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The Liquidity Effect of the Federal Reserve's Balance Sheet Reduction on Short-Term Interest Rates

Falk Bräuning

Abstract:
I examine the impact of the Federal Reserve's balance sheet reduction on short-term interest rates emanating from the declining supply of reserve balances. Using an exogenous shift in the supply of reserves, I estimate that by January 2019, when the Fed will have reduced its portfolio by $500 billion, the overnight repurchase agreement (repo) spread (relative to the lower bound of the federal funds target range) will be 10 basis points higher and the fed funds spread will be 2 basis points higher than in October 2017, all else being equal. I also find that a declining supply of reserve balances reduces recourse to the Fed's overnight reverse repo (RRP) facility, which might initially dampen the tightening effects on short-term rates of the Fed's balance sheet reduction.

Keywords: Monetary policy, interest rates, liquidity effect, Federal Reserve balance sheet

JEL Classification: E42, E43, E52, G21

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1 Introduction

In June 2017, the Federal Reserve announced a plan to reduce its $4.2 trillion holdings of Treasury securities, agency debt, and mortgage-backed securities. While the effect of these asset reductions on long-term interest rates has been the subject of extensive debate, gradually reducing the Fed's assets will also result in a reduction of its liabilities, primarily through a declining supply of reserve balances. Therefore, the portfolio reduction could affect financial markets through the liability side of the balance sheet as well as the asset side. In this brief, I focus specifically on the potential impact of the balance sheet reduction on short-term interest rates emanating from the declining supply of reserve balances.

While the current supply of reserves of about $2.2 trillion is far in excess of regulatory minimum requirements, banks demand reserves for a variety of other reasons, including for settlement purposes and to improve balance sheet ratios. As a result, even with the current large supply of reserves, draining a non-negligible amount of reserves from the banking system could affect short-term interest rates. To test for the existence of such a liquidity effect in the current environment, I exploit daily variation in the supply of reserves that are related to changes in the Treasury General Account (TGA) balance from September 24, 2013, through June 30, 2017.[1] During this period, daily changes in the TGA balance are unrelated to monetary policy or money market conditions and, therefore, qualify as exogenous supply shifts in reserves that I can use to estimate the liquidity effect.

My key findings related to the shrinkage of reserves can be summarized as follows: I estimate a significant increase in the effective federal funds spread and the overnight repurchase agreement (repo) spread (relative to the lower bound of the federal funds target range) as a response to a drain in reserves. My estimates indicate that a reduction in reserves of $100 billion will increase the effective federal funds spread by 0.5 basis points and the overnight repo spread by 2.1 basis points. Assuming the reduction in securities holdings as outlined in the Fed's plan is related one-to-one to a decline in reserves, in January 2019, the Fed will have reduced its supply of reserve balances by $500 billion (a reduction of about 23 percent

[1]The TGA is the Treasury's transaction account held with the Fed. An increase in the TGA balance drains reserves from the banking system, while a decrease in the TGA balance increases the supply of reserves. With regard to the Federal Reserve's balance sheet, this is simply a shift in liabilities between TGA balances and bank reserves.

relative to October 2017). My estimates indicate that, as a result of the drain in reserves, the repo spread will be 10 basis points greater and the fed funds spread will be 2 basis points greater than in October 2017, all else being equal (for example, the Fed's overnight reverse repo balance).

Further, my results suggest that the impact of the balance sheet reduction on short-term rates will be stronger by the end of 2018 for two reasons. First, in accordance with the June 2017 plan, the portfolio reduction will gradually increase from an initial $10 billion per month in October 2017 to $50 billion per month in October 2018. Second, I document a nonlinear liquidity effect that depends on the total supply of reserves: by end of 2018, reserve balances will have already declined substantially, and compared with October 2017, removing one dollar of reserves will have a stronger impact on interest rates. However, I also find that, because the Fed's overnight reverse repo (RRP) facility acts as a buffer to a drain in reserves, as reserves become relatively more scarce, market participants will reduce recourse to the RRP facility and provide funding to private money markets, thereby dampening the policy-induced drain in reserves.

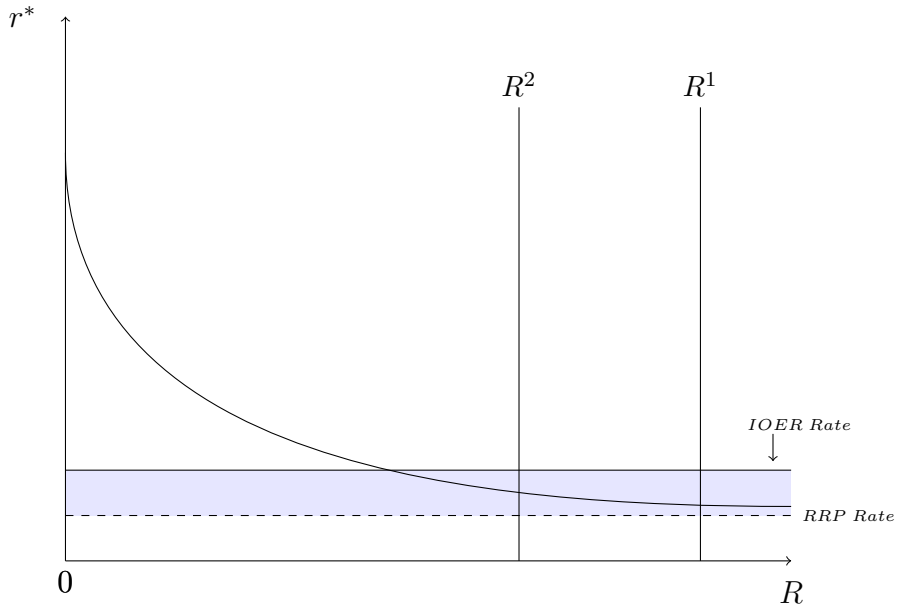
The rest of the brief is organized as follows: In Section 2, I briefly review the relationship between reserves and money market interest rates. In Section 3, I discuss how I identify a reserve supply shift to estimate the liquidity effect. Section 4 presents the estimated liquidity effect, and Section 5 concludes with policy implications.

