. Confidence intervals at the 95% level are shown for each estimate. Source: FFIEC 002, 031, 041 reports, FR Y-9C reports

Table A1

First-Stage: TGA Shock and Overnight Spreads (Weekly)

This table reports weekly first-stage regressions of overnight spread changes on the weekly TGA shock. The weekly TGA shock is the sum of daily TGA shocks over the H.8 Wednesday-to-Wednesday measurement window, in $100 billion units, excluding calendar quarter-end H.8 dates. The dependent variable is the Wednesday endpoint spread change, measured in basis points as the spread at the current H.8 Wednesday anchor minus the spread at the previous H.8 Wednesday anchor; when needed, the anchor uses the last active market day on or before the H.8 Wednesday. The full weekly sample runs from 2009-01-14 to 2025-12-24. The QE sample pools 2009-01-14 to 2014-10-29 and 2019-11-06 to 2021-11-24; the QT sample pools 2014-11-05 to 2019-10-30 and 2021-12-01 to 2025-12-24. Panel A uses FFR–IOR. Panel B uses the historical SOFR proxy relative to IOR, following the daily first-stage construction: holiday gaps are linearly interpolated, while weekly changes spanning the splice-boundary dates 2014-08-22 and 2018-04-03 are set missing, leaving Panel B with two fewer full-sample observations than Panel A. The coefficient on ΔTGA is the basis point change in the spread associated with a $100 billion increase in TGA. Columns (1)–(3) use the full sample with progressively more controls; columns (4) and (5) pool QE and QT periods, respectively. Standard errors are clustered by FOMC period.

Panel A: FFR-IOR

	Δ(FFR – IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	0.3301***	0.3530***	0.3018**	0.7513***	0.0609
	(0.1117)	(0.1102)	(0.1204)	(0.2265)	(0.1328)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	877	877	877	405	472
R^2	0.010	0.281	0.291	0.506	0.058

Panel B: SOFR-IOR

	Δ(SOFR-hist – IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	1.1519***	1.3256***	1.4109***	1.9114***	1.0993
	(0.3779)	(0.4929)	(0.5055)	(0.5672)	(0.7046)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	875	875	875	404	471
R^2	0.010	0.045	0.048	0.149	0.023

Table A2

First Stage: TGA Shock and Money Market Spreads Positive TGA Shocks

This table presents first-stage regressions using only positive TGA shocks (reserve drains, when the TGA balance increases), excluding calendar quarter-end dates. Panel A uses the federal funds rate minus IOR spread. Panel B uses the extended SOFR minus IOR spread, which combines the historical proxy before April 2018 with official SOFR thereafter. The SOFR extension linearly interpolates the five holiday-gap dates 2010-04-02, 2012-04-06, 2014-12-26, 2015-04-03, and 2018-04-02, while keeping the splice-boundary first differences missing on 2014-08-22 and 2018-04-03. The coefficient on ΔTGA represents the basis point change in the spread per $100 billion increase in TGA. Columns (1)–(3) use the full sample with progressively more controls. Columns (4) and (5) split by QE periods and QT periods. Column (1) reports IID standard errors; columns (2)–(5) report standard errors clustered by FOMC period. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel A: FFR-IOR

	Δ(FFR − IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	0.5674***	0.6855***	0.3896**	1.3249***	-0.2424
	(0.1500)	(0.1732)	(0.1910)	(0.3007)	(0.2301)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	1,796	1,796	1,796	769	1,027
R^2	0.008	0.122	0.192	0.203	0.206

Panel B: SOFR-IOR

	Δ(SOFR − IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	3.5708***	3.9122***	3.9251***	4.3771***	3.6066***
	(0.3888)	(0.5450)	(0.5604)	(0.7096)	(0.7929)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	1,795	1,795	1,795	768	1,027
R^2	0.045	0.150	0.150	0.284	0.102

