

Do Changes in Reserve Balances Still Influence the Federal Funds Rate?

By A. Lee Smith

Over the past decade, the implementation of U.S. monetary policy has significantly changed. Rather than adjusting the quantity of reserves in the banking system, policymakers now primarily use the interest rate paid on reserve balances—the IOR rate—to bring the federal funds rate within the target range set by the Federal Open Market Committee (FOMC). However, the current monetary policy framework has required some tweaking. Despite remarkably low day-to-day volatility in the federal funds rate, the funds rate has gradually moved higher relative to the IOR rate in recent years. One common explanation is that the funds rate has been driven higher by a rise in short-term secured financing rates (also known as repo rates), reflecting an increase in Treasury bill issuance. An alternative explanation is that even at the currently elevated level of reserve balances, the demand curve for reserves is not perfectly flat. In this case, the large decline in reserve balances over the past few years may be responsible for the upward drift in the federal funds rate.

In this article, I examine the role that declining reserve balances have played in influencing the spread between the federal funds rate and the IOR rate in recent years. Estimates from a stylized model of

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the demand for reserves suggest that declining reserve balances have placed upward pressure on the federal funds rate. These estimates are consistent with the classic liquidity effect—the inverse relationship between innovations in reserves and short-term interest rates. Evidence from a structural vector autoregression (VAR) model further suggests that this liquidity effect is an important factor in explaining why the federal funds rate has moved higher relative to the IOR rate, even after accounting for increasing repo rates. These findings suggest that the funds rate may continue to move higher relative to the IOR rate against a backdrop of balance sheet normalization and further declines in reserve balances.

Section I reviews how the Federal Reserve has implemented monetary policy in recent years. Section II presents estimates of the relationship between the federal funds rate and reserve balances using a simple regression model. Section III uses a structural VAR to study the distinct roles that declining reserves and increases in Treasury issuance play and draws some implications for the federal funds-IOR spread under further balance sheet adjustments.

I. The Federal Reserve's Post-Crisis Operating Framework

The transition from a monetary policy operating framework based on adjustments in reserve balances to one based on administered rates was born out of necessity. In late 2008, the funds rate swung widely around the target rate set by the FOMC. On September 15, 2008, the day that Lehman Brothers filed for bankruptcy, the funds rate traded at 64 basis points above the target rate against a backdrop of heightened uncertainty and greater demand for highly liquid assets. Later that same week, as the Federal Reserve expanded and enhanced its programs to provide liquidity to financial markets, the funds rate traded at 52 basis points below the target rate.

As the global financial crisis continued to unfold, the FOMC sought to fulfill its role as lender of last resort and ease financial conditions by expanding the Fed's balance sheet. The expansion of the Fed's asset holdings was accompanied by large increases in reserves that, absent any other forces, would have pushed the federal funds rate toward zero as banks sought to lend their excess reserves. To maintain independent

control over the funds rate amid the rapid increase in reserves, the Fed began paying banks interest on their reserve balances in October 2008.¹

In an environment of abundant reserves, arbitrage should, in theory, drive the funds rate toward the IOR rate. For example, any bank offering to make an overnight loan at a rate above the IOR rate should be undercut by competitors equally flush with reserves offering lower rates. This competition to supply overnight loans should limit upward drift in the funds rate relative to the IOR rate. Moreover, any bank wanting to lend funds overnight would choose to earn the risk-free IOR rate by keeping its excess reserves parked at the Fed rather than lending at a lower rate in the unsecured federal funds market.

In practice, however, the funds rate has traded persistently below the IOR rate due to the presence of nonbank lenders in the federal funds market. For example, government-sponsored enterprises (GSEs) such as Fannie Mae, Freddie Mac, and the Federal Home Loan Banks (FHLBs) hold reserve accounts at the Fed but are not eligible to earn interest on those reserve balances. Because these GSEs are not eligible to earn the IOR rate, they are willing to make loans on the federal funds market at rates below the IOR rate.² As a result, the usual arbitrage relationships have broken down.

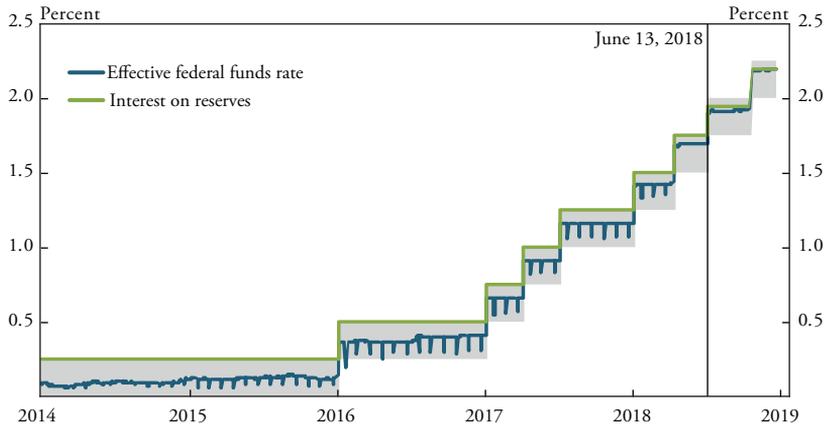
Because the IOR rate does not put a firm floor on the funds rate, the FOMC has supplemented the payment of interest on reserves with another facility that transacts with a wide range of counterparties, including the aforementioned GSEs.³ Eligible counterparties for the overnight reverse repurchase agreement (ON RPP) facility are offered an overnight interest rate below the IOR rate. Since interest rate liftoff, the FOMC has set a 0.25 percent target range for the federal funds rate, with the IOR rate near the top and the ON RPP rate at the bottom of the range. This system of interest rate control has been called a “leaky” floor because the funds rate typically drops below the floor set by the IOR rate but almost always remains above the subfloor set by the ON RPP rate.⁴

The daily federal funds rate has been remarkably stable in this system. Chart 1 shows the target range for the federal funds rate (gray area), the IOR rate (green line), and the effective federal funds rate (blue line) from August 2014 to October 2018.⁵

Over this period, the federal funds rate has fallen outside the range

Chart 1

Fed's New Framework for Targeting the Federal Funds Rate



Notes: Shaded regions show the target range for the federal funds rate. The vertical line denotes June 13, 2018, which is when the Board of Governors of the Federal Reserve System set the IOR rate at 5 basis points below the upper limit of the FOMC's target range.

Sources: Federal Reserve Bank of New York (Haver Analytics) and Board of Governors of the Federal Reserve System (Haver Analytics).

set by the FOMC on only one day—December 31, 2015. The federal funds rate often drifts lower at month's end and to some extent even lower at quarter- and year-end.⁶ Outside of this somewhat predictable volatility, the current framework for interest rate control has largely eliminated high-frequency movements in the federal funds rate that are not related to policy actions of the FOMC.⁷

However, the federal funds rate has been moving steadily toward the upper limit of the target range, raising questions about how the current monetary policy framework will need to evolve. Shortly after interest rate liftoff, the funds rate traded about 12 basis points below the IOR rate—squarely in the middle of the target range set by the FOMC. But by June 2018, the funds rate was just 5 basis point below the IOR rate. Because the IOR rate was at the top of the FOMC's target range for the funds rate, the funds rate was at risk of breaching the upper limit of the target range. Therefore, when the FOMC increased the target range for the federal funds rate by 0.25 percent in June 2018, the Board of Governors of the Federal Reserve System increased the IOR rate by only 0.20 percent. Chart 1 denotes this tweak in the operating framework with a vertical black line where the IOR rate visibly falls closer to the midpoint of the target range. In October 2018, however, the funds

rate moved up again and converged on the IOR rate, and in December 2018, the Board tweaked the IOR rate again. While more IOR tweaks are feasible to keep the funds rate comfortably within the target range, it is unclear what forces are placing upward pressure on the funds rate.