2 Reserves and Money Market Interest Rates

The Fed's large-scale asset purchases in response to the financial crisis have been funded primarily through an increase in the supply of reserve balances that are in excess of regulatory minimum reserve requirements. Regulatory reserve requirements are a key driver of banks' demand for reserves when excess reserves are low; however, they are not the only driver. Other important factors that generate demand for reserves include the role reserves play in improving balance sheet ratios, such as liquidity ratios or risk-weighted capital ratios. Even more important is the function of reserves as the settlement means in the interbank payment

system.[2] Moreover, because the Fed has started paying interest on reserves (IOER), banks now demand reserves to earn an arbitrage spread by borrowing funds from counterparties that are not eligible to earn the IOER rate, such as government-sponsored enterprises (for example, Bech, Klee, and Stebunovs 2012). All these factors are also relevant when excess reserves are large.

Figure 1: Total Reserves and the Federal Funds Rate



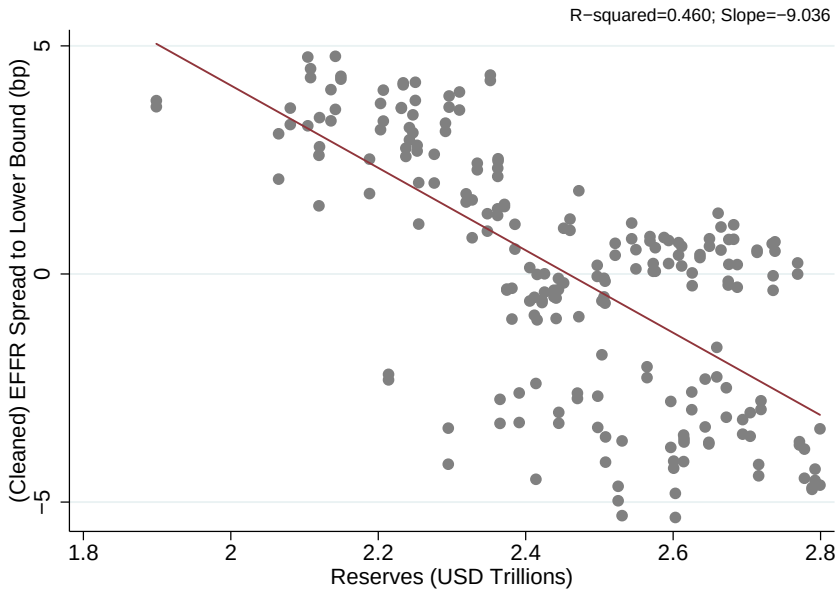
Note: The figure illustrates the effective federal funds rate (r^*) as a function of the total amount of reserves (R) in the banking system. The upper bound of the shaded area is the interest rate paid on excess reserves (*IOER Rate*), and the lower bound of the shaded area is the interest rate of the overnight reverse repo facility (*RRP Rate*). The liquidity effect is defined as $\frac{\partial r^*}{\partial R}$.
Source: Author's illustration.

As a result, a key parameter that determines the shape of the supply and demand curves in money markets—and hence the resulting equilibrium interest rates—is the total amount of reserves in the system (that is, provided by the central bank). Using the federal funds market as an example, Figure 1 illustrates the relationship between the equilibrium money

[2]In fact, whenever a bank raises funds externally, such as by borrowing in the money markets, it acquires reserves, for example, to settle customer payments or for interbank purchases of assets (for banks, reserves are similar to what deposits are for households). Even if two nonbanks engage in a money market transaction, banks will generally need to settle this transaction using reserves. The role of reserves in the money markets and the payment system is reviewed, for example, in Cook and LaRoche (1993).

market rate and the total amount of reserves in the system.[3] As the supply of reserves is reduced by the Fed (say from R^1 to R^2), the effective federal funds rate increases. Based on empirical evidence (for example, Marquez, Morse, and Schlusche 2013), the figure is drawn to highlight that if reserves are relatively scarce, because, say, excess reserves are low, then a given change in the total amount of reserves will likely have a stronger impact on the effective federal funds rate; that is, the liquidity effect is large.

Figure 2: Empirical Relationship between Federal Funds Rate and Reserves



Note: Weekly data from 2013w39 through 2017w41. The effective federal funds spread (to the lower bound of the target range) is cleaned for seasonality as described in the text.
Source: Haver, author's calculations.

