September 13, 2019

Summary of Analytical Results for the September Report on Reserve Conditions

This memo summarizes staff analyses that informed the Report on Reserve Condition prepared for the September FOMC meeting. Staff conducted these analyses to help support the FOMC's assessment of factors influencing money market rates as reserves decline to lower levels.

Sections I and II of this memo assess the relationship between reserves and the federal funds rate. Through a variety of econometric techniques, staff analyses suggest that a negative relationship between reserves and the federal funds rate exists. This relationship currently implies only small changes in the federal funds rate, although the sensitivity of the rate to reserves is stronger at lower levels of reserves. As such, these results do not suggest that reserves are currently close to the "steep" part of the reserve demand curve. Looking ahead, staff analysis suggests that the expected declines in reserves through year-end could put some upward pressure on the federal funds rate, but that the rate is unlikely to rise above the top of the target range unless the relationship between reserves and rates steepens further.

Section III of this memo shifts to factors that influence the spread between repo rates and IOER. Staff analysis suggests that net issuance of Treasury securities and dealer inventories have both long-term and short-term effects on repo rates. The projected trajectory of Treasury issuance over the remainder of 2019 is forecasted to increase the equilibrium level of GC repo rates by about 1 basis point, with temporary spikes on the order of 6 to 12 basis points, if dealer inventories remain constant. Should dealer inventories rise, these effects could be larger. A range of models suggest that the movement in repo rates passes through to federal funds rates, though the degree is considerably less than one-for-one when spreads of repo rates to IOER are modest.

I. The Recent Relationship between Reserves and the Federal Funds Rate[1]

In March 2018, money market dynamics appeared to change significantly amid declining reserves and a large run up in Treasury bill issuance. To measure the sensitivity of the federal funds rate to the level of reserves from April 2018, we estimate the slope of the demand curve using the simple equation given below:[2]

$$(FFR_t - IOER_t) = \alpha + \beta(Reserves_t) + \varepsilon_t \qquad (1)$$

We consider the spread of the federal funds rate to IOER to account for effects of changes in the policy range as well as the effects of the three technical adjustments to IOER in our sample period. Since reserves and the overnight rate follow nonstationary processes during this period, we estimate the above equation in differences. We also drop month-end days from the sample to exclude the effects of reporting days when many borrowers scale down their positions to meet regulatory or internal targets.

In our baseline regressions, we currently estimate that a one-day decline of $100 billion in reserves may exert less than 1 basis point of upward pressure on the federal funds rate. For a $100 billion decline in reserves over the course of a week, the estimated weekly change in the rate is about 1.5 basis points. Over the last few months, the uncertainty around the estimated slope parameter increased amid less pronounced declines in reserves.

Theoretical models that characterize the relationship between overnight interest rates and the level of aggregate reserve balances generally predict that, as reserve levels decline, the responsiveness of rates to changes in the supply of reserves increases; that is,

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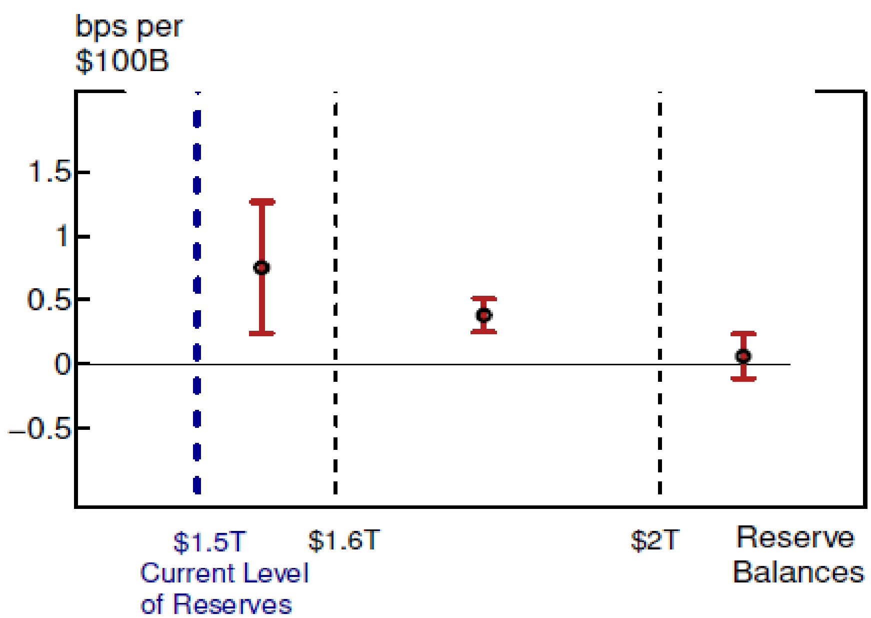
[1] Alyssa Anderson, Chris Gust, and Zeynep Senyuz. We thank James Clouse, Sam Schulhofer-Wohl and Patricia Zobel for helpful comments. Arazi Lubis provided excellent research assistance.