The factor most often cited for the rise in the federal funds-IOR spread is the large increase in the issuance of Treasury bills. The federal deficit increased following the passage of the Tax Cut and Jobs Act in December 2017. As a result, the U.S. Treasury increased its issuance of debt securities, including Treasury bills. Typically, yields on Treasury bills and Treasury repo rates, which are repurchase agreements secured by Treasuries, are lower than the unsecured federal funds rate. However, as the supply of Treasury bills increased, their prices fell, and their yields have increased alongside repo rates. Both repo rates and Treasury bill yields have recently moved near or above the federal funds rate, which could be putting upward pressure on the funds rate. Indeed, Federal Reserve Chairman Jerome Powell referenced this dynamic in the June 2018 press conference when asked why the technical tweak to the IOR rate was needed: “I think there’s a lot of probability on the idea of just high bill supply leads to higher repo costs, higher money market rates generally, and the arbitrage pulls up federal funds rate towards IOER.”

Rising repo rates, perhaps due to higher Treasury bill issuance, could raise the federal funds rate relative to the IOR rate through several potential mechanisms. The model of Schulhofer-Wohl and Clouse (2018) provides one potential mechanism whereby changes in repo rates relative to the IOR rate alter the incentive for GSEs to trade in the federal funds market. In particular, when repo rates move higher above the IOR rate, perhaps due to increased Treasury bill issuance, GSEs have less incentive to make loans on the federal funds market as they can earn the higher repo rate. Moreover, the negotiated rate on loans still made on the federal funds market will be influenced by the GSEs’ other investment opportunities, which could also put upward pressure on the funds rate.

The more than 30 percent decline in reserve balances since 2014 is another plausible explanation for the rise in the federal funds-IOR spread. Reserve balances peaked at about \$2.8 trillion in 2014 and have since declined to around \$1.6 trillion. Reserves have declined due to both reductions in the size of the Fed’s balance sheet beginning in

October 2017 and growth in nonreserve liabilities. In particular, the Treasury has increased the balance in its Treasury General Account (TGA) at the Fed. The TGA balance increases when the Treasury receives payment from another Fed account holder; unless this increase is offset, it results in a decline in reserves. In addition, brisk currency growth has also reduced reserve balances as banks satisfy their customers' demand for cash by reducing reserves.

Reductions in reserves can lead to increases in the federal funds-IOR spread due to the downward sloping demand for reserves. The quantity of reserves demanded is typically thought to be negatively related to the federal funds-IOR spread. This spread represents a bank's opportunity cost of holding reserves to meet its internal liquidity needs in lieu of loaning them out overnight to another bank. As this spread decreases, banks will tend to hold more reserves due to the lower opportunity cost. Therefore, a decrease in the Fed's supply of reserves would be associated with an increase in the federal funds-IOR spread, all else equal. This inverse relationship between reserve or monetary aggregates and short-term interest rates underpins the "liquidity effect," or the tendency for decreases in reserves to lead to increases in interest rates.

The degree to which monetary policy can continue to be implemented independent of the level of reserves depends on the magnitude of the liquidity effect. When reserves are abundant, there should be no meaningful liquidity effect. In this environment, any modest increase or decrease in reserves will have little effect on banks because they have more than enough liquidity. Currently, aggregate reserve balances (about \$1.6 trillion) are still far in excess of required reserve balances (about \$140 billion), casting doubt on the idea that aggregate reserves are yet scarce enough to drive the funds rate higher.

However, the global financial crisis may have resulted in a structural increase in banks' demand for reserves to meet both regulatory liquidity metrics and their own precautionary demand for liquidity (Logan 2018). Banks may now have different motives for engaging counterparties on the federal funds market beyond simply meeting reserve requirements. Moreover, as Potter (2018) discusses, the "flat" portion of the demand for reserves may not be perfectly flat. Therefore, whether the current quantity of reserves is large enough to effectively eliminate the liquidity effect remains an empirical question.

II. A Simple Regression Model of the Federal Funds-IOR Spread

The Fed's new operating framework enables a direct approach to estimating the causal link between declining reserves and the funds rate. In particular, the Federal Reserve Bank of New York's Open Market Desk (the Desk) no longer conducts daily open market operations to offset forecast shifts in the demand and supply of reserves as they did before 2008. Instead, fluctuations in reserves emanate largely from shifts in autonomous factors (for example, TGA balances, currency growth, and foreign repos) and reductions in the FOMC's balance sheet. To the extent that these factors are not shifting in response to the spread between the IOR rate and the funds rate, the liquidity effect can be directly estimated by regressing this spread on reserve balances using ordinary least squares (OLS).⁸

I use week-ending-Wednesday data to regress the spread between the funds rate and the IOR rate on the natural log of reserve balances held at Federal Reserve banks. The daily funds rate is obtained from the H.15 report, and reserve balances are obtained from the H.4.1 report. The regression model takes the form:

$$FF_t - IOR_t = \alpha + \beta 100 \ln(\text{Reserves}_t) + \delta X_t + \varepsilon_t, \quad (1)$$

where the dependent variable is the spread (in basis points) between the effective federal funds rate (denoted by FF_t) and the interest rate paid on reserves (denoted by IOR_t). The independent variables include a constant, 100 times the natural log of reserve balances in trillions of dollars, and controls—which include a dummy variable for the month-end drops in the funds rate and, in some instances, the spread between repo rates and the IOR rate (in basis points).⁹ The estimation sample is September 2014 through November 2018. The beginning date closely aligns with the peak in reserve balances and also marks the first available date of the Secured Overnight Financing Rate (SOFR) repo rate series (details on all series used in the analysis are available in the appendix).¹⁰

Regression estimates of the liquidity effect

Regression models reveal a robustly negative relationship between the quantity of reserves and the federal funds-IOR spread. Table 1 provides a summary of the estimates. The first row reports

Table 1
Regression Models of the Federal Funds-IOR Spread

Independent variable	Dependent variable: federal funds-IOR spread			
	(1)	(2)	(3)	(4)
Reserves	-0.28*** (0.03)	-0.31*** (0.01)	-0.26*** (0.03)	-0.33*** (0.02)
Repo spread			0.08** (0.03)	0.00 (0.01)
Constant	13.96*** (2.62)	16.12*** (0.89)	13.23*** (1.99)	18.13*** (1.66)
Month-end dummy	-9.57*** (0.73)	-9.83*** (0.67)	-9.67*** (0.73)	-8.27*** (0.42)
Regression R ²	0.80	0.55	0.83	0.96
Observations	222	222	222	60
Estimation sample	Aug. 2014 to Nov. 2018	Aug. 2014 to Nov. 2018	Aug. 2014 to Nov. 2018	Oct. 2017 to Nov. 2018
Durbin-Watson	0.35	0.38	0.41	1.35
MAD estimation	No	Yes	No	No

* Significant at the 10 percent level

** Significant at the 5 percent level

*** Significant at the 1 percent level

Notes: Standard errors are in parentheses and, except for column (2), are all Newey-West HAC with 12 lags. The regression R² in column (2) is a pseudo R² calculated as 1 minus the ratio of the sum of absolute deviations in the full model and the sum of absolute deviations in a model with only an intercept.

Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

the estimate of β across four different model specifications. Although the specifications have different controls, estimation strategies, and estimation samples, the estimate of β is consistently around -0.3 across columns. The estimates of β in the first row of Table 1 quantify the liquidity effect and imply that a 1 percent decline in reserves raises the federal funds rate (relative to the IOR rate) by about 0.3 basis point.

