Reserve Demand and Balance Sheet Run-off

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Abstract: To normalize and tighten monetary policy after large-scale asset purchases, central banks need to decide when, how fast and by how much to reduce the size of their balance sheets. Understanding reserve demand is central for evaluating the amount of feasible balance sheet runoff but received little attention until spikes in US short-term money market rates in September 2019 showed that the Federal Reserve had reduced reserves to the point of creating a shortage of safe and liquid short-maturity assets. We document that reserve demand is negatively related to the effective federal funds rate (EFFR)-interest on reserves (IOR) spread but the relation is unstable over the 2009m1-2022m1 period. We argue that deposits affect banks' reserve demand and find a stable reserve demand curve once deposits are accounted for, with a tight negative relation emerging between the EFFR-IOR spread and "deposit-adjusted reserves". Increasing amounts of deposits over the 2009m1-2022m1 period (driven partly by higher financial assets of households) imply that a scarcity of liquidity would now result much before reserves-to-GDP was reduced to 7% of GDP as in the policy normalization phase leading up to September 2019. We use our estimated reserve demand function to quantify more modest amounts of feasible reserve reduction.

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1. Introduction

As part of their process of policy normalization/tightening after the COVID crisis, central banks need to decide when and by how much to reduce the size of their balance sheets. A precedent for policy normalization is the U.S. experience after the Great Financial Crisis. In the 2017 Addendum to its Policy Normalization Principles and Plans, the FOMC stated that, over time, the size of its balance sheet would be determined by the demand for reserve balances:

> *"The Committee currently* ***anticipates reducing the quantity of reserve balances****, over time, to a level appreciably below that seen in recent years but larger than before the financial crisis; the level will reflect the banking system's* ***demand for reserve balances*** *and the Committee's decisions about how to implement monetary policy* ***most efficiently and effectively*** *in the future."*[2]

In a regime with ample reserves and interest on reserves (IOR), reserve demand is typically modeled as a decreasing function of the market interest rate on other short-term assets (such as the effective federal funds rate). If commercial banks had no balance sheet costs due to liquidity or capital regulation, the market interest rate would be between the primary credit rate (at which banks can borrow from the Federal Reserve) and the IOR (the rate banks earn on funds they deposit with the Federal Reserve). This equilibrium would emerge because banks would arbitrage away the market interest rate-primary credit spread if this was positive (borrowing at the primary credit rate and investing at the market rate) or arbitrage away the IOR-market interest rate spread if that was positive (borrowing at the market rate and investing at the IOR). With balance sheet constraints, the market interest rate can equilibrate outside this range. Importantly, the market rate can be below the IOR. This will happen for sufficiently large reserve supply if banks require an extra return to be enticed to hold this large reserve supply. When the market rate is below the IOR, banks can obtain part of the funds needed to hold the stock of reserves by borrowing at the market rate and investing at the IOR, earning enough of a spread to cover balance sheet costs. This equilibrium only emerges if other investors do not have access to reserves earning the IOR. In practice, Federal Home Loan Banks do not have access to interest-bearing reserves and lend funds to banks in the federal funds market. To ensure that the market rate does not fall too far below the IOR, the Federal Reserve has set up what is effectively a type of reserve balance but that earns a lower interest rate and is available to a broader set of financial institutions. This is the overnight reverse repo (ON RRP) facility. If sufficiently many investors have access to the ON RRP in sufficiently large amounts, the market interest rate will equilibrate above or at the ON RRP interest

[2] Policy Normalization Principles and Plans (federalreserve.gov). Similarly, the latest "Principles for Reducing the Size of the Federal Reserve's Balance Sheet" released on 1/26/2022 states that "Over time, the Committee intends to maintain securities holdings in amounts needed to implement monetary policy efficiently and effectively in its ample reserves regime."

rate. Ihrig, Senyuz and Weinbach (2020) illustrates the reserve demand function as a function of the market interest rate. Their Figure 1 is shown as Appendix Figure 1 for reference.

This framework pins down the level of the market interest rate at or above the rate on the ON RRP. Since only banks have access to borrowing at the primary credit rate (and doing so carries some stigma), the market rate can equilibrate above the primate credit rate in times of high borrowing demand. Aside from such times, by setting the three administered rates, the FOMC can set the market interest rate at a desired level, if it supplies the appropriate amount of reserves. If reserve demand is flat (horizontal) at a market rate equal to the ON RRP rate, the FOMC could set reserve supply equal to the lowest level of reserves on this flat part of the reserve demand curve (denote this reserve value as Reserves*). With reserve supply set at Reserves*, the market interest rate would then equal the ON RRP rate. The FOMC could also choose to reduce reserves below Reserves*, targeting a market rate above the ON RRP rate (to ensure a more efficient supply of reserves). If the FOMC wants the market rate to equilibrate at a particular value, it will need to adjust reserve supply in response to reserve demand shocks or adjust the three administered rates (ON RRP, IOR and primary credit) in response to demand shocks.

What is missing from this framework is an understanding of what drives reserve demand other than the administered rates, i.e., the location of the reserve demand function in the left-right dimension. This involves an understanding of both the "typical" reserve demand function and of shocks to the reserve demand function.

We already have substantial insight into drivers of reserve demand shocks from the period before the ample-reserves regime. In this earlier regime, reserve demand was driven by reserve requirement and by banks' demand for holding reserves above the regulatory minimum. Banks' need for required reserves followed directly from the amount of money they created in the form of deposits (with reserve requirements set as a percentage of transactions deposits, see Archived Reserve Maintenance Manual). Banks could choose to hold reserves above the regulatory minimum to facilitate transactions, to avoid overdrafts with the Federal Reserve. Judson and Klee (2009) discuss banks' use of reserves to settle payments in the Federal Reserve's Fedwire payment system. Describing banks' time-varying demand for reserves, they explain that "Payment flows tend to be elevated at month-start, mid-month, the twenty-fifth of the month, month-end, and on days after holidays, owing in part to corporate tax due dates, principal and interest payments on securities, and pent-up flows after a long weekend." During the scarce reserve-zero IOR regime, the Federal Reserve carefully modeled the demand for excess reserves and adjusted reserve supply on a daily basis in order to ensure that the federal funds rate traded near the federal funds rate target. The lessons from the earlier regime came to fore again during the events of September 2019 when the market interest rate (notably the

Treasury repo rate) spiked above the primary credit rate in response to two "high payment flow" events (tax payments and Treasury issuance).[3]

What the earlier literature cannot teach us is the drivers of the "typical" reserve demand function in the ample-reserves regime. In this paper, we argue that the central driver of reserve demand – above and beyond the Federal Reserve's administered rates – is bank deposits. We also estimate the slope of the reserve demand function with respect to the market interest rate (relative to IOR), the central parameter for understanding how much the market interest rate will change with reserve supply for given deposits. Our results show that with appropriate functional forms, reserve demand is well described as a function of deposits and the market interest rate-IOR spread (using the effective federal funds rate, EFFR, for the market rate). Once one accounts for both reserve demand determinants (the interest rate spread and deposits), the reserve demand function appears surprisingly stable over the 2009m1-2022m1 period. Specifically, the (EFFR-IOR) spread has a clear and stable negative relation to a measure of reserves that is adjusted for deposits ("deposit-adjusted reserves"). Intuitively, while reserves supply liquidity to banks, deposits generate a need for liquidity, implying that the tightness of liquidity in the short-term money market (reflected in the EFFR-IOR spread) is driven by both reserves and deposits.

An important aspect of our estimation is that it is done at the monthly level using monthly averages of the relevant variables. We choose this frequency to reduce the effect of possible endogeneity of reserves to high-frequency demand shocks such as those described above occurring on high-payment flow days. Our approach thus assumes that most of the variation in reserves at the monthly frequency is not due to demand shocks but is instead driven by monetary policy, notably the rounds of quantitative easing and tightening over the sample. As we will show, this policy-induced variation in reserves is clearly visible in the data.

In terms of deposits, we discuss potential drivers of the increase in deposits-to-GDP over the period since 2009, arguing that increased financial wealth and the level of interest rates appear important. Our estimates of the reserve demand function are robust to instrumenting deposits with financial wealth and the level of interest rates and a test for overidentifying restrictions supports the endogeneity of these instruments. This helps rule out the possibility that the role of deposits as a driver of reserve demand is a spurious finding, driven by deposits being correlated with the reserve demand residual.

Crucially, the relation between the EFFR-IOR spread and deposit-adjusted reserves can be used as a guide to balance sheet runoff. As of January 2022, reserves are \$3.90T or about 15.7% of GDP. Our relation

[3] Work on the September 2019 yield spikes include Correa, Du and Liao (2021), Afonso, Cipriani, Copeland, Kovner, La Spada and Martin (2020), and Copeland, Duffie and Yang (2021).

predicts that if the FOMC allowed a rundown in the stock of reserves to 7% of GDP (currently around $1.74T), as was done in the prior policy normalization, the EFFR-IOR spread would be substantially above zero (on average, in monthly data) and much higher than in September 2019. This finding is due to the much higher level of deposits currently (both in dollars and as a percent of GDP) than during the last policy normalization cycle. To make the EFFR clear at a chosen level, on average over the month, this finding implies that the Federal Reserve would thus need to set the IOR at a lower value relative to the mid-point of the target range (and our relation can be used to guide the IOR value). However, a high EFFR-IOR spread has been associated with daily yield spikes in market rates that may be deemed undesirable and may not fully be addressed by the FOMC's new Standing Repo Facility. We therefore use our estimated relation between the EFFR-IOR spread and deposit-adjusted reserves to predict which value of reserves would lead to a similar predicted value for the EFFR-IOR spread as in September 2019 given current deposits. We estimate that this would happen around reserves of $2.77T, about 11.1% of GDP. Given the events of September 2019, this reserve level may also be deemed too low. As a more conservative approach, we estimate the value of total reserves at which the EFFR is predicted to clear around the IOR (on average, in monthly data). This value comes to $3.34T, about 13.5% of GDP.