Table A3

First Stage: TGA Shock and Money Market Spreads Negative TGA Shocks

This table presents first-stage regressions using only negative TGA shocks (reserve injections, when the TGA balance decreases), excluding calendar quarter-end dates. Panel A uses the federal funds rate minus IOR spread. Panel B uses the extended SOFR minus IOR spread, which combines the historical proxy before April 2018 with official SOFR thereafter. The SOFR extension linearly interpolates the five holiday-gap dates 2010-04-02, 2012-04-06, 2014-12-26, 2015-04-03, and 2018-04-02, while keeping the splice-boundary first differences missing on 2014-08-22 and 2018-04-03. The coefficient on ΔTGA represents the basis point change in the spread per $100 billion decrease in TGA. Columns (1)–(3) use the full sample with progressively more controls. Columns (4) and (5) split by QE periods and QT periods. Column (1) reports IID standard errors; columns (2)–(5) report standard errors clustered by FOMC period. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel A: FFR-IOR

	Δ(FFR − IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	-0.2798	-0.3169	-0.1929	-0.1333	-0.1810
	(0.1711)	(0.2350)	(0.2148)	(0.2096)	(0.3297)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	2,214	2,214	2,214	1,110	1,104
R^2	0.001	0.063	0.179	0.138	0.207

Panel B: SOFR-IOR

	Δ(SOFR − IOR) (bps)				
	(1)	(2)	(3)	(4)	(5)
ΔTGA ($100bn)	-1.2573***	-1.2705**	-1.2944**	-0.5568	-1.8177**
	(0.3983)	(0.5854)	(0.5883)	(0.4584)	(0.9160)
FOMC Period FE		✓	✓	✓	✓
ΔONRRP Control			✓	✓	✓
Sample	Full	Full	Full	QE	QT
Observations	2,213	2,213	2,213	1,110	1,103
R^2	0.004	0.147	0.148	0.325	0.057

Table A4

Bank Characteristics and Reserve Holdings

Notes: This table presents the results of estimating: $Y_{it} = \beta_1 F_i + \beta_2 G_i + \beta_3 (F_i \times G_i) + \Gamma X_{it} + \epsilon_{it}$, using quarterly data for U.S. bank holding companies (BHCs), 2009:Q1–2024:Q4. Here Y_{it} is the log of reserves held by BHC i at time t. The vector X_{it} includes lagged bank size, the aggregate supply of reserves, and other balance-sheet controls. Standard errors are clustered at the BHC level. Columns (1)–(3) relate reserve holdings to (i) a foreign-bank indicator F_i, (ii) a G-SIB indicator G_i, and (iii) their interaction. Columns (4)–(6) add controls for log assets and log deposits; column (5) restricts the sample to foreign banks, and column (6) excludes G-SIBs. G-SIBs face stricter post-GFC liquidity and capital rules–most notably the Liquidity Coverage Ratio (LCR) and CCAR stress tests–which raise their demand for high-quality liquid assets such as reserves. Moreover, their central role in wholesale funding and payment systems necessitates larger settlement balances. ***, **, and denote significance at the 1 %, 5 %, and 10 % levels, respectively.

	log(Reserves)					
	(1)	(2)	(3)	(4)	(5)	(6)
F	3.361***		2.763***	1.661***		1.665***
	(0.2209)		(0.2127)	(0.1513)		(0.1516)
G		7.382***	8.555***	3.316***	0.5838**	
		(0.2182)	(0.2338)	(0.1344)	(0.2363)	
F × G			-4.299***	-1.508***		
			(0.3891)	(0.2224)		
Balance Sheet Control				✓	✓	✓
Reserve Supply Control	✓	✓	✓	✓	✓	✓
Sample	All	All	All	All	Foreign	Non-GSIBs
Observations	305,310	305,310	305,310	295,643	7,873	294,034
R^2	0.15	0.15	0.20	0.46	0.58	0.40

Table A5

Liabilities Adjustment Given Reserve Change
Large Domestic Banks

This table reports two-stage least-squares estimates for large domestically chartered commercial banks using weekly level changes in billions of dollars from 2009 to 2025. The endogenous regressor is weekly Δ reserves, instrumented with the raw Wednesday-to-Wednesday TGA shock measured in units of 100 billion dollars. All specifications include FOMC-period fixed effects and cluster standard errors by FOMC period. Quarter-end sample dates are excluded, matching the raw TGA absorption table. Large time deposits are LTDLCBW027NBOG, other deposits are ODSLCBW027NBOG, internal funding is measured as max(NDFLCBW027NBOG, 0), and wholesale funding is H8B3094NLGD divided by 1,000. Wholesale funding includes federal funds purchased, securities sold under agreements to repurchase, and other borrowed money. ***, **, and * denote significance at the 1%, 5%, and 10% levels.