The magnitude of the estimated liquidity effect in terms of absolute changes in reserves is much smaller in recent years compared with estimates from the pre-2008 period. For instance, Carpenter and Demiralp (2006) estimate that a \$1 billion decline in reserves increases the federal funds rate by 1 to 3 basis points. However, the estimates in the first row of Table 1 imply that a \$1 billion decline in reserves, which would amount to less than a 0.05 percent decline in reserves over the estimation sample, would have essentially no effect on the funds rate. The reduction in the estimated liquidity effect

relative to Carpenter and Demiralp (2006) may reflect the nonlinear nature of the demand for reserves. If the demand curve for reserves becomes flat when reserves are abundant, then a \$1 billion change in reserves would be expected to have a much smaller effect when the quantity of reserves is large. For this reason, I estimate a linear relationship between the federal funds-IOR spread and the natural log of reserves, which can capture nonlinearity in the demand for reserves.¹¹ One implication of log demand is that a 1 percent change in reserves has the same effect on the funds rate regardless of the level of reserves.

The magnitude of the liquidity effect in terms of the relative change in reserves is similar to that found by Carpenter and Demiralp (2006) using pre-2008 data. In particular, the level of reserves averaged about \$20 billion in Carpenter and Demiralp's sample period. Therefore, their results, which imply that a \$1 billion decline in reserve balances lifts the funds rate by 1 to 3 basis points, can be interpreted as implying that a 5 percent decline in reserves would lift the funds rate by 1 to 3 basis points. In comparison, the estimates in column 1 of Table 1 imply that a 5 percent decline in reserves in recent years similarly lifts the funds rate by about 1.5 basis points.

Fluctuations in reserves are able to explain much of the recent variation in the federal funds-IOR spread. The first column of Table 1 shows the estimates from regressing this spread on a constant, the natural log of reserve balances, and month-end dummy variables. In this simple regression model, the R^2 is 0.80, implying that less than a quarter of the variation in the federal funds-IOR spread is left unexplained. In other words, week-to-week variations in reserve balances explain the bulk of the observed movements in the federal funds-IOR spread, holding month-end effects constant. Over the estimation sample, 100 times the log of reserves has declined by a factor of 46, and the federal funds-IOR spread has increased by 16 basis points. Given the estimate of β of -0.28 , the observed decline in reserves can explain almost 13 basis points of this 16 basis point rise.

The estimate of the liquidity effect is robust to outliers. The second column of Table 1 shows the regression coefficients found by minimizing the sum of the absolute value of the errors, ε_t , which is more robust to outliers than the specification in the first column, which minimizes the sum of the squared errors. Outliers have been a

concern in prior research estimating the liquidity effect. In particular, Thornton (2001) argues that Hamilton's (1997) seminal estimates of the liquidity effect are largely driven by a few large movements in the funds rate. The similarity of the estimates between columns 1 and 2 in Table 1 suggests that outliers are not driving the liquidity effect in the recent period.

Accounting for the role of repo rates

Although the column 1 and 2 regressions show a strong link between the quantity of reserves and the federal funds-IOR spread, they do not include variables potentially important to the federal funds-IOR spread. For example, several recent theoretical models suggest the repo spread influences the federal funds-IOR spread (Arfonso, Armenter, and Lester 2018; Schulhofer-Wohl and Clouse 2018). In light of these results, my previous estimates of the liquidity effect could be biased because they omit this potentially important explanatory variable. Column 3 of Table 1 shows parameter estimates after adding the SOFR-IOR spread (the repo spread) to the set of control variables. Including the repo spread in the regression has no significant effect on the coefficient estimate on reserves. However, the repo spread enters positively in the federal funds-IOR spread regression, which suggests that it could also help explain the recent rise in the funds rate relative to the IOR rate.

The regression model that includes both reserves and the repo spread attributes a greater quantitative role to reserves in explaining the recent rise in the funds rate. For instance, adding the repo spread to the regression appears to have a small effect on the R^2 , raising it from 0.80 to 0.83. Moreover, the model attributes most of the 16 basis point rise in the federal funds-IOR spread to declining reserves. The regression estimates imply that about 12 basis points of the rise is due to the liquidity effect, while less than 2 basis points of the rise is due to higher repo rates. The small contribution from rising repo rates may reflect the low estimate of pass-through from repo rates to the federal funds rate. For example, the estimated coefficient on the repo spread in column 3 of Table 1 suggests that less than 10 percent of movements in repo rates pass through to the funds rate.

Repo spreads were relatively stable through much of the estimation sample, which may be one reason why the estimated pass through from

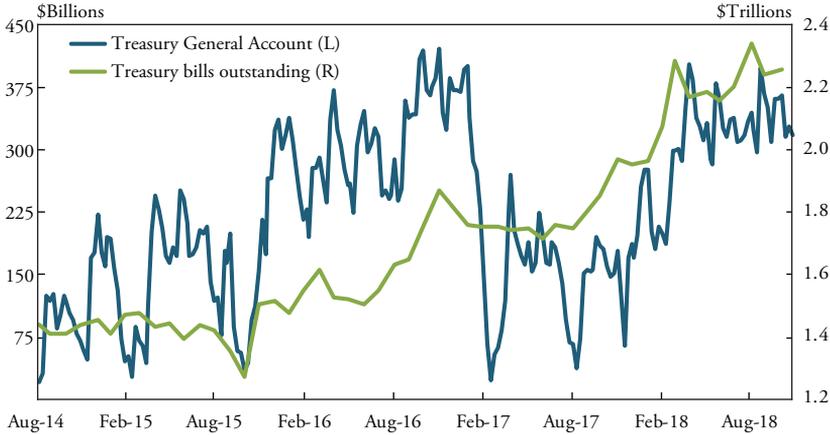
the repo spread to the federal funds-IOR spread is low. For example, repo spreads began to rise in earnest in recent quarters as Treasury bill issuance has increased. Column 4 of Table 1 shows regression estimates over the period from October 2017 through November 2018. This shorter sample more squarely focuses on the recent period when repo rates have been rising amid greater Treasury issuance. The starting date of this sample also marks the initiation of balance sheet reduction by the FOMC, which is one source of declining reserve balances. The concurrent rise in repo rates and decline in reserves over this sample could lead to sharper estimates of the independent effects of reserve balances and repo rates on the federal funds rate. However, over this recent sample, the coefficient on the repo spread is zero and no longer significant.

The low degree of estimated pass-through from the repo spread to the federal funds-IOR spread, especially in the post-October 2017 sample, may result from the high correlation between the repo spread and reserves. When two independent variables are highly correlated, it is difficult to estimate their individual effects. For example, when the regression model is estimated without reserves, the coefficient on the repo spread nearly doubles and becomes highly significant in the post-October 2017 sample. The instability of the coefficient on the repo spread suggests the need for a more careful structural analysis to identify the underlying forces driving the federal funds-IOR spread.

Decompositions of the federal funds-IOR spread from this simple regression model may overlook the complex interactions among reserves, repo rates, and the funds rate. For example, some of the decline in reserves can be linked to increased Treasury bill issuance. Chart 2 shows that as the amount of Treasury bills outstanding has increased, so, too, has Treasury's general account balance. Increases in the TGA necessitate a decline in reserves: for example, payments made to Treasury after bill auctions reduce the reserves of the account holder who purchased the Treasuries. In this sense, pressure on the funds rate due to rising repo rates and increased bill issuance may be mistakenly attributed to the liquidity effect. Similarly, a reduction in reserves could broadly increase short-term rates, including repo rates. These interplays suggest the need for a structural model to disentangle the independent roles played by the liquidity effect and rising repo rates.

Chart 2

Treasury's General Account Balance and Treasury Bills Outstanding



Sources: Federal Reserve Bank of New York (Haver Analytics) and Board of Governors of the Federal Reserve System (Haver Analytics).

