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Abstract

For the second time in the brief 12-year period between 2008 and 2020, central banks have once again turned to asset purchase programs to combat a global economic downturn. While balance sheet expansions have become familiar, balance sheet normalization has proven more elusive. Nevertheless, an understanding of the consequences of unwinding asset purchases is necessary for well-informed decisions over the deployment of these unconventional policy tools. This paper provides a first analysis of the financial market effects of balance sheet normalization based on the U.S. experience between 2017 and 2019. We find evidence that balance sheet normalization tightens financial conditions. Importantly, we show these effects cannot be merely characterized as Quantitative Easing in reverse. In particular, we find that balance sheet normalization was associated with larger liquidity effects than were evident during various phases of balance sheet expansion.

JEL Classification: E3, E4, E5

Keywords: Monetary Policy, Balance Sheet, Liquidity Effect, Structural VAR, Financial Conditions

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1 Introduction

Central bank balance sheets now play a prominent role in monetary policy. The COVID-19 pandemic serves as a case in point. In March of 2020 the Federal Open Market Committee (FOMC) cut the federal funds rate to near zero and initiated Treasury and agency mortgage-backed securities (MBS) purchases at a rapid pace as the coronavirus spread across the globe. Other central banks carried out similar actions including the European Central Bank, the Bank of England, and the Bank of Japan. While exiting from these accommodative policies may be a distant thought at this time, central bankers have signaled an intent to eventually reduce their balance sheets (see Bailey, 2020; Powell, 2020). Thus, knowledge of the effects of unwinding the central bank’s balance sheet is essential for informed decisions regarding the provision and withdrawal of policy accommodation via the central bank’s balance sheet.

Despite its importance, there is scant empirical analysis of the financial market effects of unwinding the central bank’s balance sheet. However, such independent investigations may be unnecessary if the process of balance sheet reduction, typically dubbed Quantitative Tightening (QT), simply works as quantitative easing (QE) in reverse. For instance, based on the state-of-the-art estimates that Swanson (2020) provides, if the measured effects of expanding the Federal Reserve’s balance sheet were symmetric—an implicit assumption inherent in the linear estimates employed by much of the QE literature—then we could assume that the unwinding of the Federal Reserve’s balance sheet has no effect on overnight interest rates but leads to increases in longer-term bond yields and prompts an appreciation in the foreign-exchange value of the US Dollar, thereby tightening U.S. financial conditions.

We, however, present evidence of strong asymmetries between balance sheet expansions and unwinds based on the Federal Reserve’s 2017-2019 experience with balance sheet reduction. A core source of these asymmetries originates in the market for bank reserves, as is evident by visible changes in the magnitude of the liquidity effect across balance sheet expansion and normalization. Figure 1 superimposes reserve balances on top of a simple estimate of the liquidity effect from a rolling-window regression of the federal funds rate (less the interest rate paid on reserves) on a constant and the log of reserve balances. Liquidity effects appeared relatively muted during the balance sheet expansion for a number of reasons, including the natural lower bound that zero placed under short-term interest rates despite rapid growth in reserves. However, from 2017 through 2019, a period during which bank reserves declined from more than $2.0 trillion towards $1.4 trillion amid reductions in Federal Reserve’s asset holdings, the magnitude of the liquidity effect roughly doubles.
In addition to the differences in the magnitude of the liquidity effect that we document, numerous other differences existed between the Federal Reserve’s balance sheet expansion and unwind. Most prominently, balance sheet normalization was void of the large announcement effects that accompanied asset purchases. Relatedly, balance sheet reduction ensued at a materially slower rate than balance sheet expansion since assets were not actually sold but rather allowed to mature without replacement. And the backdrop against which normalization took place differed materially from balance sheet expansion. Balance sheet normalization was conducted during a period of relative calm, whereas the Federal Reserve’s asset purchases were carried out amid severe economic and financial strain. And, unlike much of the QE era where central banks were easing in unison, balance sheet normalization was carried out in isolation in the U.S., while other major central banks were maintaining or expanding the size of their balance sheets (Dilts-Stedman, 2019).