[2] The rate used in the empirical staff models described in this memo is the volume-weighted average federal funds (VWA FF) rate, and not the Effective Federal Funds Rate (EFFR), which is the volume-weighted median. VWA FF has more variation than the EFFR as the average captures all movements in the distribution. Results are qualitatively similar, albeit more uncertain, when the EFFR is used instead of the VWA FF rate. The correlation of 5-day changes between the EFFR and VWA FF rate is about 0.85 over our sample period. The correlation between the two series approaches 1 when changes are calculated over longer windows.

the demand curve for reserves steepens. To identify points at which the demand curve becomes steeper as reserves decline, we estimated a threshold regression, which allows for the slope of the reserve demand curve to vary with different levels of reserves. We estimated a model with two thresholds, which allows for three regions of the reserve demand curve with different slopes. The model is estimated in differences with the threshold variable specified as the level of reserves.

Figure 1 plots the point estimates for the slope coefficient and the 95% confidence bands at different reserve levels using the thresholds determined by the model. The model identifies two thresholds at reserve levels of $2 trillion and $1.6 trillion. We find evidence of a non-zero slope for reserve levels below $2 trillion. The rate shows slight sensitivity to changes in reserves for reserve levels between $1.6 and $2 trillion, and somewhat greater sensitivity when reserves fall below $1.6 trillion.

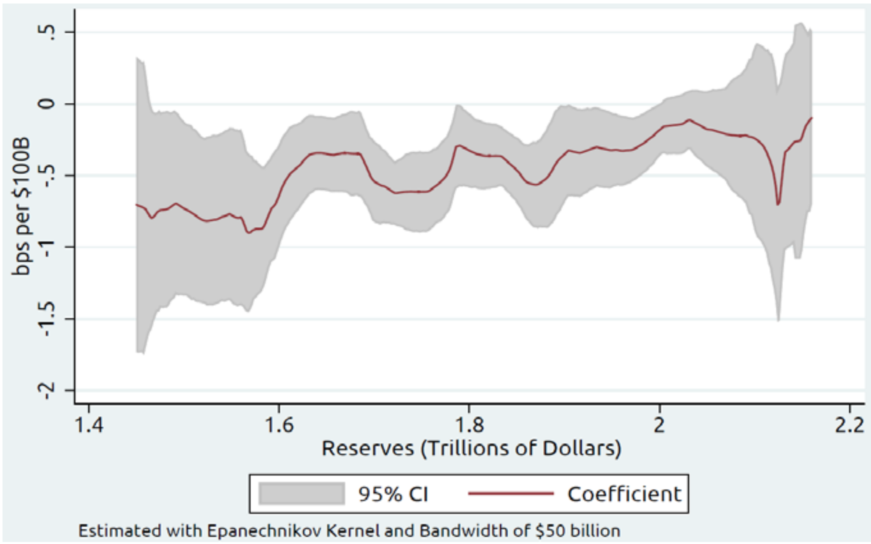
Figure 1: Sensitivity of the Federal Funds Rate to the Level of Reserves



Note: Black dashed lines show estimated thresholds from the model. Red bars show the 95% confidence bands around the point estimates.

We also estimated a nonparametric local linear regression where the relationship between the rate and reserves does not take a predetermined form. Effectively, this method estimates the slope of the relationship separately at each level of reserves where observations with similar levels of reserves carry more weight in the estimation procedure. Figure 2 plots the slope estimate from this regression over different levels of reserves. The slope becomes negative and statistically significant for reserve levels below $2 trillion. The increased magnitude of the coefficient as well as the increased uncertainty around the estimate for reserve levels below $1.6 trillion are consistent with the findings of the threshold regression described above.

Figure 2: Estimate of the Slope from a Local Linear Regression



Multivariate Analysis of Reserves and Money Market Rates

Reserves are not the only factor influencing the federal funds rate. Higher repo rates during our sample period also appear to have put upward pressure on the federal funds rate at times, as market participants can arbitrage between the two markets. To fully characterize rate-reserves dynamics, we expand our analysis to jointly model overnight unsecured and secured rates and reserves using a trivariate vector autoregression (VAR) model specified as follows:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \varepsilon_t, \qquad E\varepsilon_t \varepsilon'_t = V \tag{2}$$

where $y_t = \left(Reserves_t, r_{u,t} - IOER_t, r_{s,t} - IOER_t\right)'$ and ε_t is a vector of disturbances assumed to be uncorrelated with all variables at $t-1$ or earlier. We use the volume-weighted average federal funds rate for the unsecured rate ($r_{u,t}$) and the SOFR repo rate for the secured rate ($r_{s,t}$).[3] Consistent with the univariate analysis, we consider spreads instead of rates to control for the changing stance of monetary policy, as well as the effects of technical adjustments to the IOER over the sample period. In addition to excluding month-ends, we also exclude the days after month-ends since it typically takes longer for repo rates to readjust after reporting days.[4] We also include reserves as a dependent variable so that both rates and reserves are treated endogenously and movements in rates are allowed to affect not only the demand for reserves but also the supply. In particular, some factors that affect the supply of reserves, such as the foreign RP pool, ON RRP, and GSE balances, are rate-dependent.