These reserve levels are all vast compared to the level of reserves before the financial crisis. Back then, banks managed their deposits with reserves under $100B. How was that possible? A simple answer is that before the Fed started to pay interest on reserves, banks had steep incentives to economize on reserves given that they did not pay interest. Banks were generally at a corner solution for reserve holdings and held only the required amount of reserves (excess reserves were small). With positive interest on reserves, holding reserves is cheaper (the spread between the Fed funds rate and IOR is small, often even negative) and excess reserves are most of the total. Banks are no longer at a corner solution for reserve holdings and adjust them as a function of the (Market rate (EFFR)-IOR) spread.

2. The instability of the reserve demand function

Figure 1 provides a time series plot of the reserves-to-GDP ratio and the EFFR-IOR spread using monthly average data since 2009.[4] The policy-induced variation in Reserves/GDP is apparent with the series increasing around the times of QE1, QE2, QE3, after September 2019 (as the FOMC increased reserves due to reserve scarcity) and with the COVID-related LSAPs. Following the end of the QE rounds, Reserve/GDP falls due to a combination of lower reserves and higher nominal GDP.

[4] We calculate monthly averages from weekly data for reserves and daily data from EFFR-IOR. We assume that GDP was the same across months within the quarter. All data are from FRED.

The reserves-to-GDP ratio has a clear negative relation with the EFFR-IOR spread, consistent with the above-described reserve demand framework of U.S. monetary policy implementation. However, the relation is unstable in that the EFFR-IOR spread is higher in the later part of the sample for a given Reserves/GDP value. Notably, the EFFR-IOR spread is substantially above zero in September 2019 for Reserves/GDP around 7%, in contrast to a negative EFFR-IOR spread in December 2010, when the Reserves/GDP was also around 7%.

To further illustrate the reserve demand function instability, Figure 2 provides scatter plots of the EFFR-IOR spread against ln(Reserves) (Panel A) and Reserves/GDP (Panel B). We have labeled the data points that precede reserve expansions. The reserve demand curve appears flatter when reserves expand than when they contract. Smith and Valcarcel (2021) have documented this slope difference comparing the period 2009Q1-2014Q3 period of overall reserve expansion to the 2014Q4-2019Q3 period of overall reserve contraction. Figure 2 confirms the flat slope during the subsequent reserve expansions. Furthermore, by connecting the data points, our figure shows that the differential slope pattern holds even within the 2009Q1-2014Q3 period, implying that the relation holds over several reserve expansion-contraction cycles. We will argue, however, that this fact does not mean that there is something fundamentally different about reserves expansions and reserves contractions. Instead, there appears to be an omitted variable that increases reserves demand over time leading to the observed expansion-contraction pattern. This results in a relation that looks like a hastily installed string of garland lights, or an unstable Phillips curve. We will argue that just like time-varying inflation expectations make the Phillips curve unstable if inflation expectations are not considered, time-varying deposits make the reserve demand curve unstable when deposits are not accounted for and deposits have been increasing (even relative to GDP) over the period since 2009.

3. Estimating a stable reserve demand function by accounting for deposits

The theoretical and empirical literature on reserve demand during the ample reserves-positive IOR regime focuses on the first determinant of reserves demand, the spread between the market interest rate (on some alternative investment to reserves) and the IOR. Theoretically, deposits should be an additional important determinant of reserve demand. This is the case across various types of banking:

Narrow banking: Required reserves equal deposits as deposits are backed one-for-one by reserves.
Fractional reserve banking: Required reserves equal a constant fraction of deposits. In a scarce reserves version of fractional reserve banking, the central bank restricts the supply of reserves to manage bank lending.

Ample reserves banking: The demand for reserves is affected by deposits for economic and regulatory reasons. Economically, deposits need backing by reserves to be liquid and (in the case of uninsured deposits) safe. In terms of liquidity, reserves facilitate transactions due to bank deposit inflows and outflows. Therefore, even aside from reserve requirements, banks having higher levels of deposit liabilities need more reserves to meet the higher volume of interbank transactions associated with customers' deposit balances.[5] Furthermore, reserves represent one of many potential investments for banks and banks may decide to invest a substantial fraction of their assets in reserves if private sector lending opportunities are poor and the opportunity cost of holding reserves is. One can think of banks as facing a portfolio problem of allocating their assets (funded mainly with deposits) among reserve balances, loans, and securities investments. In terms of regulation, under the liquidity coverage ratio, banks need to hold more high quality liquid assets (HQLA) if they have more deposit liabilities, and reserves are one possible HQLA. The amount of HQLA required equals a bank's estimated net cash outflow over a 30 calendar-day period of significant stress. It is thus a function of both deposits and deposit volatility.

Figure 3 illustrates the increase of deposits as a share of GDP over time. The left figure graphs deposits held with all commercial banks relative to nominal GDP, showing a sharp increase starting around 2000. Over the period of ample reserves since 2009, Deposits/GDP increase from 50% in 2009M1 to 76% in 2021M9. The right figure shows various types of deposits. The increase in overall deposits is driven by an increase in demand deposits and other liquid deposits (which include savings accounts). As liquid deposits require more reserve backing (for both economic and regulatory reasons) this fact is particularly pertinent to understanding the instability of reserve demand over time when deposits are not considered.

The main contribution of our analysis is to estimate the effects of deposits on reserve demand, showing that a stable reserve demand function emerges. We estimate a reserve demand function of the following form[6]

$$Reserves = \alpha \; Deposits^{\beta} e^{\gamma(Market\ interest\ rate - IOR)} \tag{1}$$

Taking logs, and using the effective federal funds rate (EFFR) as the market interest rate, and adding an error term (u), this implies

$$(EFFR - IOR) = a + b * \ln(Reserves) + c * \; ln(Deposits) + u \tag{2}$$

[5] For simplicity, we use total deposits in our specification. Results are similar if we omit time deposits and focus on demand and other liquid deposits which account for the majority of deposits over our sample (as documented in Figure 3).
[6] Goodfriend (1982) models reserve demand as a function of deposits (either demand or time) and the level of market interest rates. With interest on reserves, the opportunity cost of reserves if the spread between the market interest rates (for which we use EFFR) and the IOR.

where a=-(1/γ)*ln(α), b=(1/γ), and c=-(1/γ)*β. In the money demand literature this would be referred to as a semi-log functional form meaning that the measure of money (here reserves) enters in logs but the measure of the cost of holding money (here the EFFR-IOR spread) enters in levels.[7]

4. **Estimation results**

We use the FRED database data to obtain all the inputs into our reserve demand estimation. We conduct the estimation at the monthly frequency using monthly averages of the available data. Estimation of (2) by OLS will lead to consistent parameter estimates if shocks to reserve demand (the error term) are uncorrelated with changes in reserve supply. As discussed above, the use of monthly (as opposed to daily) data helps remove the effect of possible endogeneity of reserves associated with high-frequency demand shocks such as those described above occurring on high payment-flow days. Intuitively, if reserves demand is systematically higher on some days of the month and this is accommodated by the Federal Reserve, then this will lead to higher average reserves in monthly data but will not lead to endogeneity problems in monthly data. Our basic assumption is thus that the variation in reserves at the monthly frequency is not due to accommodation of demand shocks but is instead driven mainly by the Federal Reserve monetary policy programs. As Figure 1 made clear, the effect of successive rounds of quantitative easing and tightening is visible in the reserves data.

Table 1 presents the estimation of the reserve demand function in equation (2) for the period 2009m1-2022m1. Estimation is by OLS with *t*-statistics adjusted for autocorrelation in the residuals. The EFFR-IOR spread is estimated to be significantly related to both log reserves and log deposits with the expected signs and large *t*-statistics (*p*-values below 1 percent).

In economic terms, a 10% increase in reserves (an increase in supply tracing out a downward sloping demand curve) lowers the EFFR-IOR spread by a bit less than 2 basis points (1.83 basis points). This modest effect implies that reserve demand is highly elastic with respect to the EFFR-IOR spread. Another way to state this finding is to calculate the value of γ implied by the estimation. The estimated value of $b=(1/\gamma)=-0.183$ corresponds to $\gamma=-5.46$, implying that a 10 basis point reduction in the EFFR-IOR spread (making the market rate less attractive relative to reserves), entices banks to increase reserve holdings by 55 percent.

[7] Lucas (2000) models the demand for M1 (currency plus checkable deposits and traveler's checks). He models m=M1/GDP as a function of a nominal interest rate, r. He considers both a semi-log relation, $m=Be^{-\xi r}$, and a log-log relation, $m=Ar^{-\eta}$. We focus on the semi-log functional form since the measure of the cost of liquidity with IOR is (market interest rate-IOR) which can go negative, implying that the log-log relation is not well-defined (as $\ln(m)=\ln(A) - \eta \ln(r)$ is not well-defined for negative r).

The coefficient on log deposits is positive, consistent with the idea that higher deposits increase reserve demand and thus the equilibrium EFFR-IOR spread for given reserves supply. The estimated values of $b=(1/\gamma)=-0.183$ and $c=-(1/\gamma)*\beta=0.361$ imply $\beta=1.98$. A value of β above one means that a one percent increase in deposits leads to more than a one percent increase in reserves and thus that banks invest a higher fraction of deposits in reserves at higher levels of deposits. This could be due to a diminishing scope of banks to find good lending opportunities as deposits increase. It could also be driven by the marginal dollar of deposits being more "flightly" than the average dollar thus necessitating more reserve backing.