In light of the markedly different nature of the Federal Reserve’s balance sheet normalization, this paper aims to provide a first quantitative assessment of the financial market effects of balance sheet normalization. Given the absence of discreet announcements, we employ a novel structural vector autoregression (SVAR) identification scheme that leverages weekly Federal Reserve balance sheet data in an attempt to isolate the effects of balance sheet normalization on financial markets. The Federal Reserve’s sequencing of policy actions leads us to focus on two distinct episodes of balance sheet normalization. From 2014-Q4 through 2017-Q3, the Federal Reserve ceased net asset purchases but continued to reinvest proceeds of maturing securities. This Full Reinvestment phase resulted in a modest decline in reserves without a commensurate decline in asset holdings. Then, from 2017-Q4 through much of 2019-Q3, the Federal Reserve began to purchase fewer assets each month than were maturing. This Asset Runoff phase resulted in declines in both reserves and asset holdings.

Split sample analysis of constant-parameter as well as time-varying parameter SVAR models reveal that reserve reductions during the Asset Runoff phase of balance sheet normalization were associated with a tightening in financial conditions. This tightening is characterized by relatively large liquidity effects and transmits through money markets, Treasury markets, corporate bond markets, and foreign-exchange markets. The Full Reinvestment phase was alternatively associated with smaller liquidity effects and no material change in financial conditions. These results lead us to conclude that reductions in reserves from lower base levels, when accompanied by reductions in asset holdings, tighten financial conditions even in the absence of large announcement effects. However, this tightening transmits through markets in a different fashion than merely a QE policy in reverse.
2 Potential Transmission Channels of Balance Sheet Normalization

A combination of credit and liquidity facilities, together with a sequence of three large-scale asset purchase (LSAP) programs, swelled the Federal Reserve’s balance sheet to nearly $5 trillion in 2014 from less than $1 trillion in the years prior to the Global Financial Crisis. These purchases were largely funded through commensurate increases in bank reserves. Figures 2a and 2b show the evolution of the Federal Reserve’s liabilities and assets through these various phases of balance sheet expansion and unwind. While the credit and liquidity facilities unwound rather naturally as the crisis abated, the same cannot be said for the long-duration Treasury and federal agency securities acquired through the various QE I, II, and III programs. Therefore, a more complete normalization of the balance sheet required active adjustments in reserves management and asset reinvestment policy.

The process of normalizing the Federal Reserve’s balance sheet proceeded across two dimensions: size and composition. On the liability side of the balance sheet, normalization took place through decreases in reserve balances. From October 2014 through September 2017, reductions in reserves were accompanied by corresponding increases in currency and other non-reserve liabilities. As the FOMC fully reinvested the proceeds of maturing securities, the overall size of the balance sheet remained largely unchanged. Then, beginning in October 2017, reserves began to decline along with the size of the balance sheet as a fraction of maturing securities were allowed to runoff each month. These dynamics are illustrated in Figure 2a. The composition of the Federal Reserve’s asset holdings was also evolving throughout this period, as illustrated in Figure 2b. This multifaceted approach to normalization suggests a number of ways in which these actions could affect financial markets, possibly transmitting through short-term money markets, foreign exchange markets, as well as Treasury, corporate credit, and equity markets.

Reductions in reserves could tighten conditions in money markets and put upward pressures on short-term interest rates via a classic liquidity effect. The model in Ireland (2014), however, predicts that the Federal Reserve’s 2008 adoption of interest payments on reserve balances could eliminate liquidity effects. The prime mechanism behind that conclusion is arbitrage incentives which should drive the federal funds rate towards the interest rate paid on reserves (IOR), regardless of the level of reserve balances. Despite this persuasive intuition, the federal funds market has proven to be fairly segmented, leading to persistent spreads between the federal funds rate and the IOR. Moreover, Smith (2019) and Martin et al.
(2019) find evidence that this spread correlates negatively with reserve balances, indicating that liquidity effects remained under the Federal Reserve’s post-2008 operating framework. However, the question remains whether liquidity effects strengthened as reserve balances declined and whether this contributed to a more general tightening in financial conditions.