We found two lags to be sufficient to capture the auto- and cross-correlation dynamics among the three variables.[5] While auto-correlation has been strong for both spreads and reserves, cross-correlations of the two spreads have been much weaker and generally statistically insignificant.

We use the VAR to assess the risk that the federal funds rate rises above its target range later this year. Before doing so, it is useful to examine the model's dynamic responses by examining the effects of an unanticipated increase in the supply of reserves. Because the estimated disturbances are correlated with each other, we need to impose additional assumptions to identify such a shock. In particular, we assume that a reserve supply shock is the only shock that changes the supply of reserves within a day. Figure 3 plots the impulse response functions of each dependent variable to a shock that increases reserves by $100 billion on impact. This shock has a highly persistent effect on reserves though not a permanent effect, reflecting that the joint dynamics of reserves with secured

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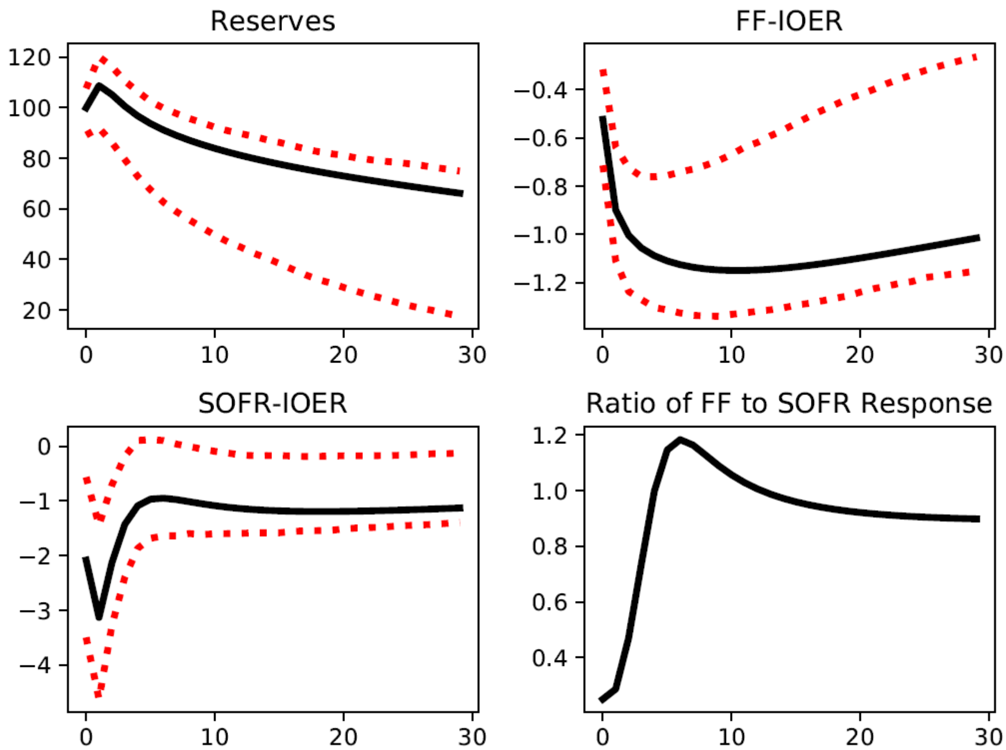
[3] Using EFFR for the unsecured rate does not yield much significance since EFFR has less variation. Alternative proxies for the secured rate, including TGCR and the primary dealer survey rate, yield very similar results.

[4] We have also tried including all dates and adding dummy variables for the day of and day after month-ends, which gives very similar results.

[5] Since we drop the day of and day after each month-end, the model uses the last available value as the lagged value. For example, the first lag for the second day after month-end would be the day before month-end.

and unsecured rates are estimated to be stationary over our sample period. When the supply of reserves increases, the federal funds rate decreases about 0.5 basis points initially, and then drifts lower to about 1 basis point 30 business days after the initial shock. These effects are largely consistent with the univariate results discussed above. The SOFR, on the other hand, has a larger initial drop of about 2 to 3 basis points, which partially retraces over time. As a result, the reserves supply shock has a similar effect after 30 days on secured and unsecured rates, as shown by the ratio of their responses in the bottom right panel.

Figure 3: Impulse Response Functions to a Shock to Reserves



With the VAR implying a similar relationship between reserves and the federal funds rate in response to supply shocks as the univariate analysis, we now turn to using the VAR to provide a probabilistic assessment of how the federal funds rate might respond to developments over the rest of the year. To do so, we condition our analysis on the Board staff's projections for reserves by using the mean estimates of the VAR to back out paths for the shocks, ε_t, that reproduce the staff's projected path of reserves. Figure 4 shows the staff projections for reserves and the mean path of the federal funds spread associated with these shocks. Conditional on the staff's path of reserve projections, the federal funds rate is expected to be about 5 or 6 basis points higher than IOER next quarter. According to the VAR, this upward pressure on the federal funds rate reflects shocks emanating not only from changes in the supply of reserves but also from demand as well as from repo markets.