Thinking in terms of liquidity supply and liquidity demand, a specification regressing the EFFR-IOR spread on Reserves/GDP and Deposits/GDP is easier to interpret. It results (not tabulated) in coefficients of -1.88 and 0.95 and implies that an increase in reserve supply of one dollar adds more liquidity than a dollar of deposits soaks up. This is intuitive as deposits can be backed not only by reserves but also (to varying degrees) with other assets.

In terms of fit, our regression in Table 1 has an R^2 of 0.887. Figure 4 Panel A illustrates the tight relation between the EFFR-IOR spread and the predicted value from the regression in Table 1. Our estimated reserve demand function implies that there should be a tight link between the EFFR-IOR spread and a measure of reserves adjusted for deposits. Rewriting equation (2) as

$$(EFFR - IOR) = a + b * \left[\ln(Reserves) + \frac{c}{b} * \; ln(Deposits)\right] + u \qquad (3)$$

shows that the appropriate measure of deposit-adjusted reserves is $\ln(Reserves) + \frac{c}{b} * \; ln(Deposits)$. Figure 4 Panel B shows the clear negative relation between the EFFR-IOR spread and this measure of deposit-adjusted reserves. The fitted line also included in Figure 4 Panel B shows the predicted value of the EFFR-IOR spread implied by the value of deposit-adjusted reserves and the regression in Table 1.

The relation between the EFFR-IOR spread and deposit-adjusted reserves appears stable over the 2009m1-2022m1 period. The tight relation contrasts sharply which what one gets without adjusting for deposits as illustrated in Figure 2. Consistent with the usefulness of our simple framework for understanding the EFFR-IOR spread, September 2019 has the lowest value for deposit-adjusted reserves and the highest value of the EFFR-IOR spread. The high EFFR-IOR spread in September 2019 is not surprising once deposits are accounted for. Given the growth in deposits from 2010 to 2019, a value of Reserves/GDP of 7% was much less accommodative than the same value of Reserves/GDP in 2010.

In Appendix Figure 2, we illustrate the separate importance of reserves and deposits as drivers of the EFFR-IOR spread. Panel A and B illustrates the importance of reserves. Panel A shows how reserves help explain movements in the EFFR-IOR spread not driven by deposits. Specifically, we plot the" deposit-adjusted spread", (EFFR-IOR)-a-c*ln(Deposits), along with the fitted value b*ln(Reserves), using the estimation from Table 1. Panel B is a scatter plot of the deposit-adjusted spread against ln(Reserves), showing a fairly tight negative relation. Panel C and D documents the importance of deposits. Panel C plots the "reserve-adjusted spread", (EFFR-IOR)-a-b*ln(Reserves) along with the fitted value c*ln(Deposits). Both the reserve-adjusted spread and ln(Deposits) (and thus c*ln(Deposits) have a strong positive trend and a sharp increase as the COVID-19 pandemic hits. Panel D provides the scatter plot of the reserve-adjusted spread against ln(Deposits), showing a clear positive relation.

5. Why did deposits grow?

In light of the importance of higher deposits for reserve demand, it is central to ascertain the drivers of deposits. An understanding of the deposit drivers is useful because it may suggest instruments for deposits. Furthermore, it may help predict deposits and thus reserve demand going forward.

We consider two possible drivers of higher deposits over the period since the start of 2009 (in dollars and relative to GDP): Growth in the size of the Federal Reserve's balance sheet and growth in households' financial assets.

Over this period the size of the Federal Reserve's balance sheet grew as rounds of QE were not followed by "QT" (quantitative tightening)) of equal magnitude (in dollars of relative to GDP).[8] The Fed has funded QE primarily with reserves. Banks have to hold these reserves in equilibrium. To fund their reserve holdings, banks can in turn (a) hold fewer other assets (loans, securities), (b) have more deposits, or (c) have more equity (or other non-deposit funding). An example in which QE causes more deposits would be a case in which nonbank investors who sold securities to the Federal Reserve under QE keep some or all of the proceeds in banks as deposits. However, several pieces of evidence run counter to the notion that QE was the main driver of increased deposits over this period. First, as shown in Figure 3, the growth in deposits started around 2000, much before the start of QE in late 2008. Second, Figure 5 graphs Deposits/GDP and Reserves/GDP over time. While both go up over the 2009-2014 period, there is a noticeable lack of decline in Deposits/GDP from 2015-2019 when Reserves/GDP fell. Third, while both Deposits/GDP and Reserves/GDP increase in 2020, this increase in deposits may be more related to lockdowns (limiting spending), fiscal stimulus, and increased risk aversion due to COVID-19 than to banks enticing customers with attractive deposits rates to fund their reserve holdings.

[8] Quantitative tightening was done via balance sheet runoff and reductions in reserve balances as the public's currency holdings grew.

Turning to the potential role for financial assets in driving the increase in deposits since the start of 2009, Figure 6 (left graph) documents a sharp increase in the ratio of the financial assets of households and non-profits to GDP over this period. Deposits represent one of many financial assets in households' portfolio choice, suggesting that higher Financial assets/GDP may lead to higher Deposits/GDP. The right graph in Figure 6 shows that households and non-profits have chosen a remarkably stable portfolio weight for deposits of about 15% over the 2009-2021 period. This suggests that the increase in deposits over this period may have more to do with increased financial wealth than QE. Higher deposits were a key source of funding for the expansion of banks' reserve holdings that in turn provided the liability counterpart to the expansion of asset holdings on the Federal Reserve's balance sheet under QE, but QE may not have been the underlying driver of deposit growth.

In Table 2 we estimate a deposit demand function for the 2009-2021 period, modeling log deposits as a function of log financial assets and a measure of the short-term interest rates (along with an error term v)

$$ln(Deposits) = d + e * ln(Financial\ Assets) + f * IOR + v \qquad (4)$$

For the short-term interest rate, we use the interest on reserves (IOR). The spread between market rates on deposits alternatives and the rate on deposits (a spread that captures the opportunity cost of holding deposits) tends to increase with the level of market interest rates as these have less than full passthrough to deposit rates (e.g., Drechsler, Savov and Schnabl (2017)). We thus expect e to be positive and f to be negative.

Since financial assets of households and non-profits are available quarterly (from the U.S. Financial Accounts) we estimate (4) at the quarterly frequency, using data for the last month of the quarter for ln(Deposits) and IOR (in both cases using monthly averages as in our earlier analysis). The estimation results in Table 2 document an estimate of e around one, consistent with the stable portfolio weight over the 2009-2021 period. The interest rate enters with the expected negative coefficient. In economic terms the coefficient f is modest as it implies a decrease in deposits of only 2.9% for a 100 bps increase in the interest rate. The fit of the estimation is good, with a high R^2 and tight relation between ln(Deposits) and the fitted value, illustrated in Figure 7.[9]

In Table 3, we estimate the reserve demand function in equation (2) with ln(Deposits) instrumented by ln(Financial assets) and the IOR. If the instruments are uncorrelated with the error term (the unobserved reserve demand shock), an IV estimation overcomes any potential bias in the estimated reserve demand

[9] If we add ln(Reserves) to the deposit demand function, it enters with a coefficient of -0.06 (t=-2.5), while the coefficient on ln(Financial assets) becomes 1.12 (t=29.22) and the coefficient on IOR becomes -0.046 (t=4.38). The larger and more significant coefficient on ln(Financial assets) than ln(Reserves) supports our argument that deposits appear more affected by financial assets than reserves over this sample period.

parameters due to correlation between the deposit demand of households (and firms) and unobserved shocks to banks' reserve demand (for example, both may be affected by economic uncertainty). Column (2) presents the result of the IV estimation, at the quarterly frequency due to the use of ln(Financial assets) which is only available quarterly. For comparison, column (1) shows the OLS estimation of equation (3) in quarterly data. IV and OLS results in similar parameter estimates. As we have two instruments for deposits, we can use a test of over-identifying restrictions to test whether exogeneity on the instruments is rejected by the data. Using the Sargan test, we find an insignificant *p*-value of 0.59, supporting the validity of the instruments for ln(Deposits). The modest difference between our baseline regression in Table 1 and the IV estimation in Table 3 suggests that deposit endogeneity is not a substantial factor bearing on our baseline estimation.

Our discussion of drivers of increasing deposits in 2009m1-2022m1 period is related to that in Acharya and Rajan (2022). They provide a model of the effect of reserves on deposit creation to understand the liquidity shortage in September 2019. In their model, the Federal Reserve finances its QE by supplying reserves to commercial banks (this adds liquidity) and commercial banks fund their additional holdings of reserves by expanding their deposit liabilities (this soaks up liquidity). Banks may also use reserves to back contingent lines of credit and to guarantee margin calls on speculation. In their model, liquidity commitments thus counter reserve supply (it is even possible that liquidity problems can be *worse* with higher reserve supply) and healthy banks hoard liquidity in crisis to be perceived as safe and attract more deposit inflows. While our arguments above suggest that the deposit increase in 2009m1-2022m1 may not have been driven mainly by QE, Acharya and Rajan's argument that liquidity is less ample the more liquidity commitments banks have (deposits, lines of credit etc.) is valid regardless of why those commitments came about. Their model thus provides a useful theoretical complement to our empirical results.

6. Implications for balance-sheet runoff

Our estimated reserve demand function in Table 1 can be used to guide balance sheet runoff. For any potential choice of the level of reserves, the reserve demand function provides a prediction of the EFFR-IOR spread given the current level of deposits. Deposits stood at \$18.069T in January 2022 (monthly average). Using the estimated parameters from Table 1, we get:

$$\begin{aligned}\text{Predicted EFFR-IOR spread} &= a + b*\ln(\text{Reserves}) + c*\ln(\text{Deposits}) \\ &= -2.060 - 0.183*\ln(\text{Reserves}) + 0.361*\ln(18069) \quad (5)\end{aligned}$$

As of January 2022, reserves were \$3.90T, amounting to about 15.7% of GDP.[10]

Three possible counterfactual levels of reserves are of particular interest.