III. A Structural VAR Model of the Shocks Driving the Federal Funds-IOR Spread

Structural VAR models have often been used to estimate the liquidity effect, typically with monthly or quarterly data. Hamilton (1997) points to one exception, Bernanke and Mihov (1998), who identify the liquidity effect using biweekly data combined with operational details of monetary policy implementation. I use a related approach by combining some institutional details around Treasury issuance with weekly data on the same three variables studied in the regression model: the natural log of reserve balances, the repo-IOR spread, and the federal funds-IOR spread to elicit the individual effects of reserve supply shocks, Treasury bill supply shocks, and federal funds-market-specific shocks. These three shocks provide a complete decomposition of the federal funds-IOR spread among three uncorrelated factors.¹²

Identifying reserve supply and Treasury supply shocks

Identifying assumptions recover the shocks of interest in the structural VAR model from the reduced-form VAR residuals. This mapping is mathematically summarized in equation (2). Identifying these shocks is necessary because the reduced form VAR residuals, denoted

by e_t , are correlated. In other words, the reduced form VAR residuals cannot distinguish between liquidity effects and Treasury supply effects on the funds rate any better than the regression model. Identification in the three-variable VAR including reserves, the repo-IOR spread, and the federal funds-IOR spread requires three restrictions.¹³ A common way to achieve identification is to assume the following triangular structure for the matrix A^{-1} , where the three restrictions are provided by zeros on the upper diagonal:

$$e_t \equiv \begin{pmatrix} e_t^{Res} \\ e_t^{SOFR-IOR\ spread} \\ e_t^{FF-IOR\ spread} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{12} & a_{22} & 0 \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{Res\ Supply} \\ \varepsilon_t^{Treas\ Supply} \\ \varepsilon_t^{FF\ Specific} \end{pmatrix} = A^{-1} \varepsilon_t. \quad (2)$$

Combining weekly data with some institutional details regarding Treasury auctions motivates the above structure.¹⁴ Aside from cash management auctions, Treasury bill auctions follow a regular schedule where the auction is announced before Wednesday and settled after Wednesday.¹⁵ Treasury auction announcements provide details about the offering, including the maturity, amount, and even the Committee on Uniform Security Identification Procedures (CUSIP) number, which enables immediate trading and pricing of the new securities on a when-issued basis. However, winning bidders from the auction settle with Treasury up to one week after the announcement (Garbade and Ingber 1995). If the winning bidder is a depository institution, the Fed, acting as the fiscal agent for the Treasury, settles the auction by debiting the bank's reserve account and crediting the TGA. Therefore, changes in reserve supply due to Treasury issuance occur on the date of issuance, whereas the rate response can occur at announcement.

The time lag between the announcement and settlement of a Treasury auction provides a credible restriction that can be applied when using week-ending-Wednesday reserves data.¹⁶ In particular, the primary identifying assumption I use to distinguish between reserve supply and Treasury supply shocks is that an increase in the repo rate due to an announced increase in Treasury bill supply should have no effect on end-of-day Wednesday reserve balances in the current week. Instead, any reduction in reserve balances associated with an increase in

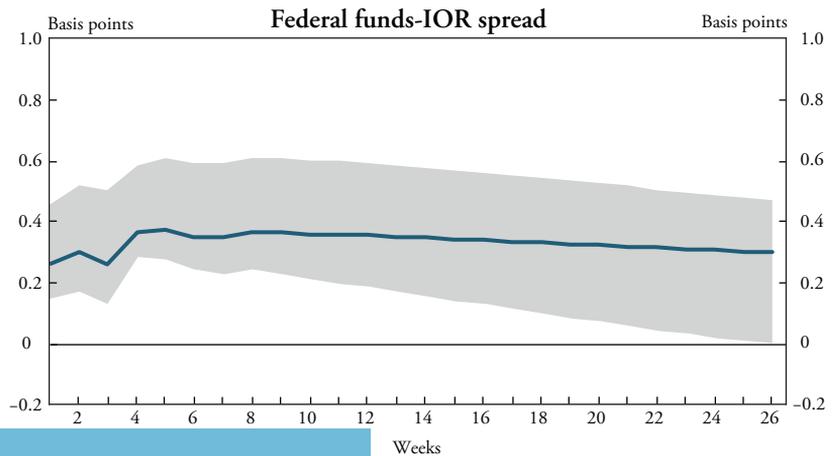
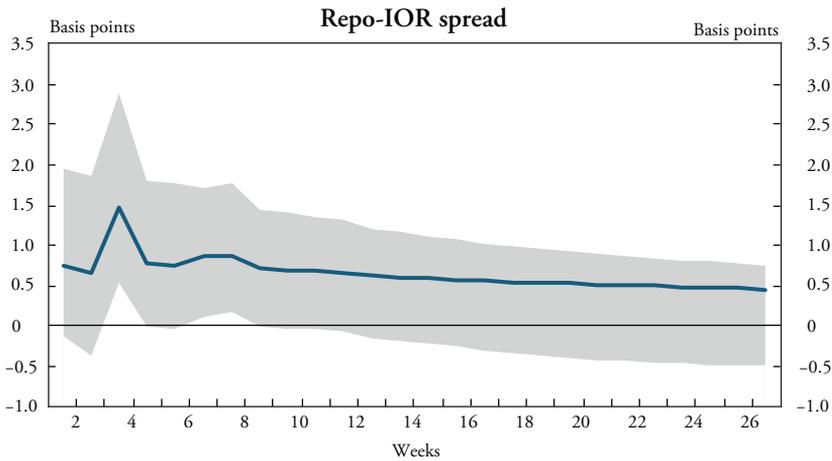
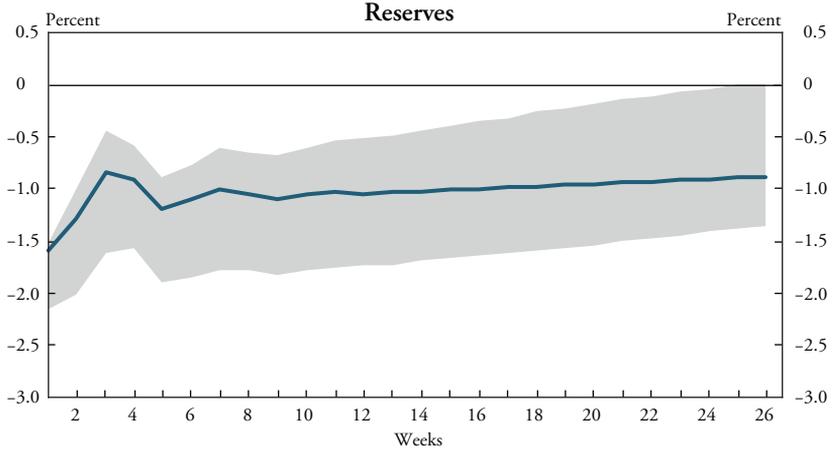
Treasury bill supply should occur the following week, at the earliest. To use a recent Treasury auction as an example, consider the 4-Week Bill auction announced on Thursday, October 4, 2018. The October 4 press release details that \$40 billion of these bills will be auctioned on Tuesday, October 9, and then issued on Thursday, October 11, which is when the winning bidders will transfer payment to Treasury. Importantly, this implies that any fluctuations in reserves between Wednesday, October 3, and Wednesday, October 10, are not directly related to this Treasury issuance. Instead, any direct effect this issuance has on week-ending-Wednesday reserve balances due to the auction settlement will first appear in the Wednesday, October 17 H.4.1 release, which enables a clean separation of the effects of declining reserves and increased Treasury issuance on the federal funds-IOR spread.¹⁷

The dynamic effects of reserve and Treasury supply shocks on the federal funds-IOR spread

A negative reserve supply shock leads to a persistent rise in the federal funds-IOR spread. Chart 3 shows the impulse response to a -1 standard deviation reserve supply shock. The qualitative dynamics are consistent with a liquidity effect, as the federal funds-IOR spread rises in response to the decline in reserves. The magnitude of this liquidity effect is similar to that predicted by the simple regression model from Section II. In particular, the impulse response in Chart 3 implies that a 1.5 percent decline in reserves leads to a 0.26 basis point rise in the funds rate in the first week and a 0.38 basis point rise after about one month. In other words, the regression model and VAR model both predict that a 1 percent decline in reserves will, over time, raise the federal funds rate (relative to the IOR rate) by about 0.3 basis points. The decline in reserves leads to even larger increases in the repo spread. The magnitude of the increase in repo rates is not precisely estimated; however, the qualitative response of the repo-IOR spread is as expected following a decline in reserves.