Figure 4 shows the 90 percent confidence band around these projections constructed using the VAR. This confidence band takes into account the uncertainty surrounding the staff's reserves projection stemming from future shocks as well as the VAR model coefficients. The 90 percent confidence band ranges from about 3 basis points to 10 basis points over much of next quarter. Accordingly, the VAR predicts less than a 10 percent chance that the federal funds rate will rise more than 10 basis points above IOER on most dates through year-end.

Figure 4: Projections for Reserves and the Federal Funds Spread

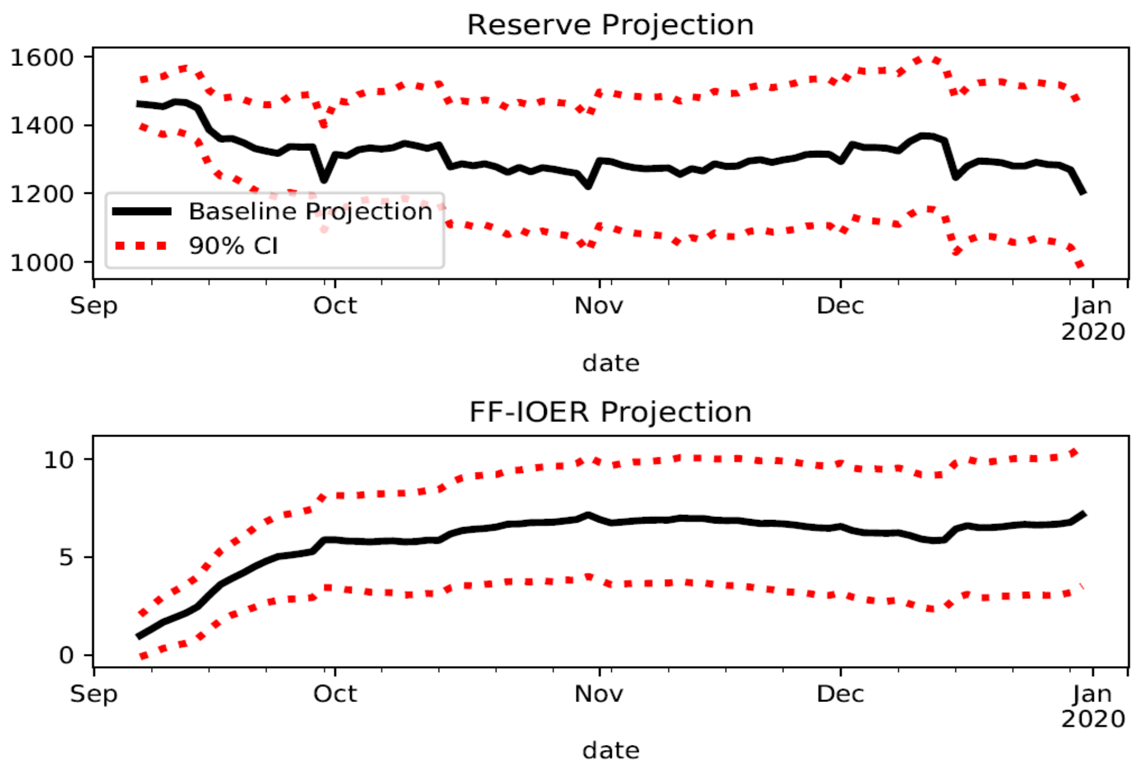
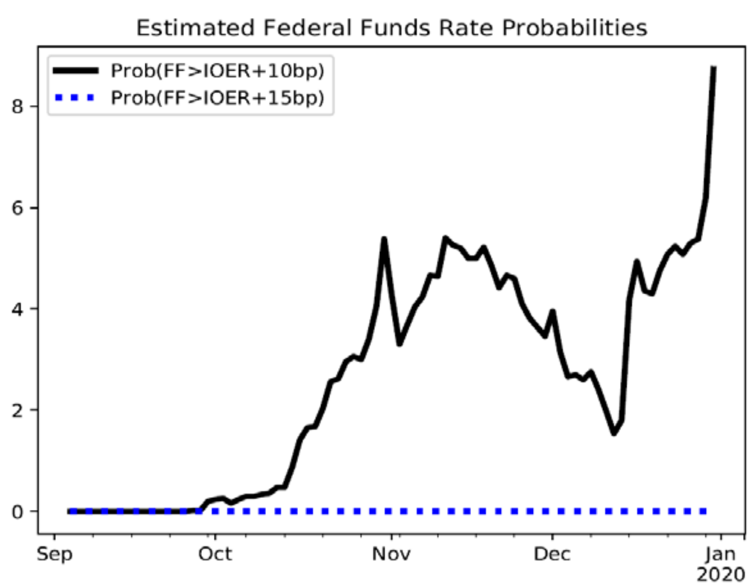