1. *Reserves equal to \$1.74T (7% of GDP)*

In the previous episode of balance sheet runoff ending in September 2019, the FOMC took actions that lowered Reserves/GDP to 7%. In January 2022, this would correspond to reserves of \$1.74T. Our estimated reserve demand function predicts that at this reserve level the EFFR-IOR spread would be 12 bps. This counterfactual is illustrated in Figure 8. The predicted EFFR-IOR spread of 12 bps would be substantially higher than any values of the spread observed in-sample. The high predicted spread is due to the much higher level of deposits currently (in dollars and as a percent of GDP) than during the last policy normalization cycle. Reserves of \$1.74T would result in a historically low (in the period since 2009M1) value of deposits-adjusted reserves.

Does the high predicted value of the EFFR-IOR spread at reserves amounting to 7% of GDP imply that reducing reserves to this level is undesirable? From the perspective of interest rate policy, not necessarily. The high predicted spread simply means that the IOR needs to be set at a lower value. If the FOMC decided to take actions that reduce reserves to 7% of GDP, then for any given federal funds rate target (or target range mid-point), the IOR would need to be set about 12 bps below the target to make the EFFR clear at a chosen Fed funds target, on average over the month. However, a high EFFR-IOR has been associated with daily yield spikes in EFFR and especially in repo rates. Appendix Figure 3 uses daily data and graphs EFFR and IOR in the left figure and the Secured Overnight Financing Rate (SOFR) and IOR in the right figure. In the months leading up to September 2019, not only was the monthly average EFFR-IOR spread above zero, but EFFR and SOFR spiked substantially above IOR on a series of occasions. The Federal Reserve's new Standing Repo Facility would help lower the risk of spikes in SOFR, but it remains untested. Reserves of \$1.74T would be a risky choice from the perspective of money market stability as deposit-adjusted reserve supply would be much below that in September 2019.

2. *Reserves equal to \$2.77T (11.1% of GDP): Would lead to the same deposit-adjusted reserves as that in September 2019*

Deposit-adjusted reserves, ln(Reserves)+(c/b)*ln(Deposits), amounted to -11.47 in September 2019. Given deposits of \$18.069T as of the end of our sample in 2021M11, ln(Reserves)+(c/b)*ln(Deposits) would equal -11.47 for reserves of \$2.77T (corresponding to 11.1% of GDP). This is the predicted level of reserves at

[10] GDP data for 2022Q1 are not yet available. We assume GDP grew by the same percent in 2022Q1 as in 2021Q4 for a 2022Q1 GDP value of \$24.843T.

which large daily yield spikes may emerge, based on the estimated reserve demand function and the experience from September 2019 and the months leading up to it.

3. *Reserves equal to $3.34T (13.5% of GDP): A more conservative choice, at which the predicted EFFR-IOR spread is zero*

As an example of a more conservative choice of balance sheet runoff, the value of reserves at which the predicted EFFR-IOR spread is 0 is reserves of $3.34T as of January 2022. From Figure 8, this compares to a predicted spread of 3 bps in September 2019 and would thus be a bit less risky in terms of money market stability.

We summarize our analysis of possible counterfactual levels of reserves in Figure 9. The figure graphs the predicted EFFR-IOR spread, -2.060-0.183*ln(Reserves)+0.361*ln(18069) (from equation 5), for various values of reserves (Panel A) or reserves-to-GDP (Panel B). Reserves are varied in increments of $100B and reserves graphed range from $600B to $4,200B. Observed reserves data for 2009M1-2022M1 range from $660B to $4,189B. In Panel A, the vertical lines are at $1,740B (7% of GDP), $2,770 (same predicted value as in 2019M9), and $3,340 (predicted value of zero). Panel B uses an estimated value of GDP for 2022Q1 of $24.843T. Reserves are again varied in increments of $100B and reserves graphed range from $600B to $4,200B. The vertical lines are at 0.07, 0.111 (same predicted value as in 2019M9), and 0.133 (predicted value of zero).

Overall, our estimated reserve demand function can be used to guide policy tightening both in terms of the setting of the IOR relative to the mid-point of the target range and in terms of evaluating which amount of reserve reduction is likely to be risky in terms of money market stability. The above calculations are done for a specific value of deposits, that prevailing in January 2022. As deposits change, so will the reserve level that leads to a given deposit-adjusted reserve value. This level can be calculated from equation (5), updating the deposit level from the value of January 2022 value.

In related work, Afonso, Giannone, La Spada and Williams (2021) estimate a reserve demand function in which the EFFR-IOR spread is modeled as a function of the ratio of reserves to banks' total assets. They work with daily data and instrument the reserve to asset ratio by the forecast error for this variable 5 days prior, using a VAR to obtain the forecast error. The idea is that the forecast error predicts reserves but will be uncorrelated with reserve demand shocks 5 days later if demand shocks tend to resolve in less than 5 days. Their estimation allows for a time-varying effect (β) of the reserves-to-asset ratio on the EFFR-IOR spread. They estimate β to be significantly negative in 2010-2011 and 2018-2019 but close to zero from 2012-2017, in the 2nd half of 2020 and in 2021. Their results imply that a negative (β) starts to emerge at reserves around 12% of banks' total assets. To compare that to our results, observe that as of the end of

November 2021, banks' total assets amount to \$22.614T. Reserves of 12% of banks' total assets would thus come to \$2.71T. This is almost identical to the reserve level of \$2.77T that we estimate would lead to deposit-adjusted reserves equal to those in September 2019. Our approach and that of Afonso et al rely on different methodologies. We exploit lower frequency (mainly QE induced) movements in reserves and use a functional form for reserves demand where constant parameters appear to provide a good fit across the 2009m1-2022m1 period. Afonso et al rely on daily reserves variation combined with IV estimation. On the basis of the functional form that they specify for the reserve demand function, their β parameter is estimated to be time-varying. Despite the different approaches, a key lesson common to both papers is that running down reserves to 7% of GDP, as was done in the last policy normalization episode, is likely to lead to strains in short-term money markets.

Based on our analysis, we finish with a few other observations about balance sheet policy.

First, our estimated deposit demand function implies that deposit demand and therefore reserves demand will vary over time with household financial wealth and interest rates. Therefore, one should not think of there being one particular value of reserve supply that will deliver a given amount of tightness of liquidity in short-term money markets. To understand reserve demand going forward, the Fed will need to monitor the development of deposits.

Second, since deposit demand is decreasing in the level of interest rates, is more balance sheet reduction possible accounting for the Federal Reserve raising the federal funds target above the ELB? Not necessarily, since deposits may flow from banks to money market funds who currently invest large amounts in the Federal Reserve's overnight reverse repo facility. Thinking of overall reserves as "regular" reserves plus ON/RRP take-up, an increase in the federal funds rate above the ELB may not create room for more balance sheet reduction.

Third, banks can back deposits with other assets than reserves, but more such assets will be needed if they are less liquid/safe than reserves. This implies that the FOMC's decisions on what assets to run off may matter for the overall scarcity of liquid short-term money market instruments. For example, if short-maturity Treasury bills provide better backing for deposits than long-maturity MBS, then allowing the former to run off would affect the scarcity of liquid short-term money market instruments less than would running off the latter. Of course, running off bills rather than MBS would lead to a smaller rise in yields on longer-maturity securities. Therefore, there is a tradeoff with regard to what assets to run off, if the FOMC wants to both keep the money market liquid and increase longer-term yields to reduce inflation.

7. Conclusion

Understanding reserve demand is central for assessing feasible balance sheet runoff. Reserve demand is negatively related to the EFFR-IOR spread but the relation appears unstable over the 2009m1-2022m1 period. We argue that deposits affect banks' reserve demand and thus works as a scale variable for the demand for reserve balances. We document a stable reserve demand curve once deposits are accounted for, finding a tight negative relation between the EFFR-IOR spread and "deposit-adjusted reserves".

Our estimation exploits monthly variation and assumes that most of the variation in reserves at the monthly frequency is not due to reserve supply accommodating demand shocks but instead driven by monetary policy, notably the rounds of quantitative easing and tightening over the sample. We argue that increasing financial assets of households as well as the level of interest rates are key drivers of deposits and show that instrumenting deposits by these two variables leads to very similar parameter estimates in the reserve demand function.

Our estimated reserve demand function can be used to guide policy tightening both in terms of the setting of the IOR relative to the mid-point of the target range and in terms of assessing which amount of reserve reduction is likely to be risky in terms of money market stability. Our estimated reserve demand function implies that feasible balance sheet reduction may be more limited that one would think based on the reserve reduction to 7% of GDP observed in the prior policy normalization episode. We find that a reduction of reserves from the level of $3.90T (16% of GDP) at the end of our sample in 2022m1 to a value of $2.77T (11% of GDP) would lead to the same deposit-adjusted reserves (as thus tightness of liquidity in short-term money markets) as in September 2019.

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Table 1. Reserve demand function

Monthly data, 2009M1-2022M1. OLS estimation. t-statistics are robust to autocorrelation up to order 12. Reserves and deposits are in $B.

	Dependent variable: (EFFR -IOR)
ln(Reserves)	-0.183***
	(t=-15.22)
ln(Deposits)	0.361***
	(21.64)
Constant	-2.060***
	(-16.76)
N (months)	157
R2	0.887

Note: *** indicates statistical significance at the 1% level.

Table 2. Deposit demand function

Quarterly data (last month of the quarter), 2009Q1-2021Q3. OLS estimation. t-statistics are robust to autocorrelation up to order 4.

	Dependent variable: ln(Deposits)
ln(Financial assets)	1.026***
	(t=33.16)
IOR	-0.029***
	(-3.61)
Constant	-2.169***
	(-6.34)
N (quarters)	51
R2	0.987

Note: *** indicates statistical significance at the 1% level.