A Treasury bill supply shock that raises the repo-IOR spread leads to a delayed rise in the federal funds-IOR spread. Chart 4 shows the impulse response to a positive Treasury supply shock. The rise in repo rates leads to a decline in reserve balances with a two-week lag, which is consistent with the structure of Treasury auctions that motivated the

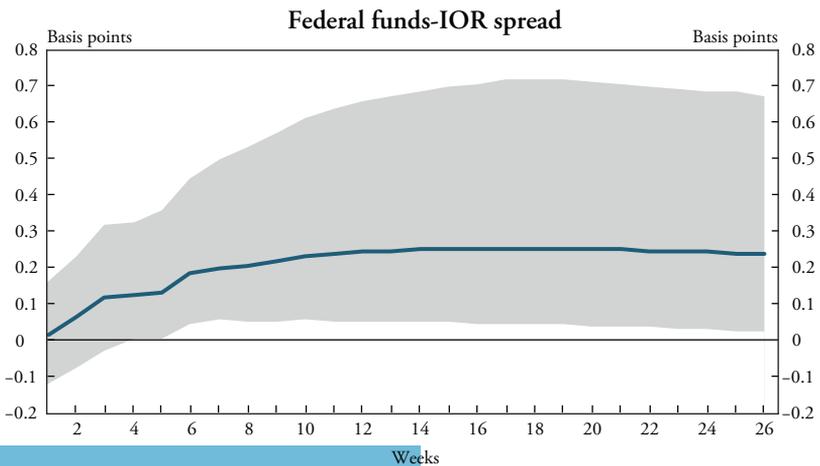
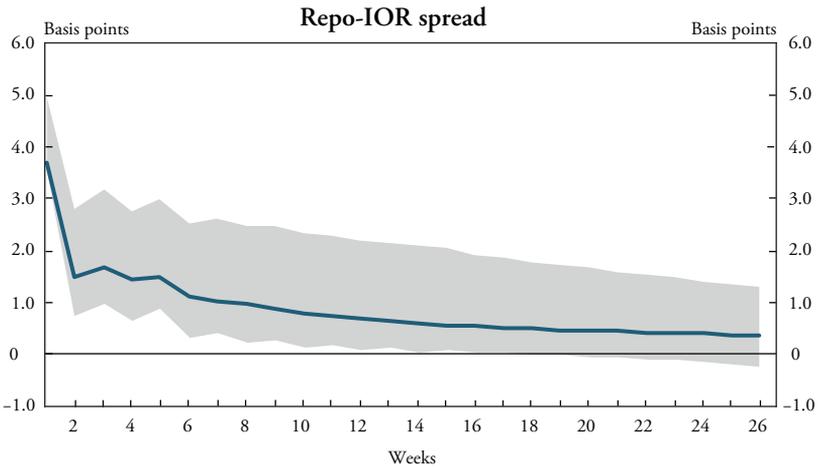
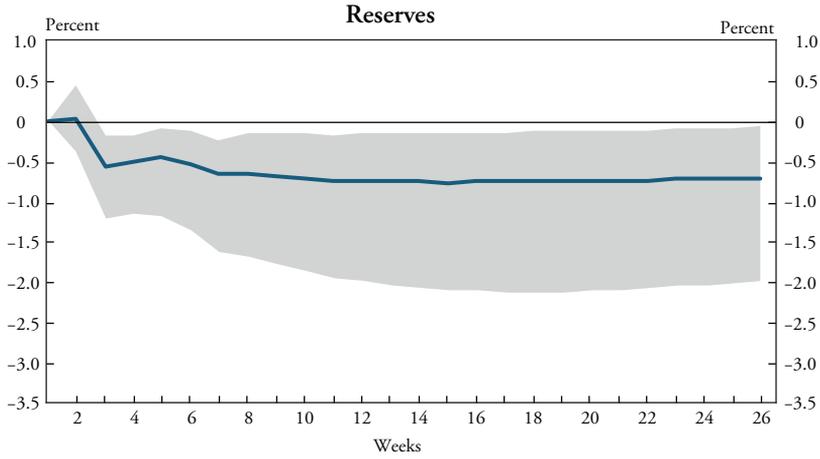
Chart 3
Impulse Response to a Reserve Supply Shock



Note: Blue lines are point estimates; gray regions are 90 percent error bands.
 Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

Chart 4

Impulse Response to a Treasury Bill Supply Shock



Note: Blue lines are point estimates; gray regions are 90 percent error bands.
 Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

identifying restrictions. The response of reserve balances in the first week is restricted to be zero. However, reserves do not decline until the third week. One interpretation of this dynamic is that while repo rates respond shortly after the Treasury auction announcement, reserve balances decline only when the bills are issued, reflecting an increase in the TGA.

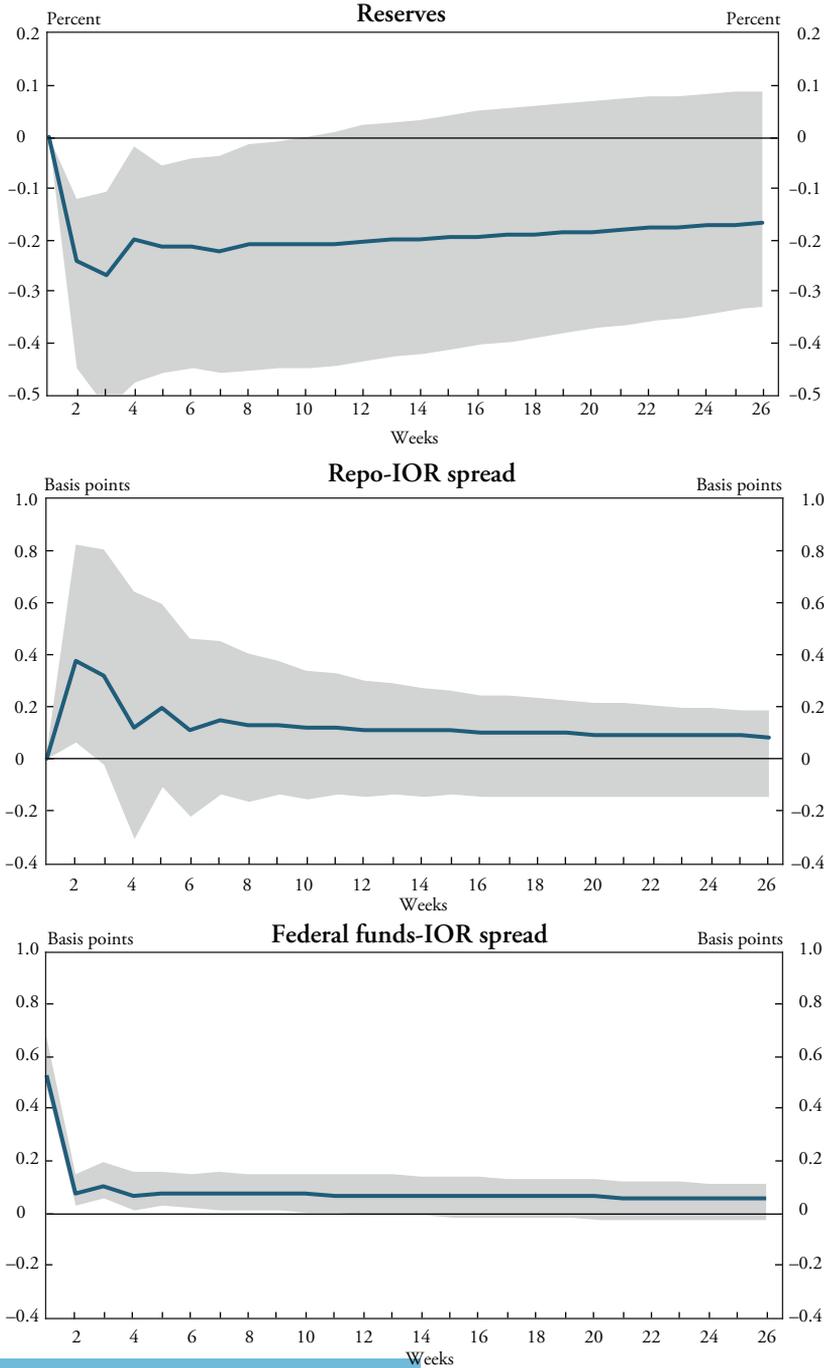
Following the increase in Treasury bill supply, repo rates rise on impact, and reserve balances decline for several months, consistent with a lasting uptick in Treasury bill issuance and a rising balance in the TGA. The rise in the repo spread passes through with some delay to the federal funds-IOR spread. Recent theoretical models of the federal funds market predict that this pass-through is likely to be incomplete due to the bargaining power of banks and GSEs (Schulhofer-Wohl and Clouse 2018). Consistent with the predictions of these theoretical models, the point estimates imply that peak pass-through is less than 10 percent, as the 4.5 basis point rise in the repo spread induces at its peak a 0.3 basis point rise in the federal funds-IOR spread.