	Δ large time deposits (1)	Δ other deposits (2)	Δ internal funding (3)	Δ wholesale funding (4)
$\Delta\widehat{Reserves}$	-0.0022	0.6596***	0.0190	0.0032
	(0.0139)	(0.1178)	(0.0196)	(0.0371)
First stage: ΔTGA ($100bn)	-32.1133***	-32.1133***	-32.1133***	-32.1133***
Observations	878	878	878	878
F-stats	44.01	44.01	44.01	44.01

Table A6

Liabilities Adjustment Given Reserve Change: QE and QT Periods
Large Domestic Banks

This table reports two-stage least-squares estimates for large domestically chartered commercial banks using weekly level changes in billions of dollars from 2009 to 2025. The endogenous regressor is weekly Δ reserves, instrumented with the raw Wednesday-to-Wednesday TGA shock measured in units of 100 billion dollars. All specifications include FOMC-period fixed effects and cluster standard errors by FOMC period. Quarter-end sample dates are excluded, matching the raw TGA absorption table. Large time deposits are LTDLCBW027NBOG, other deposits are ODSLCBW027NBOG, internal funding is measured as max(NDFLCBW027NBOG, 0), and wholesale funding is H8B3094NLGD divided by 1,000. Wholesale funding includes federal funds purchased, securities sold under agreements to repurchase, and other borrowed money. ***, **, and * denote significance at the 1%, 5%, and 10% levels. In QE2 and QT2, internal funding, defined as max(NDFLCBW027NBOG, 0), is zero throughout the subperiod, so the corresponding coefficient entries are left blank.

	QE Periods				QT Periods			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: First QE/QT Cycle							
	QE1: Jan 2009 – Oct 2014				QT1: Nov 2014 – Oct 2019			
$\Delta\widehat{Reserves}$	-0.1088*	-0.2126	0.1257	0.4019**	0.0208	0.8908***	0.0230	-0.2116***
	(0.0648)	(0.5842)	(0.1623)	(0.1884)	(0.0249)	(0.1389)	(0.0352)	(0.0532)
Observations	301	301	301	301	259	259	259	259
F-stats	5.68	5.68	5.68	5.68	41.77	41.77	41.77	41.77
	Panel B: Second QE/QT Cycle							
	QE2: Nov 2019 – Nov 2021				QT2: Dec 2021 – Dec 2025			
$\Delta\widehat{Reserves}$	0.0291	0.6943		-0.0181	0.0006	0.7132***		0.0335
	(0.0574)	(0.4982)		(0.0897)	(0.0183)	(0.1522)		(0.0556)
Observations	105	105	105	105	213	213	213	213
F-stats	2.25	2.25	2.25	2.25	21.68	21.68	21.68	21.68
Dep. Variable	Δ large time deposits	Δ other deposits	Δ internal funding	Δ wholesale funding	Δ large time deposits	Δ other deposits	Δ internal funding	Δ wholesale funding

Table A7

Global Funding Margins and Branch-Level Funding Composition

This table reports branch-level regressions of quarterly changes in funding components on the change in the three-month FX-hedged reserve margin. Columns (1)–(3) use gross funding changes; columns (4)–(6) use net funding changes, where net positions subtract the corresponding asset-side exposure before taking changes. Outcomes are scaled by lagged assets and measured in percentage points. The regressor is measured in one-percentage-point units. All specifications include branch fixed effects, quarter fixed effects, and lagged log assets. Standard errors are clustered by branch and quarter. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Δ Gross			Δ Net		
	FedFunds	Repo	HQ Funding	FedFunds	Repo	HQ Funding
Δ 3M hedged IOR spread	-0.329	-2.190***	4.493***	-0.101	-1.731***	5.769**
	(0.321)	(0.755)	(1.191)	(0.343)	(0.446)	(2.638)
Time FE	✓	✓	✓	✓	✓	✓
Balance Sheet Ctrl	✓	✓	✓	✓	✓	✓
Observations	4,754	4,754	4,754	4,754	4,754	4,754
R^2	0.030	0.035	0.061	0.028	0.026	0.050