Table 3. Reserve demand function, instrumental variables estimation

Quarterly data (last month of the quarter), 2009Q1-2021Q3. Column 1: OLS estimation. Column 2: IV estimation. t-statistics are robust to autocorrelation up to order 4.

	Dependent variable: (Effective fed funds rate-IOR)	
	(1) OLS	(2) IV Instrumenting for ln(Deposits)
ln(Reserves)	-0.185*** (t=-16.30)	-0.187*** (t=-15.16)
ln(Deposits)	0.368*** (23.46)	0.373*** (17.61)
Constant	-2.109*** (-18.89)	-2.134*** (-15.70)
N (quarters)	51	51
Instruments		ln(Financial assets), IOR
Sargan test of over-identifying restrictions		p-value=0.59 (exogeneity not rejected)

Note: *** indicates statistical significance at the 1% level.
The first stage for ln(Deposits) in column (2) is shown in Table 2.

Figure 1. (Effective Federal Funds Rate)-IOR spread and Reserves-to-GDP, time series plot

Monthly data (averages), 2009M1-2022M1

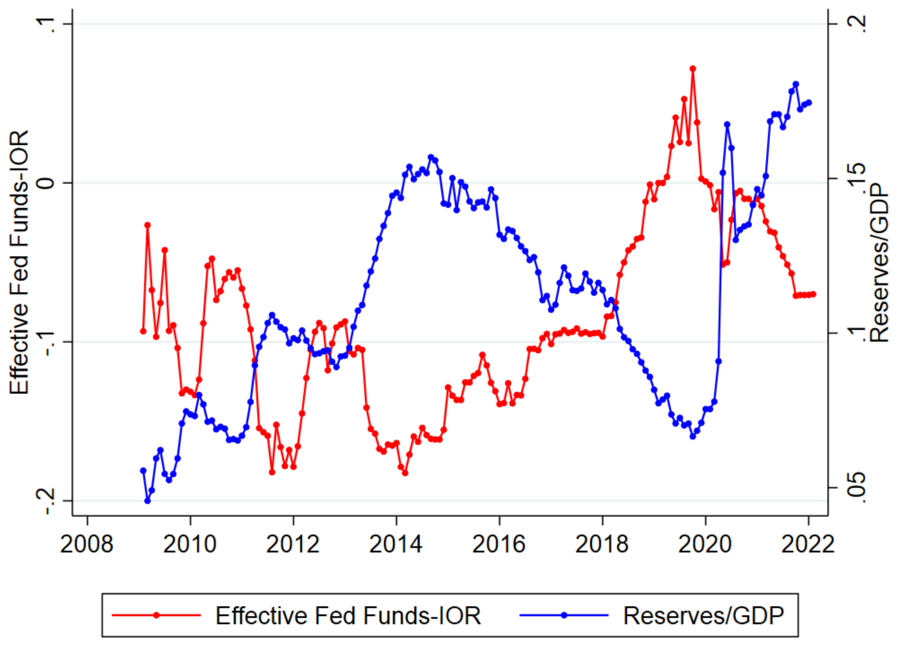
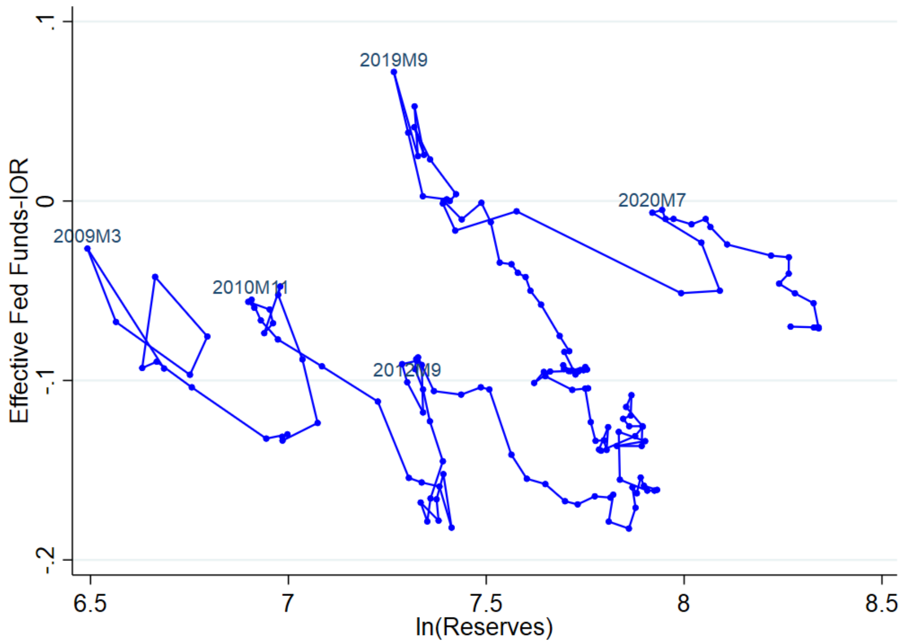


Figure 2. (Effective Federal Funds Rate)-IOR spread and Reserves, scatter plot

Monthly data, 2009M1-2022M1 in Panel A and 2009M1-2021M12 in Panel B.

Panel A. Log reserves



Panel B. Reserves-to-GDP

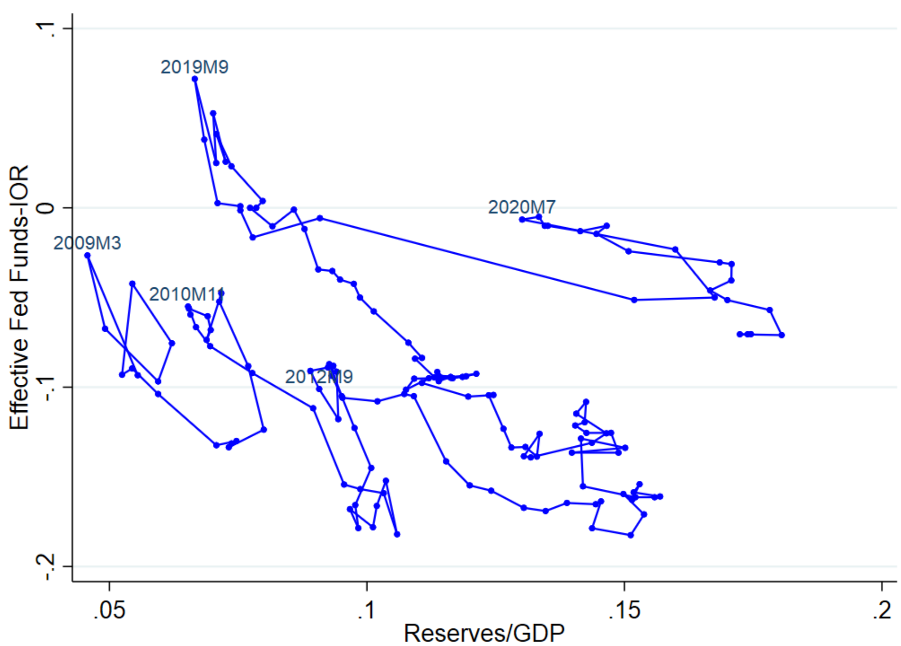


Figure 3. Deposits

In the left figure, deposits are for all commercial banks, from the Federal Reserve's H8 release (via FRED). The right figure is based on data from both the H8 and H6 release, as noted. All data are monthly averages for 1986M1-2021M12.