Federal funds-specific shocks induce short-lived, idiosyncratic movements in the federal funds rate. Chart 5 shows the impulse response to a federal funds-market-specific shock. Increases in the funds rate induced by these shocks persist for only about one week. While the immediate impact on repo rates and reserves is assumed to be zero, repo rates rise and reserves decline in later periods.¹⁸ The repo rate rises by about the same amount as the funds rate, suggesting that shocks originating in the funds market pass through about one for one to other money-market rates. The strong pass-through observed in this impulse response is consistent with Potter's (2018) observation that changes in the funds rate have transmitted fully to other overnight interest rates. Compared with reserve and Treasury bill supply shocks, the movement in the federal funds-IOR spread following a federal funds-market-specific shock are much less persistent, suggesting these idiosyncratic shocks are not a primary driver of the dynamics in the federal funds-IOR spread over longer horizons.

Which shocks are driving the federal funds-IOR spread?

Reserve supply shocks are a primary driver of the federal funds-IOR spread at both short and long horizons. Table 2 shows the variance decompositions for the federal funds-IOR spread.¹⁹ At the one-week horizon, fluctuations in reserves explain about 20 percent of the

Chart 5
Impulse Response to a Federal Funds-Specific Shock



Note: Blue lines are point estimates; gray regions are 90 percent error bands.
 Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

Table 2
**Forecast Error Variance Decomposition
of the Federal Funds-IOR Spread**

Horizon (weeks)	Reserve supply	Treasury supply	Federal funds-specific
1	19.4	0.1	80.5
4	52.2	4.7	43.1
12	66.0	17.9	16.1
Long-run	61.9	32.8	5.3

Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

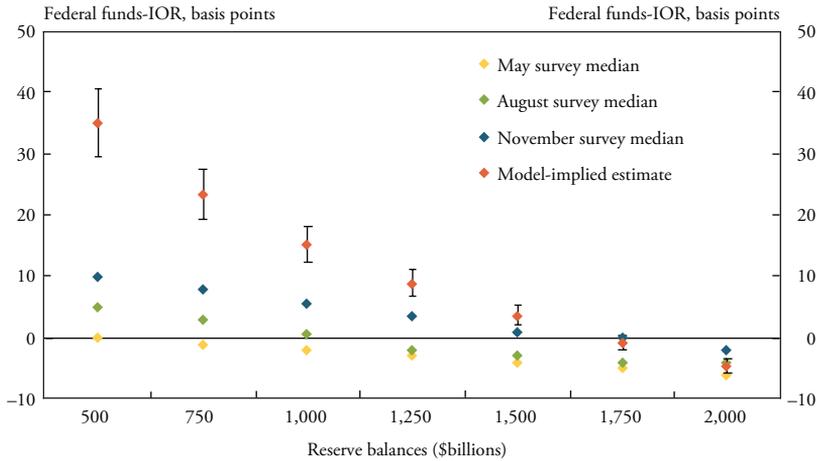
unforecastable variance of the spread, whereas federal funds-specific shocks account for the rest. Consistent with the short-lived impulse responses in Chart 5, the importance of these idiosyncratic federal funds-market shocks declines rapidly. After four weeks, these shocks account for less than half of the variation in the federal funds-IOR spread, and by three months, they account for less than one-quarter. In contrast, reserve supply shocks grow in importance over time. After one month, these shocks account for more than half of the unforecastable variation in the federal funds-IOR spread. In the longer run, reserve supply shocks account for almost two-thirds of the overall variation in the spread.

Treasury supply shocks also play a meaningful role in explaining the federal funds-IOR spread at longer horizons. As the impulse response of the federal funds-IOR spread in Chart 4 suggests, Treasury supply shocks have essentially no impact on the spread at short horizons. However, after three months, Treasury supply dynamics account for more than 15 percent of the unforecastable movements in the federal funds-IOR spread, and this share rises to almost one-third in the longer run. Reserve and Treasury supply shocks together account for almost all of the longer-run variation in the spread, with reserve supply shocks playing the most important role in determining the federal funds-IOR spread at horizons longer than one month.

Implications for the federal funds-IOR spread under further balance sheet adjustment

The estimated relationship between the level of reserves and the federal funds-IOR spread can inform predictions of how the federal funds-IOR spread is likely to evolve in an environment of declining

Chart 6
Implied Estimates of the Demand Schedule for Reserves



Notes: Black bars around model-implied estimates denote 90 percent confidence intervals. The blue, green, and yellow diamonds are estimates of the demand for reserves from the Survey of Primary Dealers conducted by the Federal Reserve Bank of New York.

Sources: Federal Reserve Bank of New York (data obtained directly from FRBNY and through Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

reserves and balance sheet normalization. Chart 6 shows the estimated demand curve for reserves using the post-October 2017 regression model from Section II with the repo spread as a control (Table 1, column 4). These parameter estimates were similar to those from the structural VAR model, bolstering their use in forecasting the federal funds-IOR spread under alternative levels of reserve balances.²⁰ Estimates from recent data suggest that the quantity of reserves demanded by banks has increased significantly above its pre-crisis average of just \$10 billion. For instance, even at a federal funds-IOR spread of 40 basis points, the quantity of reserves demanded is predicted to be about \$500 billion.²¹ This increase likely reflects increases in required reserve balances due to deposit growth and greater demand for excess reserves due to regulatory changes.