The question that I address in this brief is how economically important the liquidity effect is with the current large supply of reserve balances. As initial evidence, Figure 2 illustrates the negative relationship between the federal funds rate and the total amount of reserves by using weekly data for the period 2013w39 through 2017w41, when the supply of reserves varied between $1.9 trillion and $2.8 trillion. Because the target fed funds range has been revised several times during this period, I express the federal funds rate as a spread above

[3]Figure 1 is *not* a supply-and-demand diagram for the federal funds market. The horizontal axis does not represent the amount of reserves traded in the federal funds market. Instead, it shows the observed equilibrium federal funds rate as a function of the total amount of reserves supplied by the central bank (a parameter of the underlying demand and supply curves).

the lower bound of the target range, thereby focusing only on movements of the federal funds rate within the target range (since the lift-off in December 2015, the lower bound has equaled the Fed's RRP rate; before then, it was zero). I also clean the spread for seasonal effects, such as those related to financial reporting days, by regressing the daily values of the spread on beginning-of-quarter fixed effects, end-of-quarter fixed effects, beginning-of-month fixed effects, end-of-month fixed effects, and day-of-the-week fixed effects. I do this prior to taking the weekly mean of the spread, which I plot in the figure (reserve data are publicly available at only the weekly frequency). The figure shows that even at the current high level of reserves, there is a significant negative relationship between the federal funds spread and the supply of reserves. Based on this initial evidence, a reduction in the supply of reserves by $100 billion is associated with an increase in the federal funds spread of 4.5 basis points.

3 Identification of Liquidity Effect

To better identify the liquidity effect, I investigate supply shifts in reserve balances that are unrelated to monetary policy and money market conditions. I then estimate the effect of these supply shifts on money market rates. To obtain the supply shifts, I specifically analyze changes in the Treasury General Account balance. Since October 2008, the TGA—the U.S. Treasury Department's transaction account held with the Federal Reserve—has been the Treasury's main account used in its day-to-day operations.[4] Any increase in the TGA balance drains reserves from the system, while a decrease in the TGA balance increases the supply of reserves, all else being equal.

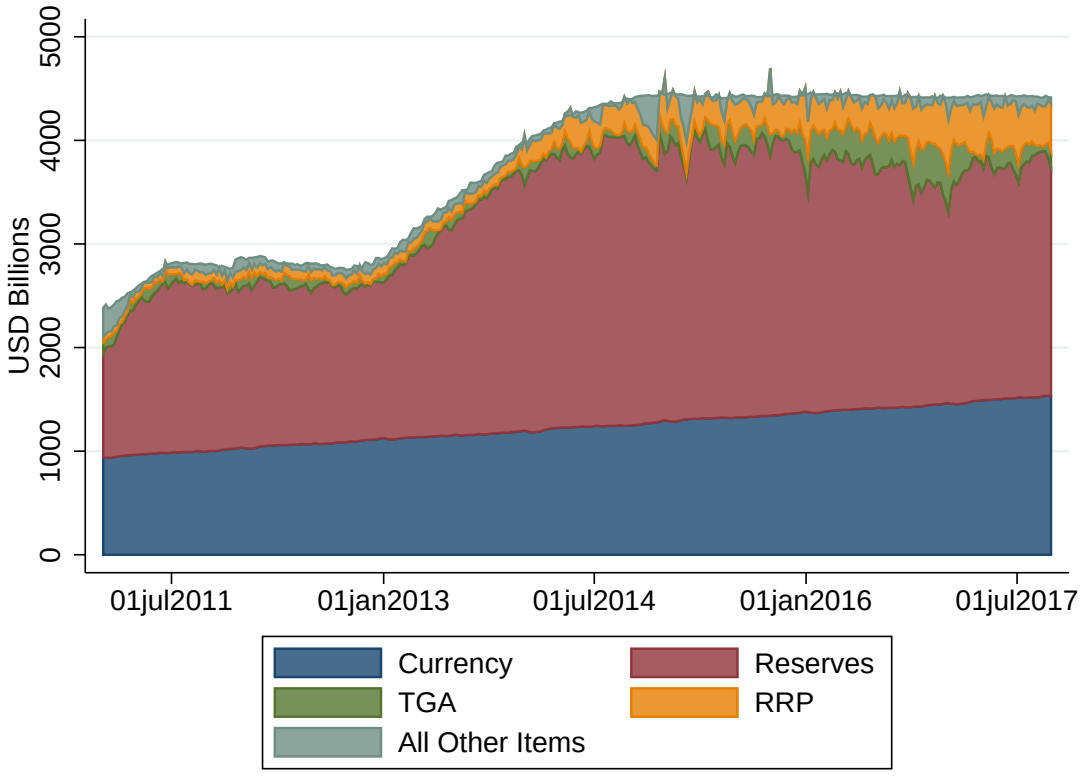
The relationship between changes in the TGA balance and changes in reserve balances becomes apparent when considering the Federal Reserve's balance sheet identity (in changes) given by

$$\Delta Assets = \Delta Currency + \Delta Reserves + \Delta RRP + \Delta TGA, \tag{1}$$

[4]Before the introduction of the IOER rate, the Treasury held most of its cash in accounts with private depository institutions, where it was remunerated at a rate slightly below the federal funds rate. However, with the IOER introduction, depositing funds with private banks that would then hold more reserves became a net loss (receive a rate below the federal funds rate but pay the IOER rate through the Fed, thereby reducing the Fed's remittances to the Treasury), and the Treasury moved nearly all of its cash balance into the TGA.

where *Currency* is Federal Reserve Notes, *RRP* is the volume of the Fed's reverse repo facility, and the smaller liability positions have been omitted. Everything else being equal, funds flowing into the TGA account, that is, funds transferred by commercial banks to the Treasury on behalf of a customer (for example, a taxpayer), drain reserves, while funds flowing out of the TGA account into private markets through the banking system increase the supply of reserves (for example, when Federal employees receive salary payments). With regard to the Fed's balance sheet, these operations represent simply a change in the composition of the Fed's liabilities, keeping the size of the Fed's balance sheet constant. On the other hand, when the Fed purchases securities from, or lends funds to, private markets, these operations increase the Fed's balance sheet, generally through an increase in the supply of reserves on the liability side.