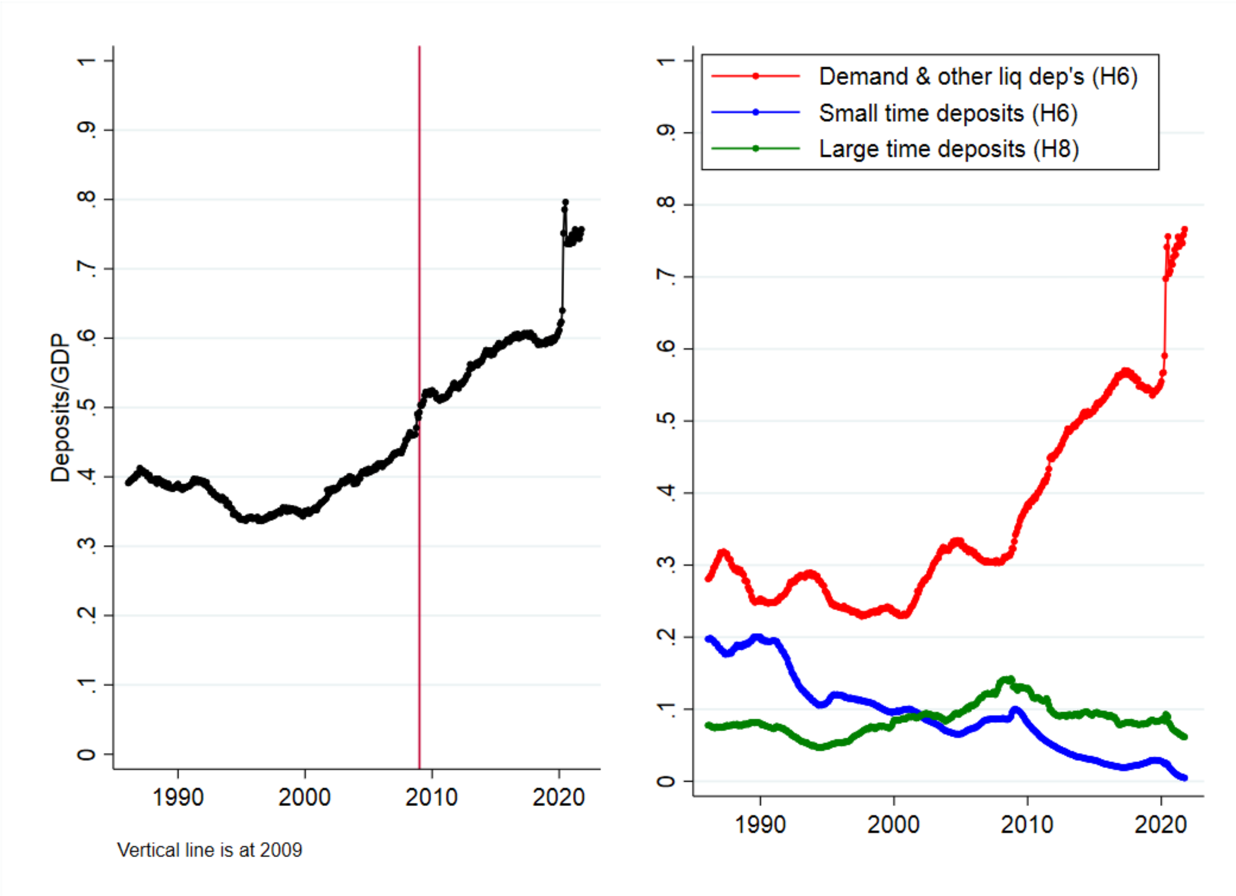
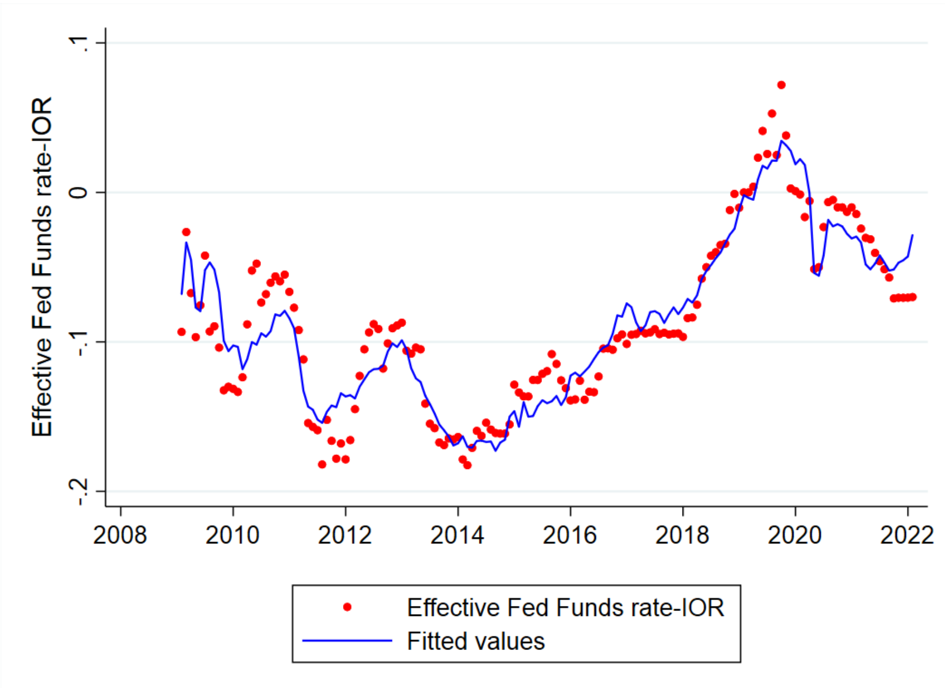


Figure 4. Fit of reserve demand function estimation

The fitted lines in both panels are based on the regression in Table 1.

Panel A. Time series plot of (Effective Federal Funds Rate)-IOR spread and fitted values



Panel B. (Effective Federal Funds Rate)-IOR spread and fitted values as function of deposit-adjusted reserves

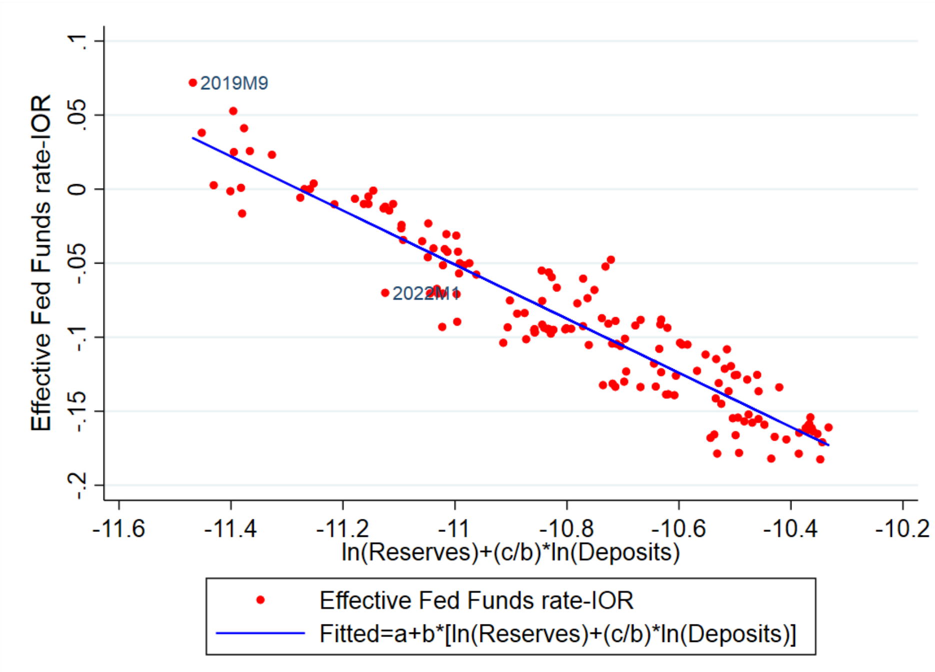


Figure 5. Reserves/GDP and Deposits/GDP

Monthly, 2009M1-2021M12.

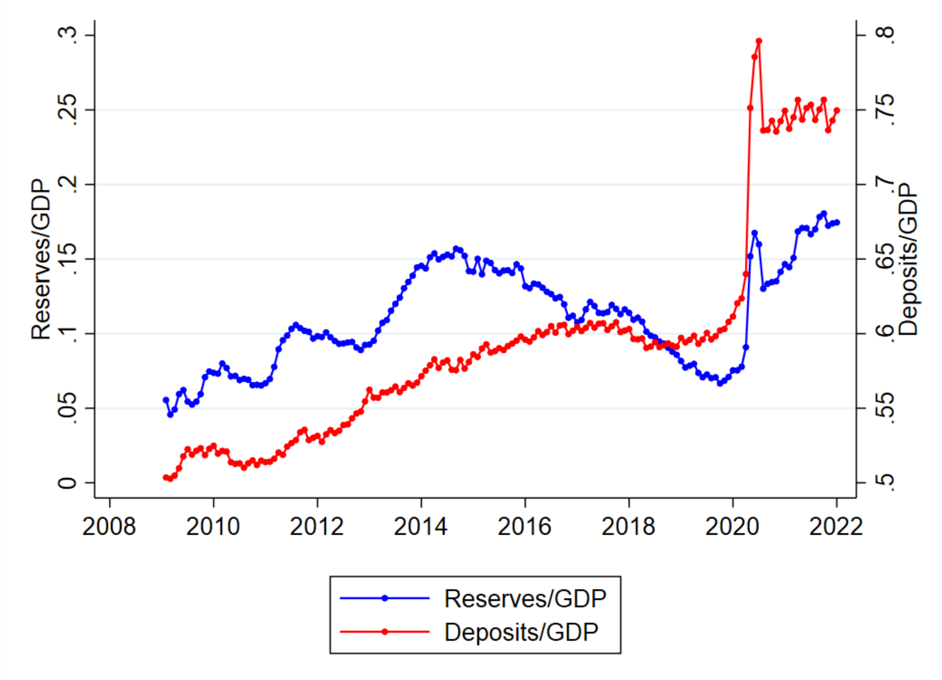


Figure 6. Financial assets of households and non-profits as a driver of deposits

Values graphed are for the last month of the quarter, 2009Q1-2021Q4.

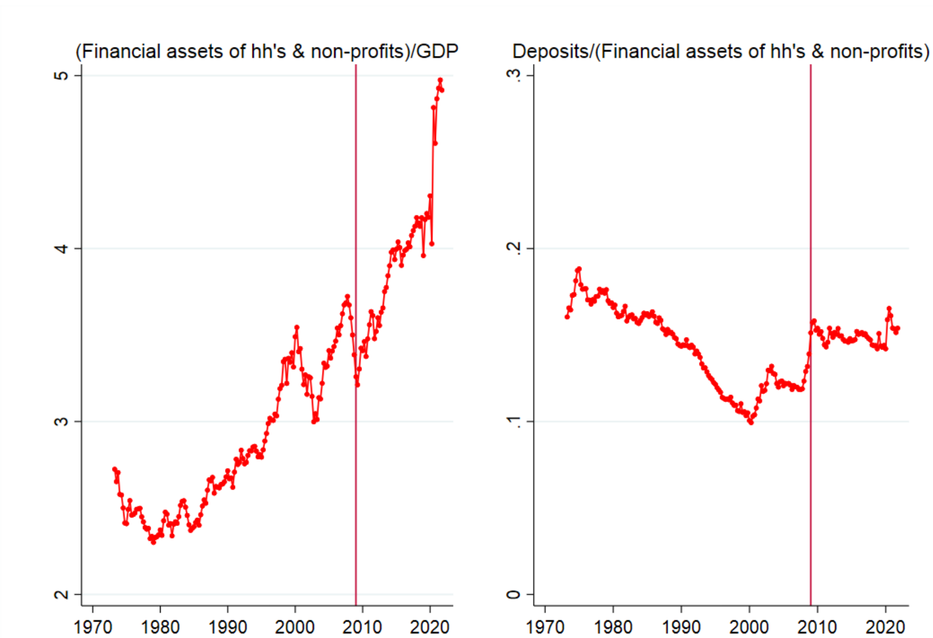


Figure 7. Fit of deposit demand function estimation

The fitted line is based on the regression in Table 2.