We can explore changes in the strength of the liquidity effect by studying the relationship between (the natural log of) bank reserves ($RES_t$) and the opportunity cost of holding reserves—the federal funds rate less the IOR—using the reduced-form regression:

$$\text{FF}_t - \text{IOR}_t = \alpha + \beta \times 100 \times \log(RES_t) + \varepsilon_t. \tag{1}$$

The magnitude of the coefficient $\beta$ in this regression measures the strength of the liquidity effect.\footnote{After 2008, shifts in aggregate reserve balances were not effectively targeting the federal funds rate ($\text{FF}_t$). Therefore, regressions of this form are unlikely to be biased by endogeneity concerns.} During the balance sheet expansion period (2009-Q1 to 2014-Q3), this regression yields a significantly negative relationship between reserves and the FF-IOR spread with $\beta = -0.086$ ($s.e. = 0.009$). Then, during the balance sheet normalization period (2014-Q4 to 2019-Q3), we find the magnitude of this liquidity effect coefficient increases to $\beta = -0.299$ ($s.e. = 0.015$). This strengthening of the liquidity effect summarizes the salient movements of the rolling window estimates of this regression shown in Figure 1.\footnote{A rolling Pearson correlation coefficient yields similar conclusions.} Figure 3 scatters the FF-IOR spread against bank reserves across these two samples and corroborates a visible strengthening of the liquidity effect during balance sheet normalization.

Our reduced form analysis suggests liquidity effects may have played a more prominent role during the balance sheet normalization period than they played during balance sheet expansion. This asymmetry can largely be attributed to the Federal Reserve’s toolkit for managing short-term interest rates. Amid balance sheet expansion, multiple forces limited the extent to which the federal funds rate could decline as reserve balances increased. These included the natural lower bound that zero placed under short-term interest rates as well as the payment of IOR. Another factor was the Federal Reserve’s deployment of the reverse-repo facility to support the federal funds rate from below. Throughout the period of balance sheet expansion, these forces limited the amount by which short-term interest rates could decline as reserve balances grew. However, there were no such forces to prevent upward pressure on short-term interest rates from emerging as reserve balances declined amid the balance sheet unwind. This allows for a potentially larger degree of pass-through from reserves to interest rates during a QT episode.
In addition to liquidity effects on domestic interest rates, declining reserve balances associated with balance sheet normalization could also lead to an appreciation of the foreign exchange value of the dollar. For instance, should a liquidity effect emanate from declining reserve balances, higher U.S. interest rates could subsequently lead to an appreciation of the dollar. The consequences of balance sheet normalization on the dollar may be amplified in an environment of monetary policy divergence (Forbes, 2019). Beyond interest rate differentials, declining reserve balances represent a reduction in the supply of dollar assets, which could, in and of itself, lead to an appreciation of the foreign-exchange value of the dollar. A large literature has studied the financial market implications of the U.S. role as the supplier of the world’s reserve currency. Krishnamurthy and Lustig (2019) specifically document a link between shifts in the supply of reserves due to Federal Reserve policy changes and the convenience yield that foreign investors are willing to pay to hold dollars. They show that the resulting shifts in the supply of global dollar assets initiated by a Federal Reserve tightening lead to an appreciation of the dollar, even after controlling for changes in cross-country interest rate differentials. They postulate this channel emerges because a Federal Reserve tightening signals either an immediate or a future reduction in the U.S. monetary base and, therefore, a reduction in the supply of safe dollar assets.