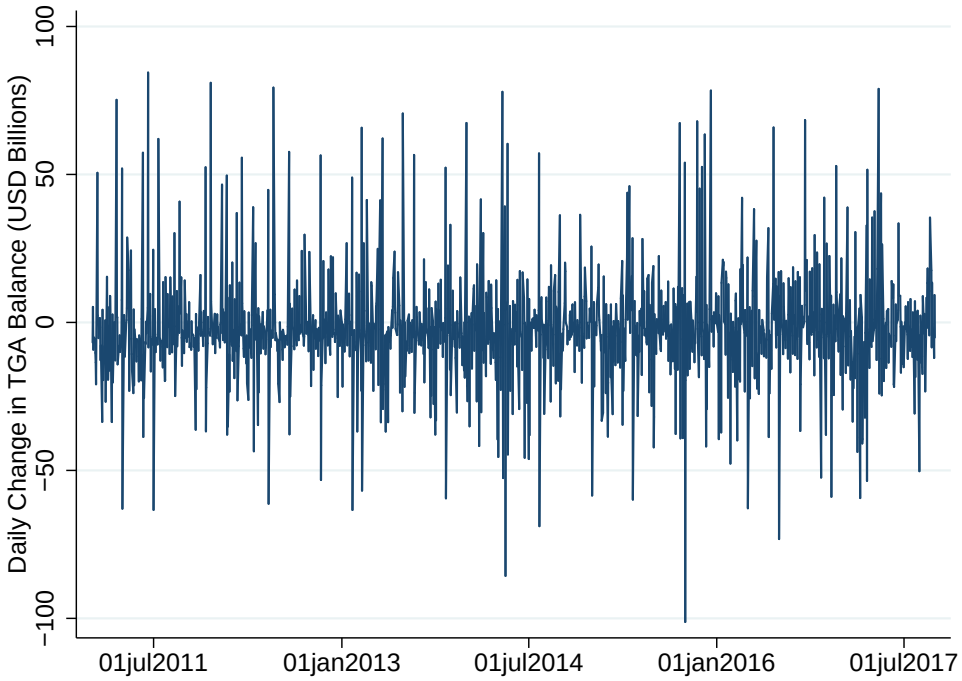
Figure 3: Composition of Federal Reserve Liabilities



Note: Currency is Federal Reserve Notes, RRP is the reverse repo balance, and TGA is the Treasury General Account balance.
Source: Haver.

Figure 3 presents the composition of the Federal Reserve's liabilities from 2011w1 through 2017w41. As the figure shows, currency and reserves are the largest positions. Moreover, after the balance sheet size stabilizes at around $4.5 trillion in 2014, the amount of reserves exhibits significant variation that is driven primarily by changes in the TGA balance and changes in the RRP facility, while short-term variation in currency and other liabilities that also affect the level of reserves are negligible.[5] I will make use of these changes in reserves to estimate the liquidity effect.

Figure 4: Daily Change in TGA Balance



Note: TGA is the Treasury General Account. The sample covers daily data from January 1, 2011, through September 30, 2017.
Source: Haver.

In particular, I use the daily changes in the TGA balance to construct a supply shift in reserves. These daily changes, which are a result of only the Treasury's day-to-day business operations, qualify as exogenous supply shifts, as they are unrelated to monetary policy

[5]Similar to an increase in the TGA balance, all else being equal, an increase in the RRP balance drains reserves. However, RRP-based changes in reserves are market initiated and therefore endogenous to money market conditions.

or money market conditions and, therefore, are suitable to identify the liquidity effect.[6] Specifically, daily changes in the TGA balance are unrelated to changes in the Fed's asset holdings and currency or other liability items such that in terms of Equation 1, it can be seen that $-\Delta Reserves = \Delta RRP + \Delta TGA$. Thus, keeping the RRP volume constant, a change in the TGA balance is related one-to-one to an opposite change in reserves. Figure 4 highlights that the daily changes in the TGA balance also are economically meaningful, fluctuating in a range of roughly +/– $100 billion.[7]

4 Estimated Liquidity Effect

4.1 Baseline Effects

I now estimate the liquidity effect on money market rates, that is, the effect of a reserve supply shift on money market rates. The generic model, which for statistical reasons I estimate in changes rather than levels, can be written as follows

$$\Delta Spread_t = \beta_0 + \beta_1 \Delta TGA_t + \beta_1 \Delta RRP_t + \epsilon_t, \tag{2}$$