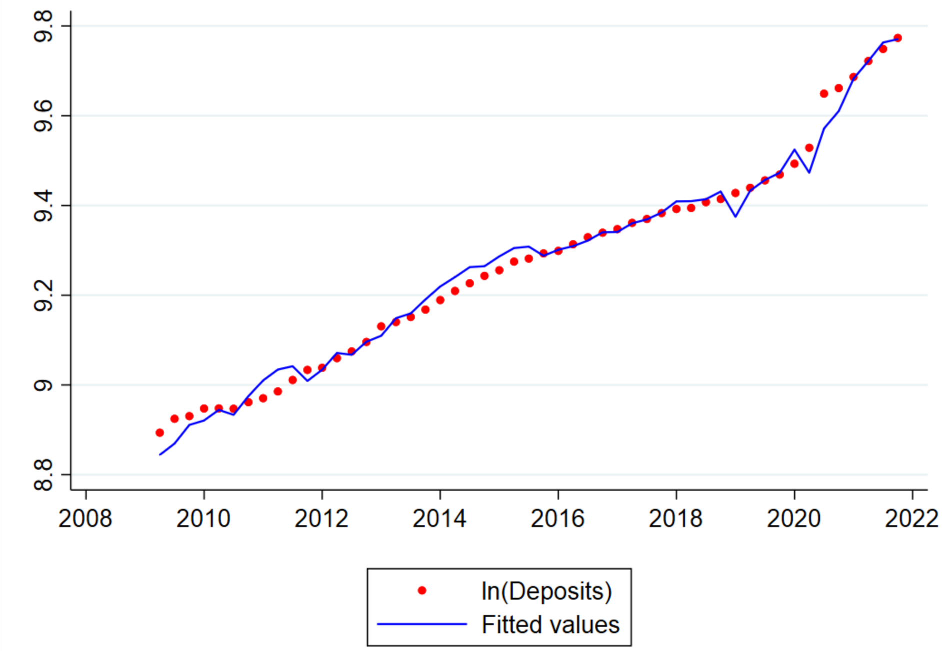


Figure 8. Counterfactual: Predicted (Effective Federal Funds Rate)-IOR spread for Reserves/GDP=0.07 in 2022M1

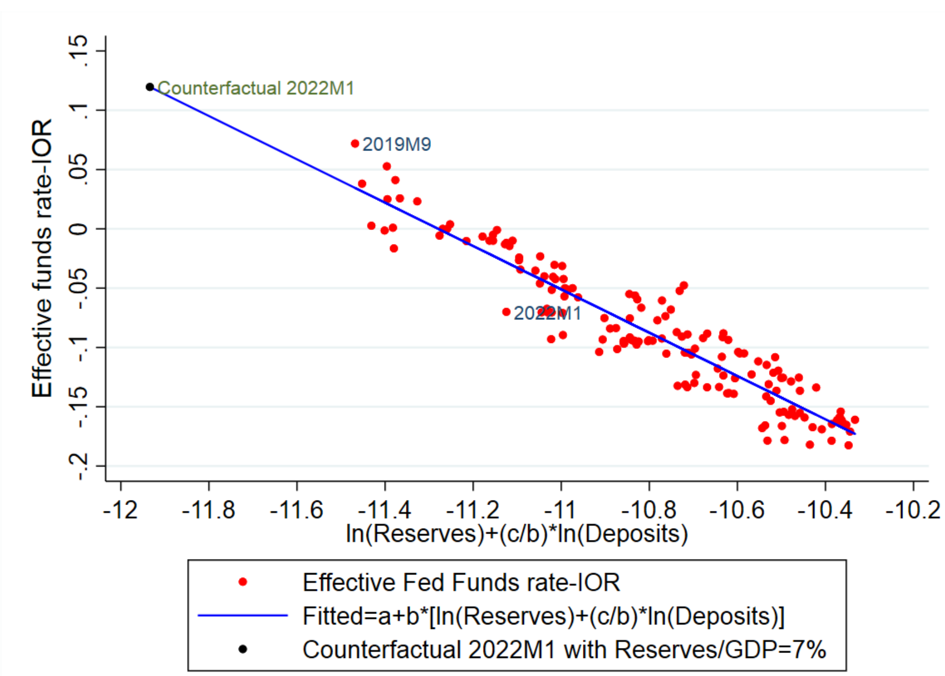
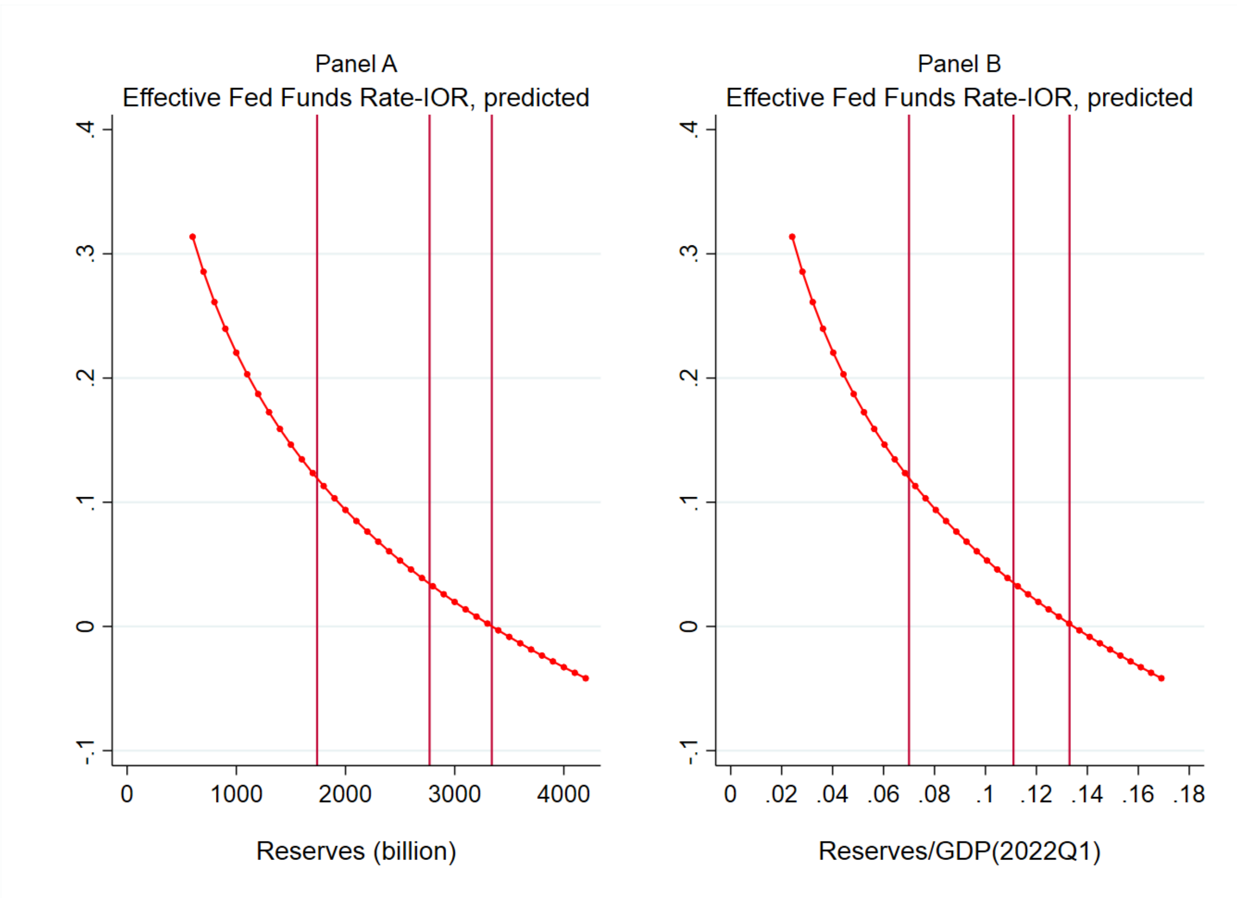


Figure 9. Counterfactual: Predicted (Effective Federal Funds Rate)-IOR spread for various values of reserves and reserves/GDP at current levels of deposits and GDP

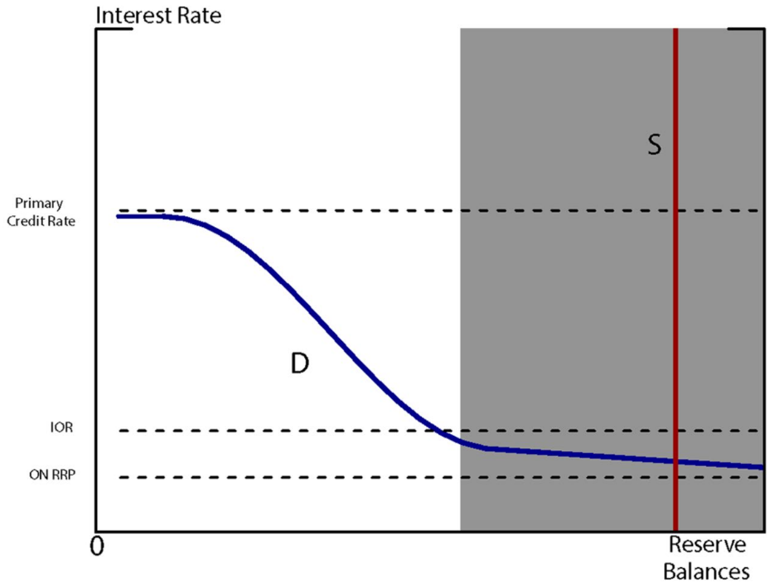
Panel A graphs the predicted EFFR-IOR spread for various dollar values of reserves, evaluated at the level of deposits of $18.069T in 2022M1. The predicted value is: a+b*ln(reserves)+c*ln(18069). Reserves are varied in increments of $100B and reserves graphed range from $600B to $4,200B. Observed reserves data for 2009M1-2022M1 range from $660B to $4,189B. The vertical lines are at $1,740B (7% of GDP), $2,770 (same predicted value as in 2019M9), and $3,340 (predicted value of zero).