The reduction of asset holdings by the Federal Reserve that occurred during balance sheet normalization could also affect riskier assets, such as corporate bonds and equities. As the composition of Federal Reserve liabilities evolved, so too did the composition of its asset holdings. On net, these changes led to reductions in the duration of assets held on the Federal Reserve’s balance sheet, thereby transferring duration back to the private sector. In particular, as securities matured, the markets desk at the Federal Reserve Bank of New York often reinvested principle payments across the maturity of Treasuries being issued—as opposed to solely purchasing the longer-term Treasuries that were acquired during the multiple LSAP programs. Figure 4 illustrates that the result of this reinvestment policy was a gradual but steady decline in the duration of the Fed’s system open market account, or SOMA, holdings from 2014 through 2019. The reduction in duration of the Fed’s portfolio beginning in 2014 could increase the amount of duration the private sector is asked to bear, which would push up longer-term interest rates according to the model in Krishnamurthy and Vissing-Jorgensen (2013). Should this transfer of duration require private investors to rebalance their portfolios, then balance sheet normalization could also lead to a reversal of any portfolio rebalancing effects, a channel that has been emphasized by Carpenter et al. (2015) in explaining the effects of LSAPs on riskier assets. Therefore, balance sheet normalization potentially increases corporate borrowing costs and lower equity prices.
3 Measuring the Effects of Balance Sheet Normalization on Financial Markets

When analyzing the effects of balance sheet normalization, the attention of policymakers likely centers on its effects on the central bank’s macroeconomic objectives. Therefore, it is likely that balance sheet effects on financial conditions take a back seat to the government directives of price stability and maximum employment. However, standard macroeconomic models generally predict that current financial conditions influence future spending and investment choices. Furthermore, there seems to be some empirical support for a non-negligible relationship between current financial conditions and future economic activity (Hatzius et al., 2010). While a direct examination of the link between balance sheet normalization and economic activity is clearly of interest, we leave this endeavor for future work. Instead, we focus mainly on financial market effects for which there is high-frequency data available, which is essential for our empirical approach.

Given the range of financial markets through which balance sheet normalization could operate, we study potential effects on a number of asset classes. Of course, not all asset prices may move in a synchronized manner, which impedes a clear assessment of the overall effects of a balance sheet unwind on financial conditions. We, therefore, rely on broad indexes to measure the net effect on overall financing conditions. While many such indexes are available, we anchor our analysis around the Goldman Sachs Financial Conditions Index (GS FCI), which is available at a daily frequency. This index is a transparent weighted sum of the federal funds rate, the 10-year Treasury yield, the BBB bond spread, the trade-weighted foreign-exchange value of the dollar, and the S&P 500. The weights are determined by the effect each component has on GDP according to a stylized macroeconomic model. As a result, shifts in this index provide a useful indicator of likely movements in real output (Hatzius and Stehn, 2018). We also perform robustness analysis using the Bloomberg Financial Conditions Index (Bloomberg FCI), which is also available at a daily frequency. Time series of both financial conditions indexes are shown in Figure 6. The two indexes’ headline reports typically move in opposite directions due to the normalization process. Namely, high levels of the GS FCI correspond to a tightening in financial conditions, whereas low levels of the Bloomberg FCI correspond to tighter financial conditions. Figure 6 inverts the Bloomberg FCI values for more direct comparability.

We orient our analysis of balance sheet normalization around the dynamics of reserve balances, a Federal Reserve liability. This decision primarily reflects the FOMC’s own ap-
proach to balance sheet normalization. While asset holdings were the focus of the balance sheet expansions, in their published principles governing balance sheet normalization, the FOMC emphasized that the underlying demand for reserves demand would inform the extent of balance sheet normalization (Federal Open Market Committee, 2017). Reinforcing this point, the end of the balance sheet unwind process followed a material increase in money-market rates amid sharp reductions in reserve balances in September of 2019. In response to this tightening in money markets, the Federal Reserve initiated temporary repo operations and outright purchases of Treasuries to again begin increasing the supply of reserves. This marked the end of the balance sheet normalization process in the U.S. at the time of this writing.