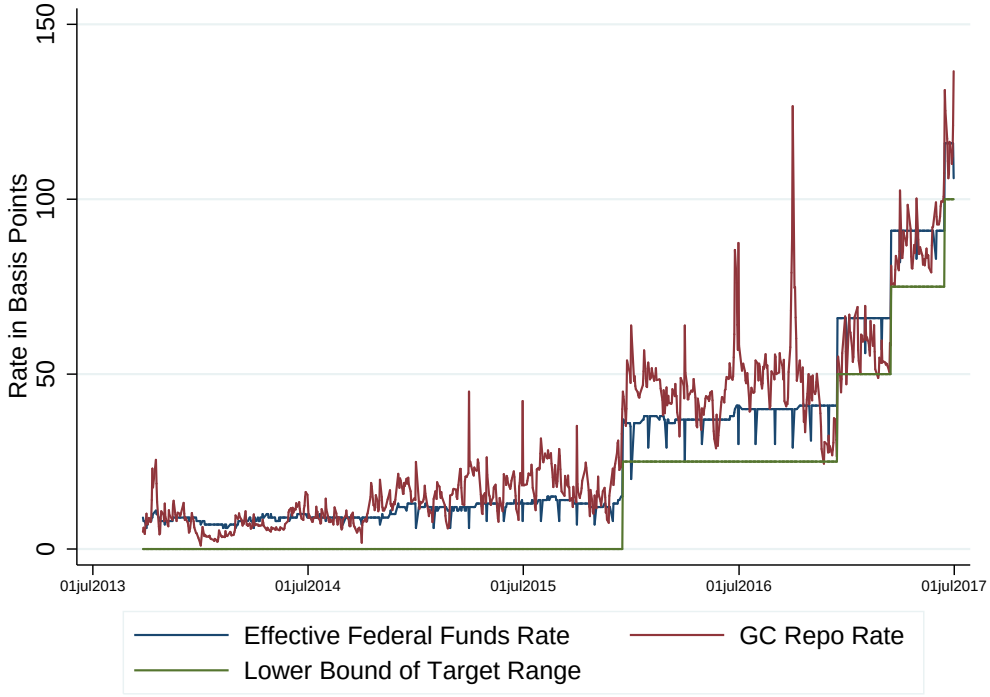
where $Spread_t$ is an interest rate spread over the lower bound of the federal funds rate target range (for example, the overnight repo rate minus the lower bound of the federal funds rate target range), and ΔTGA_t is the daily change in the TGA balance. RRP_t is the amount deposited in the Fed's overnight reverse repo facility, which I include to control for the possibility that after a positive change in the TGA balance (a drain in reserves), market participants may draw down their RRP balance to counteract the shortage of liquidity. Similarly, after a decrease in the TGA balance and the associated increase in reserves, increasing volumes in the RRP may absorb some of the additional reserves. As argued, daily changes in other balance sheet items are orthogonal to changes in the TGA balance and can be omitted

[6] Unlike before it kept a large supply of excess reserves, the Fed nowadays does not actively supply or drain reserves in response to predicted changes in the daily TGA balance to offset large changes in reserves. It is thus not necessary to compute a surprise change in the TGA balance to identify a liquidity shock as done, for example, in Hamilton (1997). As a robustness check, I have also fitted a model similar to Hamilton (1997) and used the residuals as supply shocks, leading to similar results.

[7] Pozsar (2017) provides a recent discussion of the role of the TGA balance for money markets.

from the regression.

Figure 5: Federal Funds and Overnight Repo Rate



Note: GC repo rate is the general collateral index, an average rate on overnight repos collateralized by Treasury and agency debt as well as mortgage-backed securities.
Source: Haver, Bloomberg.

My main analysis is based on 900 daily observations from September 24, 2013, through June 30, 2017.[8] Figure 5 plots the two money market interest rates that I consider in this brief—the federal funds rate and overnight repo rate—along with the lower bound of the federal funds rate target range during the sample period. To account for the apparent seasonality in the interest rates, I clean the rates prior to the analysis by regressing them on beginning-of-month fixed effects, end-of-month fixed effects, beginning-of-quarter fixed effects, end-of-quarter fixed effects, and day-of-the-week fixed effects. Controlling for seasonality isolates the effect of changes in the TGA balance on interest rate spreads, because both the TGA balance and the interest rate spreads may exhibit seasonal variation that is driven by unrelated factors. Such factors can include movements in the repo rate that are related

[8]The sample selection is driven by data availability for the daily RRP volume, but it coincides with a period when the balance sheet size was relatively constant, and fluctuations in reserve balances were driven primarily by changes in TGA and RRP balances.

to deleveraging by European banks before end-of-quarter reporting days that can coincide with regular Treasury payments at the end of quarters.

Table 1: Liquidity Effect on Short-Term Interest Rates

Dependent Variable:	Δ Fed Funds Spread (bps)		Δ Repo Spread (bps)	
	(1)	(2)	(3)	(4)
Δ TGA Balance ($ bn)	0.0033*	0.0053***	0.0143**	0.0206***
	(1.7095)	(2.7064)	(2.1627)	(3.0558)
Δ RRP Balance ($ bn)		–0.0055***		–0.0171***
		(–4.4718)		(–4.0689)
Constant	0.0007	0.0061	0.0029	0.0199
	(0.0173)	(0.1587)	(0.0218)	(0.1506)
Seasonality Controlled?	Yes	Yes	Yes	Yes
Observations	900	900	900	900
R-squared	0.0032	0.0250	0.0052	0.0232

Note: The dependent variable is the daily change in the spread of the effective federal funds rate (columns 1 and 2) or the overnight repo rate (columns 3 and 4) over the lower bound of the federal funds rate target range. A positive value of Δ TGA Balance corresponds to a drain in reserves. The sample covers daily data from September 24, 2013, through June 30, 2017. *t*-statistics are shown in parentheses. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

Table 1 presents the baseline results. In columns (1) and (2), I look at the effects in the federal funds market. In column (1), I find that a positive total change of the TGA balance increases the federal funds spread (relative to the lower bound of the target range). However, the economic effects are quantitatively small, with a $100 billion drain in reserves increasing the spread by only 0.3 basis points, potentially because the federal funds market is currently not fully functional, as indicated by small turnover volumes. Column (2) shows that this result is robust to the inclusion of the daily change in RRP volume market participants may use as a buffer to an excess or shortage of liquidity on a given day. (Note that because changes in the RRP balance are endogenous to money market conditions, the estimate of the RRP coefficient cannot be interpreted as causal.) In column (2), I estimate an effect of 0.5 basis points per $100 billion change in reserves.[9]