Figure 5 focuses more directly on the model's probabilities for high values of the federal funds rate. Conditional on the staff's reserve projections, the probability that the federal funds rate rises more than 10 basis points above IOER reaches about 8 percent by the end of December. In contrast, the probability of the federal funds rate rising above the target range (that is, more than 15 basis points above IOER) remains near zero throughout this period. The very low probability of leaving the target range reflects that the staff's projected path for reserves along with the VAR's estimated relationships between reserves, the repo rate, and the federal funds rate imply only modest upward pressure on the federal funds rate over the projection period. Moreover, while the uncertainty around projections for reserves and repo rates is sizeable, the low estimated sensitivity of the federal funds rate to reserves and the repo rate translates into predicted distributions for the federal funds rate that lie almost entirely below the upper bound of the target range.

An important caveat to this result, however, is that these relationships are estimated based on data over the last year and a half, and the relationships could change as reserves continue to decline.

Figure 5: Probabilities of the Federal Funds Rate Rising over Time



Although we restrict our baseline specification to include just the endogenous variables for simplicity, we also have experimented with alternative specifications including several Treasury issuance variables, such as net Treasury bill issuance, rolling cumulative bill issuance, and gross coupon issuance. These variables tend to have quite large effects on repo rates (4 to 5 basis point increase per $100 billion increase in Treasury issuance) initially, but small effects on federal funds rates (less than half a basis point per $100 billion in issuance). Given the limited pass-through from Treasury supply and repo to federal funds rates, we exclude these variables from our baseline specification.

II. The Longer Term Relationship between the Level of Reserves and the Federal Funds Rate[6]

Staff also studied the relationship between the level of the federal funds (FF) rates and reserves from 2010 to 2019, and used that relationship to generate forecasts of federal funds rates up to three months out to calculate a probability that the rate exceeds the top of the target range.

We find a negative relationship between federal funds rates and reserves -- both in levels and changes -- that varies over time following the evolution of the level of reserves in the system. The relationship is stronger in 2010-2012 and 2018-2019, when reserves are below $2 trillion, whereas it is practically insignificant between 2014 and 2016 as reserves exceed $2.5 trillion. In terms of magnitudes, a daily decrease of $100 billion in reserves implies an increase in the value-weighted average FF spread to IOER rate of about 1-3 bp in 2010 with reserves at around $1 trillion, and of 0.4-0.7 bp in 2019 with reserves levels at around $1.5 trillion. These effects are persistent and we find a similar relationship when we study weekly changes or levels.

We also forecast the distribution of federal funds rates at different horizons. Conditional on the level of reserves falling below $1.3 trillion by early November, the probability that the (volume-weighted average) federal funds rate exceeds the top of the target range by early November is 6 percent

For robustness, we look at the relationship between the volume-weighted median FF rate -- the current effective FF rate -- and reserves: Results remain qualitatively similar, although more uncertain.

As a caveat to this analysis, we do not take into account that the size of the banking system, and the economy has expanded. Doing so could have an effect on the estimated relationship between reserves and spreads.

[6] Gara Afonso, Domenico Giannone, and Gabriele La Spada. We thank Patricia Zobel for helpful comments.

The Relationship between Federal Funds Rates and Reserves

Our baseline specification of the relationship between fed funds rates and reserves is:

$$\Delta(Fed\ Funds\ Rate - IOER)_t = \alpha + \beta \Delta Reserves_t + \varepsilon_t$$

We choose a specification in changes to control for time trends, and take the spread between a measure of fed funds rates and the IOER to control for monetary policy. We use the volume-weighted average fed funds rate (VWA FF) as our baseline rate because it provides more variation than the volume-weighted median (VWM FF), allowing us to better capture the relationship between rates and reserves.[7,8] Importantly, we exclude observations in the 1-day window around month-ends as some banks reduce their short-term liabilities around end-of-month, which affects both the spread and the level of reserves.

Figure 1 presents the coefficients of the ordinary least squares (OLS) estimates of our baseline specification at daily (panel (a)) and weekly (panel (b)) frequency.[9] It shows a negative relationship between changes in the spread and in reserves that depends on the level of reserves and displays an inverted smile pattern: The relationship is significant in 2010-2012 and 2018-2019, whereas it is insignificant between 2014 and 2016. A $100 billion daily decrease in reserves implies a contemporaneous increase in the spread of about 2 bp in 2010, where reserves were around $1 trillion, and 0.7 bp in 2019 with reserves levels at around $1.5 trillion (panel (a)). The relationship becomes stronger in 2018-2019 at weekly frequency, and the effect of a similar decrease in reserves on the spread is slightly over 1 bp (panel (b)).

Other variables may put upward pressure on fed funds rates and comove with the level of reserves, affecting our estimates. We address this concern by controlling for money market variables and by using an instrumental variable (IV) approach. Qualitatively, the results are similar and the inverted smile (negative) relationship between rates and reserves over time persists.