In addition to the nearly 30 percent decrease in reserve balances during the Asset Runoff period, other forces—namely the increase in Treasury bill supply—are also thought to have played a role in applying steady upward pressure to money-market rates leading up to September 2019. For instance, in a June 2018 post-FOMC meeting press conference, Federal Reserve Chair Powell offered relevant remarks to this issue. When confronted with a question regarding the need for frequent downward adjustments to the IOR rate to ensure that the federal funds rate would not breach the top of the FOMC’s target range, Chair Powell attributed the upward rate pressure not to declining reserve balances but instead noted:

\[
I \text{ think there’s a lot of probability on the idea of just high [Treasury] bill supply leads to higher repo costs, higher money market rates, and the arbitrage pulls up the federal funds rate towards IOER.} \quad – \text{(Powell, 2018)}
\]

Figure 5 shows that during the 2017-2019 asset runoff period, Treasury bills outstanding increased by nearly 30 percent. As Treasury supply increased, Treasury’s general account (TGA) balance with the Federal Reserve also went up, which suggests that higher Treasury bill supply has the potential to mimic liquidity effect dynamics. Namely, increases in bill supply could increase money market rates and increase TGA balances while reducing reserve balances.\(^3\)

We develop an identification strategy to distinguish reductions in reserves associated with balance sheet normalization and reductions in reserves associated with increases in Treasury supply. We discuss our identification strategy in detail in the following section but we note here that our approach differs from the event-studies used to identify the effects of

\(^3\)The settlement of Treasuries purchases ultimately involves debiting a reserve account and crediting Treasury’s general account.
Asset purchases (including Gagnon et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2013; Swanson, 2020, among others). This decision reflects the different nature of Federal Reserve communications around balance sheet normalization relative to balance sheet expansion. Asset purchase programs were introduced by discrete announcements of a given stock or flow of asset purchases. These announcements often elicited sharp market reactions, enabling researchers to identify the financial market effects of asset purchases based on the movements in asset prices in a small window around the announcement. However, Federal Reserve officials explicitly undertook a strategy to balance sheet normalization that minimized any such announcement effects. In a June 2017 post-FOMC meeting press conference, Federal Reserve Chair Yellen described the Federal Reserve’s approach to initiating its balance sheet normalization plan by noting that (our own emphasis added):

 [...] the plan is one that is consciously intended to avoid creating market strains and to allow the market to adjust to a very gradual and predictable plan. My hope and expectation is that when we decide to go forward with this plan, that there will be very little reaction to it, that it’s clear how we intend to proceed, and that this is something that will just run quietly in the background over a number of years, leading to a reduction in the size of our balance sheet and in the outstanding stock of reserves, and that it’s something that the Committee will not be reconsidering from time to time. We think this is a workable plan, and it will, as one of my colleagues, President Harker, described it, it will be like watching paint dry, that this will just be something that runs quietly in the background.

– Yellen (2017)

The Federal Reserve’s avoidance of announcement effects leads us to pursue a time-series approach that allows for balance sheet normalization to gradually transmit to financial markets. More specifically, we combine institutional aspects of Treasury auctions with the Federal Reserve’s balance sheet data into a weekly structural VAR model to disentangle reserve reductions associated with the Federal Reserve’s balance sheet unwind from those associated with increased Treasury bill issuance. While identification is more challenging in this setting compared to an event-study framework, the use of a time-series model allows for delayed but possibly persistent effects from balance sheet adjustments, which is necessary to capture the Federal Reserve’s gradual approach to balance sheet normalization. In particular, our use of a SVAR model does not merely restrict our focus to financial market effects that manifest over minutes or hours. Instead, our approach encompasses both persistent and rapid effects as well as the possibility of propagation over weeks and months. Finally, while
we orient our identification around the liability side of the Federal Reserve’s balance sheet, we emphasize the time variation of the effects of balance sheet normalization around changes in the Federal Reserve’s asset reinvestment/runoff policy to shed light on the joint effects of reducing the Federal Reserve’s liabilities and asset holdings.