In columns (3) and (4), I look at the liquidity effect in the repo market. The repo market

[9]In unreported results, I find that after a decrease in reserves, the cross-sectional dispersion of interest rates also widens, as measured, for example, by the daily standard deviation of the federal funds rate.

is significantly larger than the federal funds market, with the daily turnover in overnight repo contracts averaging around $1.5 trillion in the first half of 2017, while the average daily turnover in the federal funds market is only $83 billion.[10] Repos also play a much more important role as a short-term funding source for banks. According to the 2017q1 Call Report data, banks borrow roughly 10 times as much in the repo market as they do in the federal funds market. Therefore, the liquidity effect in the repo market is more relevant from a policy perspective, and I will focus mainly on the repo market in the following. Column (3) shows that a $100 billion increase in the TGA balance (that is, a drain in reserves of $100 billion) is associated with a 1.4-basis-point increase in the spread between the overnight repo rate and the lower bound of the federal funds target range.[11] Again, the result is robust to the inclusion of the change in the RRP volume in column (4).

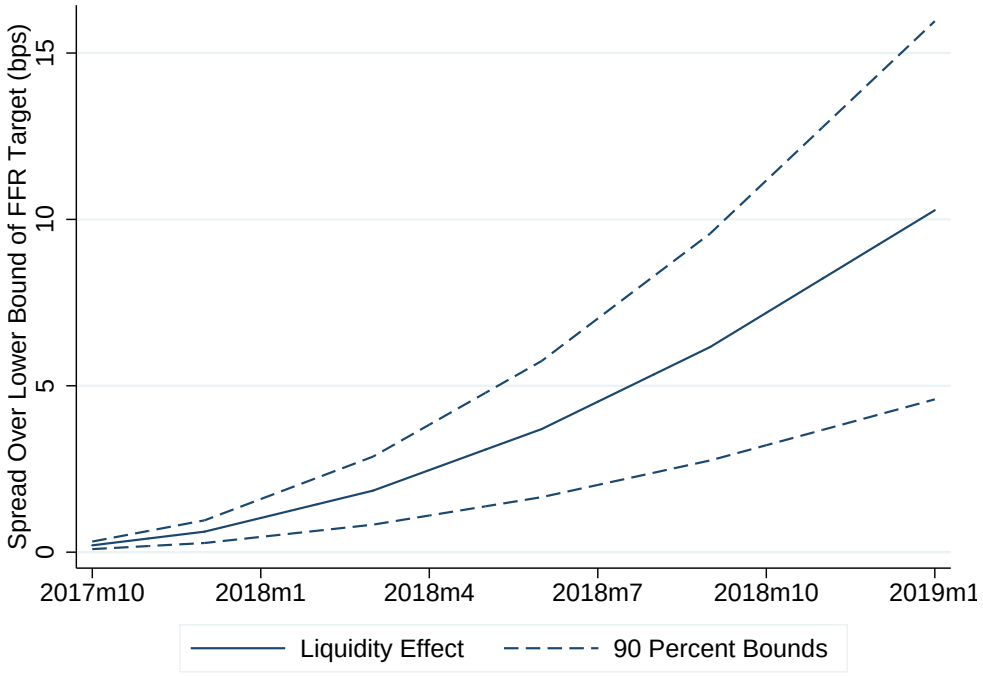
The results are robust to alternative specifications and sample periods. For example, the results are robust to excluding from the sample days when the federal funds target range changed. Further, when I estimate the model using data from after October 2014, when the Fed stopped quantitative easing and its balances sheet size was essentially constant, I get similar coefficient estimates. The results are also robust to using the repo and federal funds spreads over the rate of the Fed's RRP (which since December 2015 coincides with the lower bound of the federal funds target range). I have also estimated the model with weekly data in order to control for changes in other balance sheet items. Moreover, I have fitted several time-series models to the daily change in the TGA balance and used the residuals of these regressions as surprise changes (for example, Hamilton 1997), although, as argued in footnote 6, identifying a surprise change in the TGA balance is not necessary in the current monetary policy implementation framework. Importantly, I have also used the daily change in the TGA balance that is not driven by daily change in net Treasury debt outstanding, because changes in the stock of Treasury debt securities affect the TGA balance, but they could simultaneously affect money market conditions (in particular, repo rates that are often

[10]Note also that the set of participants in the repo market is larger compared to the federal funds market. In particular, money market mutual funds do not participate in the federal funds market, as they do not hold reserves (but they do have access to the RRP facility).

[11]I use the general collateral overnight repo index from Bloomberg, which is an average of rates on overnight repos collateralized with Treasury and agency debt as well as mortgage-backed securities. Data on overnight repos that are exclusively collateralized by Treasury securities have missing observations during my sample period, but results are qualitatively similar using overnight Treasury repos.

collateralized by Treasury debt) and introduce a bias into my results. However, all these robustness checks confirm the existence of an operational liquidity effect with quantitatively similar results.

Figure 6: Effect of Balance Sheet Reduction on Repo Spread



Note: Estimated effects on the overnight repo spread (relative to the lower bound of the federal funds target range) are based on model (4) of Table 1 and the assumption that the June 2017 plan for the reduction in securities holdings is related one-to-one to a reduction in reserves.
Source: Author's calculations.