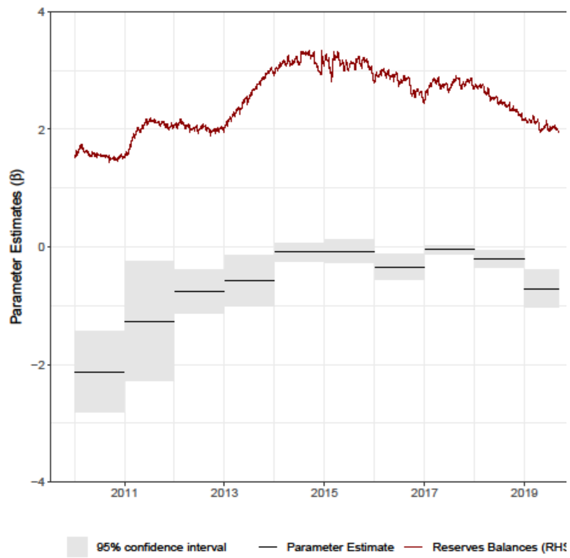
[7] During the time period covered in our analysis, the calculation of the effective fed funds rate changed from a volume-weighted average to a volume-weighted median.

[8] Detailed results of the different analyses discussed in this note as well as additional robustness analysis (not shown) are available upon request.

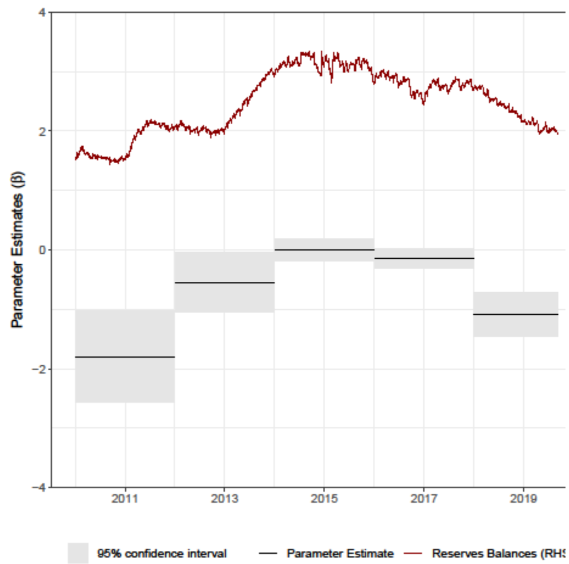
[9] Coefficients are estimated for each calendar year in the daily analysis and bi-yearly in the weekly analysis.

Figure 1: **Ordinary least squares estimates.** Parameter estimates and confidence bands of the relationship between daily (a) and weekly (b) changes in volume-weighted average fed funds spread to IOER rate and changes in reserves (left axis) and the evolution of reserves balances (right axis) from 2010-2019. Excludes a 1-day window around each end-of-month.

(a) Daily changes



(b) Weekly changes



Forecasts

We use a time-varying vector autoregressive model with stochastic volatility (TV-VAR) to construct the joint predictive distribution of reserves and spread to predict the joint evolution of reserves and spread. We model the level of these two variables at weekly frequency for the same sample used in the OLS analysis. [10] This is a flexible model that accommodates general patterns of dynamic dependence among the two variables, both in levels and changes, and variation of these relationships over time.[11] This modeling approach is convenient since it allows us to study relationships both in levels and differences, and provides an internally consistent framework to coherently

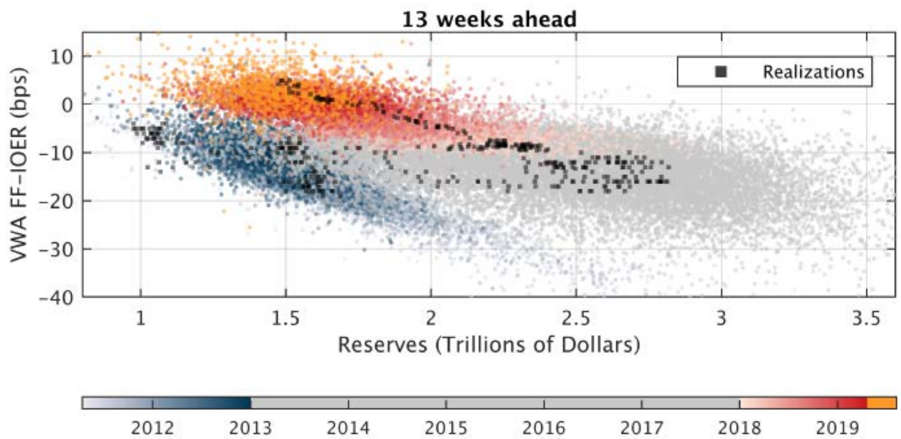
[10] We use the same parameterization and prior specification of Primiceri (2005) and Del Negro and Primiceri (2015).