The model-based estimates of the demand for reserves exceed those of financial market participants. In addition to the model-implied estimate of reserves demand, Chart 6 also shows forecasts of the federal funds-IOR spread at alternative levels of reserve balances from the Survey of Primary Dealers (SPD) administered by the Federal Reserve Bank

of New York. The model-implied demand curve for reserves has generally exceeded the SPD-implied demand curve for reserves. For example, in the May 2018 SPD, the median estimate of the quantity of reserves consistent with no spread between the federal funds rate and the IOR rate was \$500 billion. However, the model-based estimates suggest that reserve balances of about \$1.7 trillion would be needed equalize these two rates. While these estimates seem far apart, dealers' views of the federal funds-IOR spread appear to be very fluid and are moving closer to the model estimates. For example, the median estimate of the quantity of reserves that would equalize the funds rate and the IOR rate increased from \$500 billion in May 2018 to \$1 trillion in August 2018. In the November 2018 SPD, both the model and the survey median predicted a spread of zero with reserve balances of \$1.7 trillion.²²

IV. Conclusions

The recent rise in the federal funds rate relative to the IOR rate has raised questions about the primary drivers of the federal funds-IOR spread in the Fed's new operating framework. Although substantial excess reserves in the banking system and the payment of interest on reserves have weakened the liquidity effect in absolute terms, a range of estimation strategies reveals that some linkages remain between the quantity of reserves and the funds rate. A structural VAR model shows that reserve supply dynamics play an important role in determining the federal funds-IOR spread over the medium- and longer-term and that repo rate dynamics play a relatively less important role. In this sense, the level of reserves still appears to influence the federal funds rate despite the payment of interest on reserve balances. As reserve balances decline, the federal funds rate may continue to move modestly higher against the IOR rate. Such a rise could necessitate further implementation adjustments as policymakers continue to learn about the drivers of the federal funds rate in the Fed's new operating framework.

Appendix

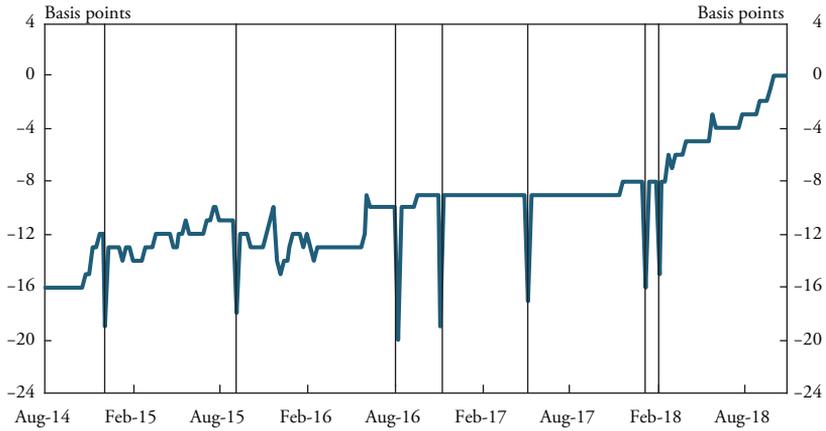
Data Used in Analysis

I use weekly data at the end-of-period Wednesday. End-of-period reserve balances data are published in Table 1 of the Federal Reserve Board's H.4.1 report. I obtain the data through Haver Analytics using the FRBW@WEEKLY code.

For all interest rates, I construct week-ending-Wednesday data from daily data. The effective federal funds rate is obtained from the Federal Reserve Board's H.15 release obtained through Haver Analytics using the FFED@DAILY code. Daily data on the IOR rate are obtained from the Federal Reserve Board's published IOER rate which is obtained through Haver Analytics using the code FAIMTN@DAILY. Finally, the secured overnight financing rate (SOFR) is used to measure the rate on Treasury repos at a daily frequency. Daily data on the SOFR are obtained from the Federal Reserve Bank of New York through Haver Analytics using the code SOFR@DAILY.

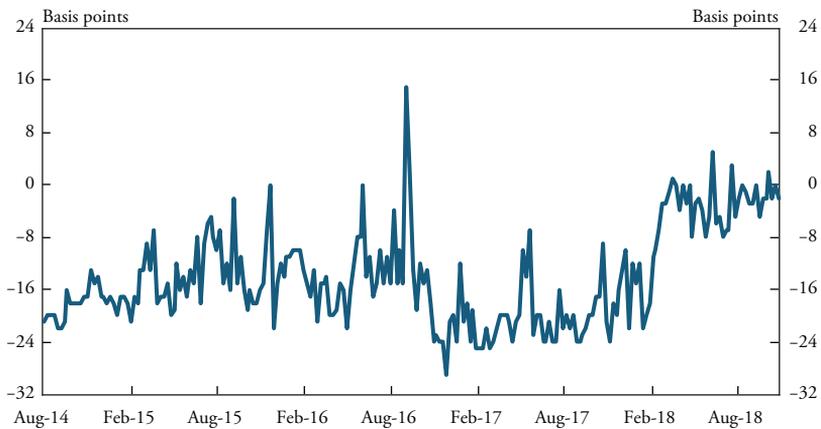
The federal funds-IOR spread is the difference between the effective federal funds rate and the IOR rate on Wednesday of each week. The repo-IOR spread is the difference between the SOFR and the IOR rate on Wednesday of each week. Both of these series, in addition to the reserve balances series, are plotted in the subsequent charts.

Chart A-1
Federal Funds-IOR Spread



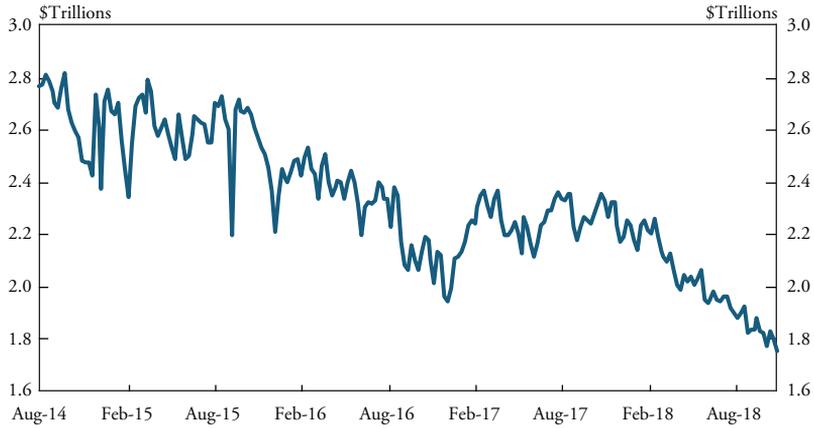
Note: The vertical lines denote month-ends.
Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

Chart A-2
Repo-IOR Spread



Note: The SOFR is used to measure the repo rate.
Sources: Federal Reserve Bank of New York (Haver Analytics), Board of Governors of the Federal Reserve System (Haver Analytics), and author's calculations.

Chart A-3
Reserve Balances



Source: Board of Governors of the Federal Reserve System (Haver Analytics).

Endnotes

¹Congress granted the Fed this authority in 2006 as part of the Financial Services Regulatory Relief Act; however, the relevant provision was not set to go into effect until October 1, 2011. The Emergency Economic Stabilization Act accelerated that date to October 1, 2008. Initially, the interest rate paid on excess reserve balances was set lower than the rate on reserve balances that banks were required to hold for regulatory purposes. However, in December 2008, when the FOMC established a 0 to 0.25 percent target range for the federal funds rate, the interest rate paid on all reserve balances was set to 0.25 percent. Until June 2018, the IOR rate remained at the upper bound of the target range of the federal funds rate. Keister, Martin, and McAndrews (2018) discuss more generally how the payment of interest on reserves can divorce the quantity of reserves from the determination of the federal funds rate.