In Figure 6, I use the estimates from Table 1, column (4), to project the effect of the Fed's balance sheet reduction as outlined in the June 2017 plan on the overnight repo spread (relative to the lower bound of the federal funds target range). Details on the June 2017 plan are provided in Table 2. The assumption I make is that a reduction in the Fed's securities holdings is related one-to-one to a reduction in reserves. The figure shows that by January 2019, when the balance sheet has shrunk by $500 billion (corresponding to a 23 percent reduction in reserves compared with October 2017), the repo spread will be about 10 basis points larger than it is in October 2017, all else being equal. Note that the projection of the overnight repo spread in the figure is not due to changes in the short-term policy rate floor,

but rather a result of the decreasing supply of reserve balances. As the figure indicates, most of the increase in the spread happens in the second half of 2018, when the Fed will have increased its monthly portfolio reduction to $50 billion.

Table 2: The June 2017 Plan of the Federal Reserve's Balance Sheet Reduction

Month	Change in Treasury Debt	Change in Agency Debt and MBS	Total Change in Portfolio	Cumulative Change in Portfolio	Reserves Remaining
Oct-17	–6	–4	–10	–10	2,242
Nov-17	–6	–4	–10	–20	2,232
Dec-17	–6	–4	–10	–30	2,222
Jan-18	–12	–8	–20	–50	2,202
Feb-18	–12	–8	–20	–70	2,182
Mar-18	–12	–8	–20	–90	2,162
Apr-18	–18	–12	–30	–120	2,132
May–18	–18	–12	–30	–150	2,102
Jun-18	–18	–12	–30	–180	2,072
Jul-18	–24	–16	–40	–220	2,032
Aug-18	–24	–16	–40	–260	1,992
Sep-18	–24	–16	–40	–300	1,952
Oct-18	–30	–20	–50	–350	1,902
Nov-18	–30	–20	–50	–400	1,852
Dec-18	–30	–20	–50	–450	1,802
Jan-19	–30	–20	–50	–500	1,752

Note: All numbers in $ billions. Reserves remaining are computed under the assumption that the reduction in securities holdings is related one-to-one to a reduction in reserves. Initial reserves in September 2017 are $2,252 billion. More details are available online at https://www.federalreserve.gov/newsevents/pressreleases/monetary20170614c.htm.

4.2 Nonlinear Effects

As illustrated in Figure 1, the liquidity effect—the effect of a change in reserves on money market rates—may depend on the level of reserves. Similarly, it could depend on the level of the federal funds target range. Moving forward in the current tightening cycle, it is important to understand potential nonlinear effects that depend on changes in these two policy parameters.

In Table 3, columns (1) and (2), I examine whether the effect of a change in reserves depends on the overnight repo rate or on the level of the federal funds target rate, defined as the midpoint of the target range. For this purpose, I include an interaction term between the TGA change and the level of the federal funds target rate. (During my sample period, there were four upward revisions of the target range.) As expected, given that daily changes in the TGA balance are unrelated to monetary policy, column (1) shows that the coefficient estimate of the change in the TGA balance is robust to the inclusion of the federal funds target rate (compare the similar point estimate in Table 1, column 4). Column (2) shows that the effect of a change in the TGA balance does not depend on the level of the federal funds target. Therefore, I conclude that the liquidity effect does not significantly depend on the level of interest rates.

Next I look at potential nonlinear effects that depend on the total amount of reserves outstanding. Intuitively, removing $100 billion of reserves should have a stronger effect when the total reserves supply is $1 trillion compared with $2 trillion. During my baseline sample, the Fed's supply of reserves was relatively stable. Therefore, to identify a nonlinear liquidity effect that depends on the level of reserves, I use earlier data from January 1, 2011, through October 31, 2014, a period when the total supply of reserves varied substantially between $1 trillion and $2.8 trillion due to the Fed's large-scale asset purchases (QE).[12]

Table 3, column (3), shows that the average effect of an increase in the TGA balance is greater for the federal funds rate and the overnight repo rate during this period when

[12]For this longer period, I do not have daily data on the RRP volumes. However, RRP volumes were small during this period, and my previous results indicate that omitting the RRP variable does not introduce a large bias in the TGA coefficient (if anything it would introduce a slight downward bias into the estimates). Data on the total supply of reserves are available at only a weekly frequency. In the daily regressions, for each day, I use the most recent available information.

Table 3: Nonlinear Liquidity Effect

Dependent Variable:	Δ Repo Spread (bps)			
	Baseline Sample		QE Sample	
	(1)	(2)	(3)	(4)
Δ TGA Balance ($ bn)	0.0205***	0.0214**	0.0333***	0.0355***
	(3.0506)	(2.0692)	(7.8105)	(8.2682)
Δ TGA Balance * FF Target Rate (%)		–0.0031		
		(–0.1062)		
FF Target Rate (%)	–0.0761	–0.0752		
	(–0.1378)	(–0.1361)		
Δ TGA Total * Reserves ($ tr)				–0.0282***
				(–3.5102)
Reserves ($ tr)			0.0418	0.0436
			(0.2541)	(0.2668)
Constant	0.0417	0.0413	0.0008	0.0053
	(0.2023)	(0.2000)	(0.0095)	(0.0654)
RRP Control?	Yes	Yes	No	No
Seasonality Controlled?	Yes	Yes	Yes	Yes
Observations	900	900	1,000	1,000
R-squared	0.0232	0.0232	0.0578	0.0693