[11] We conducted a simulated pseudo out-of-sample forecasting exercise to evaluate the predictive accuracy of the model in real time. The model performs well indicating that the framework is able to capture in a parsimonious way the salient features of a changing economic environment.

predict the joint evolution of spread and reserves, accounting for all sources of uncertainty, including structural changes.

Figure 2 presents the real-time 13 week-ahead forecasts of the spread between the VWA FF rate and the IOER rate.[12] Blue dots correspond to the pre-2013 period; red dots indicate post-2018 forecasts. The chart shows that the relationship between rates and reserves changes over time and is consistent with OLS findings. In the more recent period 2018-2019, the relationship that has become steeper than in 2013-2017. The relationship is almost as steep as in 2011-2012; the main difference being that it has shifted upward.

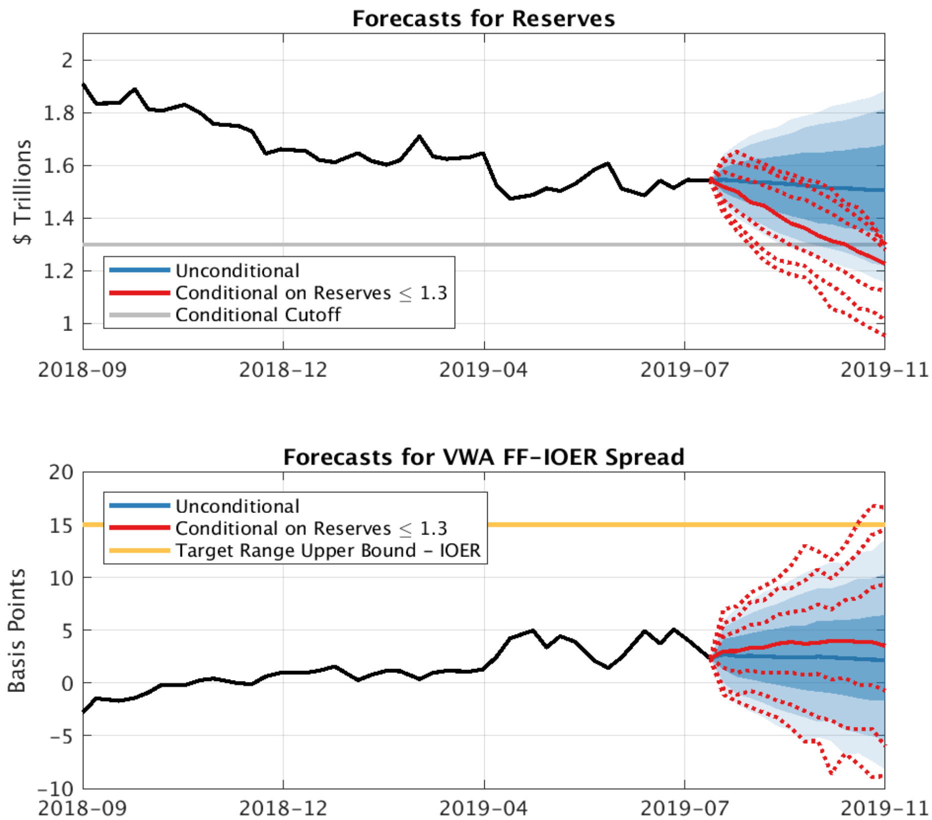
Figure 2: **13 week-ahead out-of-sample TV-VAR forecasts from 2011 to 2019.** Unconditional forecasts 13 weeks ahead (early November). The model is estimated from January 5, 2010 onwards. Out-of-sample forecasts are generated recursively each week starting from April 19, 2011 to August 6, 2019. 100 draws are plotted for each week. Colors display groupings by time period. Black solid dots correspond to the realized observations.



The model also allows us to forecast the spread to the IOER rate conditional on different levels of reserves and to address the question of how likely it would be for the fed funds rate to exceed the top of the target range. Figure 3 reports selected quantiles of the predictive density for spreads, based on both an unconditional path for reserves, using model dynamics and historical data, and conditioned on the level of reserves being at or below $1.3 trillion in early November.

[12] All forecasts presented in this note are based on the time-varying vector autoregressive model and should not be confused with the forecasts produced by the NY Markets Group.

Figure 3: **2019 TV-VAR Marginal Predictive Distribution: Unconditional vs. Conditional**. Marginal predictive distributions for the VWA FF-IOER spread (basis points). 68%, 90% and 95% bands are shown for both the unconditional distribution (blue) and conditional distribution (red), conditioning on the level of reserves being at or below $1.3 trillion in November 2019 (i.e., 13 weeks ahead). The model is estimated from January 5, 2010 to August 6, 2019.



By early November, the median unconditional forecast for the spread to IOER is slightly over 2 bp while the median conditional forecast is 3.5 bp under the assumption that reserves will fall below $1.3 trillion by that time. Table 1 shows that the unconditional probability that the spread to the IOER rate is larger than 15 basis points, exceeding the top of the target range, is close to 4% and that the conditional probability ranges between 5% and 7.5% assuming that reserves drop below $1.4, $1.3 and $1.2 trillion by early November.