²This exception alone may not seem sufficient to eliminate arbitrage. IOR-eligible institutions should be eager to borrow from GSEs at rates below the IOR rate and then deposit the borrowed money at the Fed to earn the spread between the IOR rate and the federal funds rate. Indeed, if enough banks were willing to engage in this arbitrage, the federal funds rate would rise toward the IOR rate. But once again, there are impediments to this arbitrage in practice. In addition to the usual monitoring costs associated with making an unsecured loan, the regulatory costs for a bank to expand its balance sheets have risen in the wake of the financial crisis. As a result, fewer banks are likely to act as arbitrageurs unless the return is sufficiently high. The cost of engaging in the arbitrage opportunity presented by the spread between the IOR rate and the federal funds rate is lower for foreign banks, which are not subject to the FDIC assessment fee based on the size of a domestic institution's balance sheet. Therefore, for some time, the bulk of trading volume on the federal funds market occurred between GSEs and foreign banks. For further details, see Afonso, Entz, and LaSueur (2013) and Gagnon and Sack (2014). More recently, as the federal funds rate has moved closer to the IOR rate, arbitrage incentives have played a reduced role in driving federal funds market activity.

³These transactions are essentially overnight deposits secured by Treasury securities.

⁴Kahn (2010) provides a more comprehensive overview of the Fed's post-crisis operating framework.

⁵The effective federal funds rate is actually a volume-weighted measure of rates on trades through New York brokers. Therefore, there is an entire distribution of interest rates at which federal funds transactions occur, some that might fall outside the target range set by the FOMC. I generically refer to the federal funds rate in reference to the rate published daily in the Board of Governors' H.15 release.

⁶This pattern emerges due to the incentives for foreign financial institutions to shrink their balance sheets around regulatory filing periods.

⁷One reason for the reduced volatility in the federal funds rate may be the change to a volume-weighted median from a volume-weighted mean which took place in 2016. However, even prior to this change in the calculation of the federal funds rate, volatility in the funds rate had declined in the post-crisis framework. For details of the methodological change in the calculation of the funds rate, see the Federal Reserve Bank of New York's site: <https://apps.newyorkfed.org/markets/autorates/fed%20funds>

⁸Identifying the causal link between reserves and the funds rate was much more challenging prior to 2008. Until 2008, the Desk actively adjusted the supply of reserves to achieve the funds rate target, which meant that a portion of the change in reserve balances on any given day represented the endogenous response to expected changes in the supply and demand for reserves. Hamilton (1997) and Carpenter and Demiralp (2006) address this endogeneity by focusing on forecast errors the Fed staff made when anticipating shifts in the demand and supply of reserves. Bräuning (2017) also points out that the current operating framework allows for the direct estimation of the liquidity effect, which he obtains by focusing on daily fluctuations in TGA balances. I find similar regression estimates using the natural log of TGA balances as an instrument for the natural log of reserves. In particular, using a GMM approach, I estimate the coefficient on the natural log of reserves to be -0.25 , close to the OLS estimate of -0.28 .

⁹I choose to work with the regression model in levels because most theoretical models posit a relationship between the level of reserves and the federal funds rate, as in Thornton (2010) and in the model of Ireland (2014). However, this raises some practical concerns for the calculation of confidence intervals in the presence of highly persistent variables. To address these concerns, I follow the recommendations in Lazarus, Lewis, Stock, and Watson (2018) as a robustness check and use a lag truncation parameter of $T \times 3/16$ for the calculation of Newey-West standard errors, where T is the sample size, and calculate critical values for the t-test from a t-distribution with eight degrees of freedom. The significance of the regression coefficients from this robustness check indicated the same significance levels as each coefficient presented in Table 1.

¹⁰The Secured Overnight Financing Rate (SOFR) is a broad measure of the cost of borrowing cash overnight collateralized by Treasury securities. For more information on the SOFR, see: <https://apps.newyorkfed.org/markets/autorates/sofr>

¹¹Carpenter and Demiralp (2006) provide some evidence of nonlinear demand for reserves, as they show that the liquidity effect declines when the reserves are abundant (except on settlement Wednesdays). The log demand for reserves generates a similar qualitative pattern because the slope of the demand for reserves is time-varying and equal to $\beta / Reserves_t$, so that larger reserve balances flatten the demand for reserves. Moreover, responses to the Federal Reserve Bank of New

York's Survey of Primary Dealers (SPD) have, in some months, suggested that the demand curve for reserves is thought to be nonlinear, with a given change in reserves having a larger effect on the federal funds-IOR spread at lower quantities of reserves (see, for example, Chart 6). That said, the results in this article are generally robust to using the level of reserves as opposed to the natural log of reserves.

¹²Given the subsample instability, particularly in the repo spread, I use October 2017 through November 2018 as the estimation sample for the VAR. Three lags are included in the VAR which, according to standard lag-selection criteria including AIC, BIC, and Hannan-Quinn, are sufficient to eliminate serial correlation in the VAR residuals. A month-end dummy variable and a constant are also included. As in the regression model, reserves enter in 100 times their natural log and the interest rate spreads enter in basis points.

¹³Generally, identification requires $N(N-1)/2$ restrictions where N is the number of variables in the VAR.

¹⁴The last row of the matrix A from this structural VAR can be interpreted as a reserves demand equation, taking the same form as the regression model in Table 1, Columns 3 and 4. However, since the coefficients of the matrix A are estimated from the VAR residuals, any concerns about the OLS regression estimates in Table 1 being driven by a spurious correlation from trending variables is alleviated. Hence, the SVAR estimates of the last row of the matrix A are, in of themselves, of interest. The estimated coefficient on reserves in the federal funds-IOR spread equation from the SVAR model (with 90 percent posterior intervals) is -0.16 ($-0.06, -0.26$). The coefficient on the repo spread from the SVAR model is 0.00 ($-0.04, 0.04$). Hence, the SVAR model estimates a slightly smaller, but still significant role to reserves in driving the federal funds rate and attributes very little role to repo rates.

¹⁵Details on the timing of Treasury auction announcements, auctions, and issuance are obtained from <https://www.treasurydirect.gov/instit/auctfund/work/auctime/auctime.htm>

¹⁶Gorodnichenko and Ray (2018) similarly use the timing between auction announcement and the auction date to elicit the effects of unexpected demand for Treasuries. They relate their results to the Fed's LSAP programs.

¹⁷The identifying restrictions are also consistent with increases in repo rates for reasons other than Treasury issuance so long as the rise in repo rates is unrelated to contemporaneous increases in reserves. Also, this identifying restriction does not rule out a repo rate effect at the time of Treasury settlement, as the response of repo rates and reserves are left unconstrained in subsequent months.

¹⁸One interpretation of this dynamic is that a rise in money-market rates reduces the quantity of money demanded in aggregate, which in turn reduces deposits and thus reserve balances. The timing structure of the VAR assumes that this portfolio-rebalancing occurs with at least a one-week lag.

¹⁹Variance decompositions reveal the share of variation in each variable due to each of the three structural shocks at any given horizon. They essentially combine the dynamics reflected in the impulse responses with the relative size of each shock.

²⁰For example, the SVAR model implies the following relationship between the federal funds-IOR spread and reserve balances and the repo-IOR spread: $FF_t - IOR_t = -0.16 \times 100 \ln(Reserves_t) + 0.0 \times (SOFR_t - IOR_t)$.

²¹These estimates should be interpreted cautiously, as the demand for reserves may be nonlinear in ways that this simple regression model may not capture. Specifically, I estimate the demand for reserves using data from a period when reserve balances have fluctuated in the neighborhood of \$2 trillion. I then use this estimated demand curve to project interest rates when the quantity of reserves is closer to \$1 trillion. The confidence intervals shown in Chart 6 are constructed to reflect some of this uncertainty—therefore, the width of the 90 percent confidence bands around the federal funds-IOR spread grows as the projected level of reserves declines further below the mean of the estimation sample.

²²The model-based estimate is about \$1.5 trillion when the estimation sample ends before May 2018, suggesting the timing difference between the model-based estimates and the survey estimates is not an important factor in explaining the gap between the two forecasts.

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