Note: The dependent variable is the daily change in the spread of the overnight repo rate over the lower bound of the federal funds rate target range. The target rate is defined as the midpoint of the target range. A positive value of Δ TGA Balance corresponds to a drain in reserves. The Baseline Sample in columns (1) and (2) covers daily data from September 24, 2013, through June 30, 2017, while the QE Sample in columns (3) and (4) covers daily data from January 11, 2011, through October 31, 2014. *t*-statistics are shown in parentheses. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent level, respectively.

the average amount of reserves was $1.9 trillion (as compared to an average of $2.5 trillion during the baseline sample). This is consistent with the assertion that the liquidity effect is greater when reserves are relatively more scarce. In column (4), I estimate this nonlinear effect directly using an interaction term. The coefficient on the interaction term is identified based on the in-sample variation of reserves. I find that a drain in reserves by $100 billion increases the overnight repo spread by an additional 2.8 basis points when the total supply of reserves is $1 trillion smaller. In other words, draining $100 billion when reserve balances are at $1 trillion will have a greater effect on money markets compared with draining $100 billion when reserve balances are at $2 trillion. This suggests that the liquidity effect will grow as the Fed balance sheet shrinks.

4.3 Effect on RRP Facility

The RRP facility acts as a market-initiated buffer for an excess or shortage of liquidity in the market; when the market experiences a shortage of reserves relative to demand, and there is an associated increase in money market rates, market participants may reduce their RRP balance, provide the funds to the market, and thereby dampen the effect of a policy-induced drain in reserves.[13] On the other hand, when a lot of reserves are available relative to demand, volumes in the RRP facility may increase. In Table 4, I provide direct evidence for this mechanism by showing that after a drain in reserves, identified by an increase in the TGA balance, both the RRP volume and the number of counterparties depositing in the RRP decrease. My estimates indicate that a $100 billion drain in reserves decreases the RRP volume by $16 billion (column 1) and reduces the number of counterparties (bids) depositing in the RRP by 3.4 (column 2).

Table 4: Liquidity Effect and Recourse to RRP Facility

Dependent Variable:	Δ RRP Balance ($ bn)	Δ RRP Bids (#)
	(1)	(2)
Δ TGA Balance ($ bn)	–0.1635***	–0.0344***
	(–4.3529)	(–2.8077)
Constant	6.7814***	2.0046***
	(4.0677)	(3.6820)
Seasonality Controlled?	Yes	Yes
Observations	900	900
R-squared	0.6320	0.6171

Note: The dependent variable is the daily change in the volume deposited in the RRP facility (column 1) or the daily change in the number of counterparties that use the RRP facility (column 2). The sample covers daily data from September 24, 2013, through June 30, 2017. *t*-statistics are shown in parentheses. ***, **, and * indicate significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

These results are robust to controlling for well-known seasonality in the RRP balance (for example, Anderson and Huther 2016) by including dummy variables for the last day of a quarter, the first day of a quarter, the last day of a month, the first day of a month, and for each day of the week. For example, it is possible that the schedule for payments from the

[13] In 2017:Q2, the average daily RRP balance was $167 billion.

TGA on quarter ends coincides with movements in the RRP balance for unrelated reasons (for example, a reduction in European banks' borrowing in the repo market at the end of the quarter that leads to an increase in deposits into the RRP by repo cash providers). The results are robust to using a broader set of seasonal controls.

5 Conclusion

My finding that a reduction in the supply of reserve balances is likely to have an economically relevant effect on money market rates has several implications for policy.

First, assuming that the balance sheet reduction is on autopilot as outlined in the June 2017 plan, the associated reduction in reserves is a built-in factor that puts upward pressure on short-term interest rates. Indeed, the balance sheet reduction and the short-term policy rate target range both affect short-term rates, potentially conflicting or reinforcing each other. Policymakers should be aware of these forces when deciding on a desired path for short-term interest rates (for both the level of rates and the timing of rate changes). In particular, my projections suggest that the upward pressure of the liquidity effect on money market rates will become stronger as the Fed increases its monthly portfolio reduction and as the balance sheet is reduced from the current level.

Second, current forecasts about the future path of the short-term rate should be re-evaluated if they do not contain the liquidity effect resulting from the balance sheet reduction and may need revision. Communicating a possible liquidity effect associated with the balance sheet reduction may be important for a continued smooth and gradual removal of policy accommodation during this tightening cycle. Neglecting the liquidity effect on forecasts about future short-term rates may also affect long-term rates through the expectations hypothesis.

Third, my estimates of the liquidity effect are based on historical data and are subject to the usual limitations. Market-based signals may provide an effective real-time indicator of the strength of the liquidity effect. Specifically, a way to identify in real time the extent to which the balance sheet reduction is putting upward pressure on short-term rates is to monitor the movements of short-term rates relative to the lower bound of the fed funds

target range in combination with market participants' recourse to the RRP facility. Indeed, a declining volume in the RRP facility may initially dampen the effect of a shrinkage in reserves on short-term rates. However, a consistent reduction in RRP volumes may indicate that market demand for liquidity increases and the liquidity effect is stronger.

Finally, a more general question related to the monetary policy implementation framework is how much of a shrinkage of the balance sheet and associated reduction in reserves can be achieved without pushing the effective federal funds rate above the IOER rate. For this situation to unfold, reserve balances would need to decline substantially. In that case, the target range would need to be widened or the operational framework could revert back to a situation where the federal funds rate is steered through active management of reserves using open market operations.

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