Table 1: Probability that the VWA fed funds rate exceeds the top of the target range

Unconditional	Conditional on different levels of reserves		
	Reserves < $1.4tr	Reserves < $1.3tr	Reserves < $1.2tr
3.7%	5.3%	6.1%	7.5%

III. A Model of Stock and Flow Effects of Issuance on General Collateral (GC) Repo Rates[13]

Given the possibility that increased repo rates could pass-through to the federal funds rate, staff studied the effect that expected Treasury issuance might have on the GC repo rate. We estimated an error-correction model that separates rate dynamics into two relationships: one that captures the impact of changes in the outstanding stock of Treasury securities over the long run, and one that captures the impact of net Treasury issuance flow over the short run. The long-run relationship is represented by a cointegrating equation specified in levels; the short-run relationship is represented by a dynamic equation specified in daily changes. The two equation are linked by an error-correction term in the short-run equation, which describes the tendency of the system to return to the equilibrium defined by the long-run equation after short-term deviations.

We used the primary dealer survey rate as the measure of the GC repo rate. Explanatory variables in the long-run equation included the levels of the following variables: the IOER rate, the amounts outstanding of Treasury bills and Treasury coupon securities, the aggregate assets under management of government money market funds, and the aggregate level of net Treasury positions held by primary dealers. Explanatory variables in the short-run equation included daily changes in these same variables, as well as interaction terms between the level of net dealer positions and two sets of variables: daily changes in the Treasury amount outstanding variables (that is, daily net issuance) and calendar dummies for the start and end of each month. These interaction terms allow the impacts of net issuance and month-end on repo rates to vary with the level of net dealer positions; for example, higher dealer inventories could be associated with larger short-term increases in the GC repo rate for a given amount of net Treasury issuance. The equations do not explicitly incorporate any direct impact that changes in the quantity of reserves might have on repo rate dynamics.

The model was estimated using data from December 2008 to August 2019, excluding data from the last day of 2018 – when there were anomalously large swings in

[13] Tony Baer, Federal Reserve Bank of New York

repo rates due to period-end reporting – but keeping other month-end dates. In the long-run equation, the level of Treasury bills outstanding has a positive and statistically significant effect on level of the GC repo rate. In the short-run model, net issuance of either bills or non-bill Treasury securities is associated with statistically significant temporary increases in the repo rate. The coefficient on the error correction term in the short-term model suggests that when the rate deviates from equilibrium (for example, in response to net issuance), it decays back to equilibrium with a half-life of about 5 business days.

We used the model to predict the impact of Treasury issuance over the rest of the year, using FRBNY projections for Treasury issuance. Results of this simulation suggest that the equilibrium level of GC repo rates will rise about 1 basis point as a result of Treasury issuance over the rest of the year. The model also predicts that there could be short-term spikes in the repo rate above the equilibrium level of about 6 basis points on non-month-end dates and 12 basis points on month-end dates (Figure 1).[14] These predictions assume that other explanatory variables in the model remain constant, including the aggregate level of net Treasury positions held by primary dealers. If, instead, net dealer positions were to increase, GC repo rate predictions would be higher, and the temporary impacts of both net issuance and month-end calendar effects would be larger. It is also important to note that recent GC repo rate outcomes have been higher than predicted by the model, especially on month-end dates (Figure 2).

[14] Coupon settlements occur on mid-month and end-of-month dates.

Figure 1: Predicted Changes in GC Repo Resulting From Net Issuance and Month-End Effects

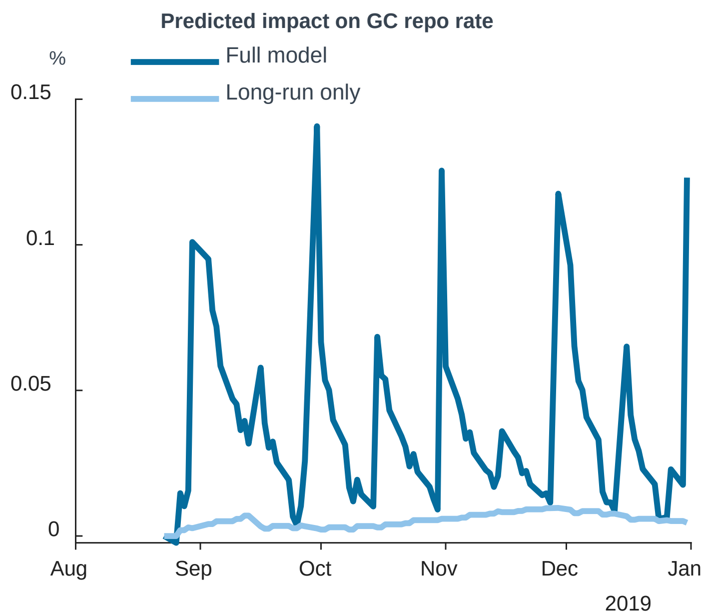


Figure 2: Differences between Actual GC Repo Rates and Model Predictions Since 2018