Panel B graphs the predicted EFFR-IOR spread for various ratios of reserves to GDP, evaluated at the level of deposits of $18.069T in 2022M1 and estimated 2022Q1 GDP of $24.843T. The predicted value is a+b*ln(reserves)+c*ln(18069) and the value on the x-axis is reserves/24843. Reserves are again varied in increments of $100B and reserves graphed range from $600B to $4,200B. The vertical lines are at 0.07, 0.111 (same predicted value as in 2019M9), and 0.133 (predicted value of zero).



Appendix Figure 1. Reserve demand as a function of the market interest rate

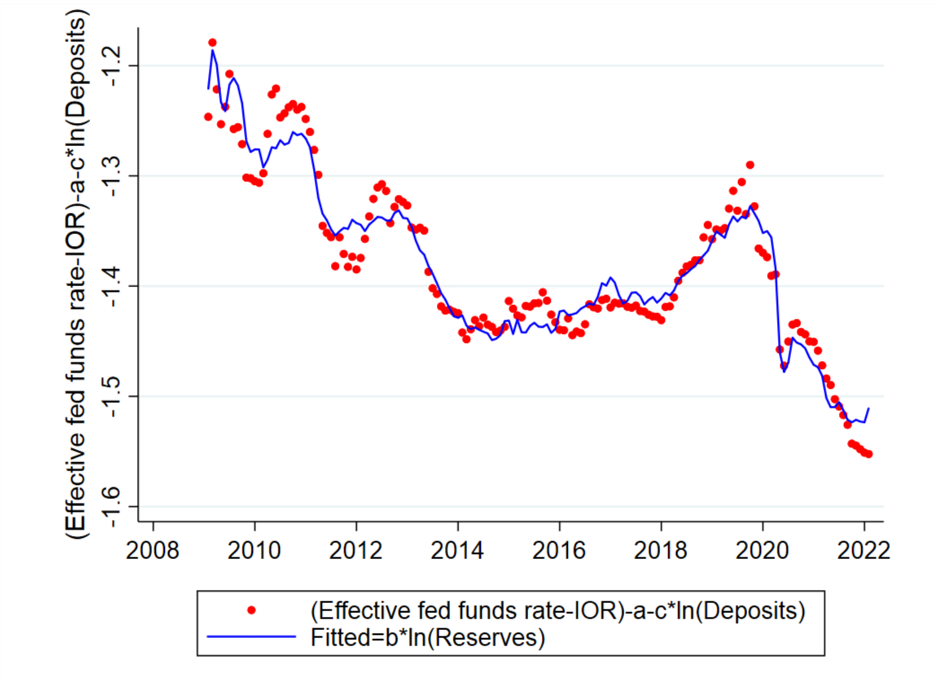
Source: Ihrig, Senyuz and Weinbach (2020)



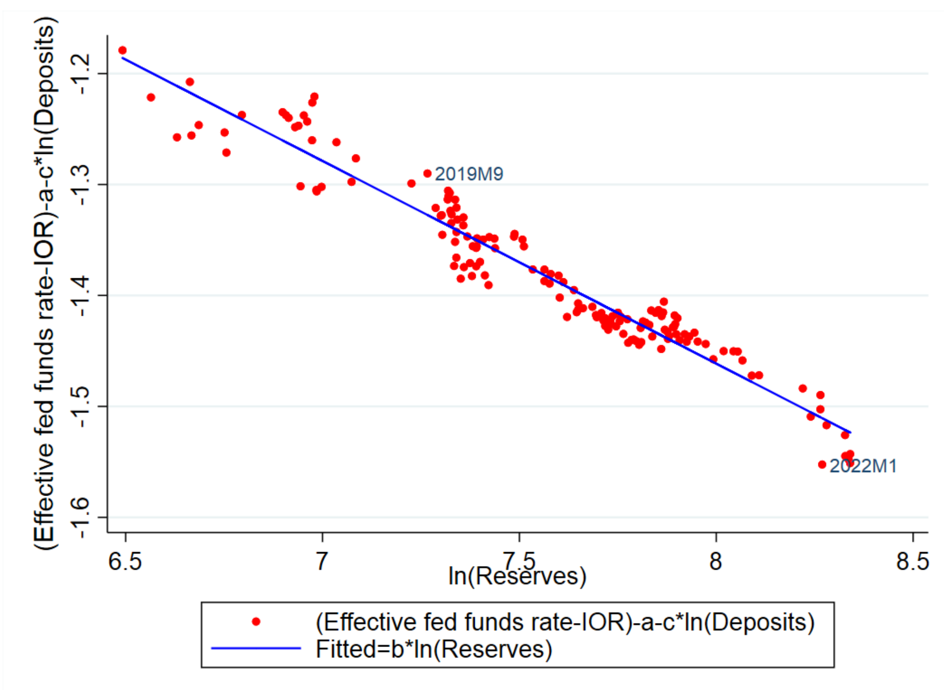
Appendix Figure 2. The separate roles of reserves and deposits

All panels are based on the regression in Table 1.

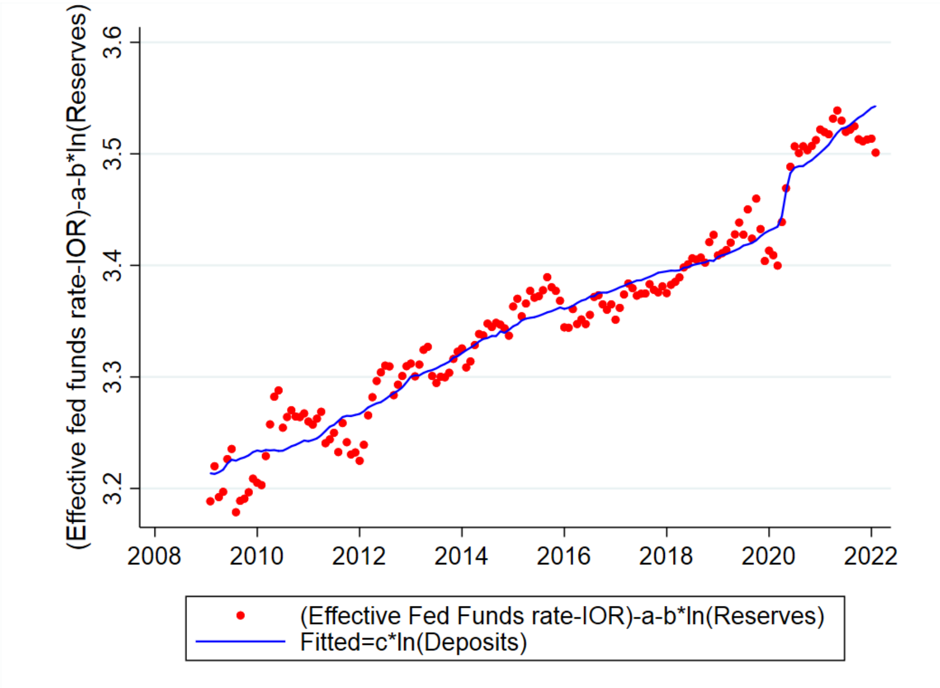
Panel A. The role of reserves, time series plot



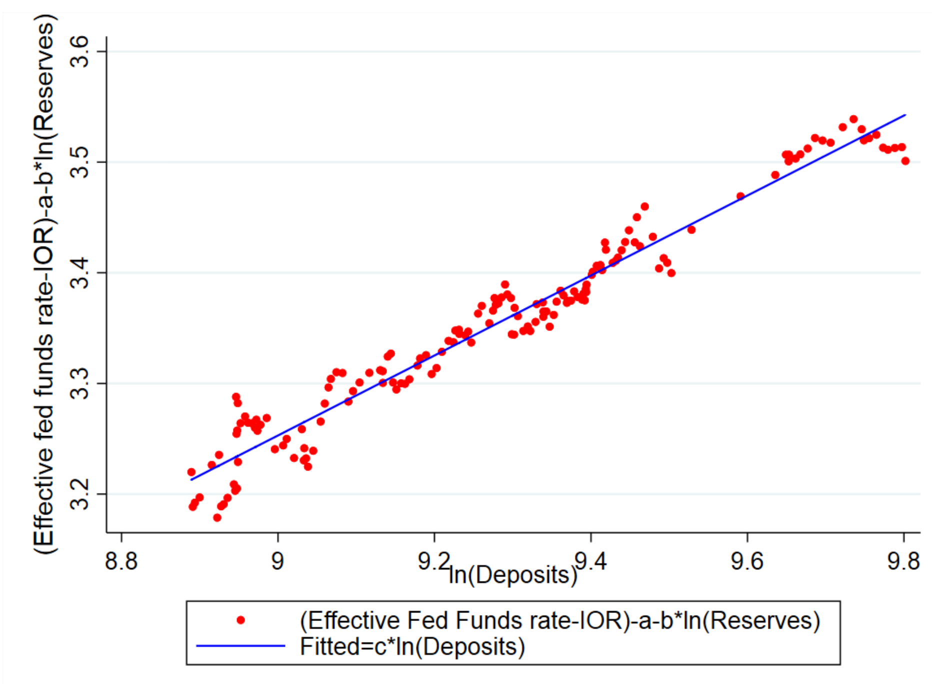
Panel B. The role of reserves, scatter plot



Panel C. The role of deposits, time series plot



Panel D. The role of deposits, scatter plot



Appendix Figure 3. Yield spikes

Daily data, January 2016 to January 2022.