4 A Structural VAR Model of Balance Sheet Normalization

There have been many investigations of the effects of changes in central bank reserves on interest rates, financial markets, and the broader economy (see Strongin, 1995; Christiano, Eichenbaum and Evans, 1996; Iwata and Wu, 2006; Curdia and Woodford, 2016; Demiralp, Eisenschmidt and Vlassopoulos, 2019, among many others). While many approaches, particularly those employing SVAR models, have typically used monthly or quarterly data, Bernanke and Mihov (1998) consider biweekly data informed by operational concepts on the implementation of monetary policy.

We pursue a similar approach by bringing to bear some institutional details regarding the time lag between the announcement and settlement of Treasury auctions together with the Federal Reserve Board’s week-ending-Wednesday balance sheet data. All of the SVAR models we study in this paper consist of the same set of three core variables at a weekly frequency. Then, additional variables such as financial conditions indexes are rotated in and out of the model. We consider values as of Wednesday for the following variables: the natural log of reserve balances, the repo-IOR spread, and the FF-IOR spread. Our strategy allows us to extract the individual effects of reserve supply shocks, Treasury bill supply shocks, and federal funds-market-specific shocks. However, we focus our attention on the effects of reserve supply shocks, which are inextricably related to the balance sheet unwind. Furthermore, our analysis sheds light on the role that other factors may play in shaping financial conditions. These include increases in Treasury bill issuance and idiosyncratic shifts in the federal funds market, both of which occurred as the Federal Reserve pursued its balance sheet unwind. Given that balance sheet normalization, increased Treasury issuance, and other idiosyncratic shifts in the federal funds market all have the potential to buffet financial conditions, we pursue an identification strategy to disentangle these concurrent developments.
4.1 Identifying Restrictions

It is unlikely a reduced-form VAR model that includes data on the central bank’s balance sheet, Treasury and overnight bank funding markets, and indicators of the tightness/slack in financial markets will yield uncorrelated residuals. An identification strategy is necessary to achieve a clean separation between the multiple factors potentially impinging on financial conditions. Our prime concern is to establish a clear distinction between the Federal Reserve’s balance sheet unwind and U.S. Treasury supply dynamics.

One way to achieve this distinction is to assume a lower-triangular structure for the impact matrix that maps the vector of residuals to that of the identified structural shocks. This requires attention to the order in which the variables enter the system. We impose a lower-triangular formulation and the following ordering: \( x_t = [(100 \times \log(RES_t); (SOFR_t - IOR_t); (FF_t - IOR_t); Z_t)]^t \) where SOFR is the secured overnight financing rate, a broad measure of Treasury repo rates constructed by the Federal Reserve Bank of New York, \( Z_t \) is either an index of financial conditions or the price/yield of a particular asset, and \( t \) is the value of each variable as of Wednesday each week. We model these variables as a VAR(p) on weekly data:

\[
\theta(L)x_t = e_t
\]

where \( \theta(L) = I_4 - \theta_1 L - \cdots - \theta_p L^p \) is a p-th order lag polynomial and \( e_t \) is a mean zero vector of reduced-form VAR residuals with covariance matrix \( \Sigma = PP' \).

We recover the underlying structural VAR by specifying the linear mapping, \( e_t = P\epsilon_t \), between \( e_t \), the reduced-form VAR residuals, and \( \epsilon_t \), the structural shocks of interest, where:

\[
\begin{pmatrix}
    e_{t}^{Res} \\
    e_{t}^{SOFR-IOR} \\
    e_{t}^{FF-IOR} \\
    e_{t}^{Z}
\end{pmatrix}
= 
\begin{pmatrix}
    p_{11} & 0 & 0 & 0 \\
    p_{21} & p_{22} & 0 & 0 \\
    p_{31} & p_{32} & p_{33} & 0 \\
    p_{41} & p_{42} & p_{43} & p_{44}
\end{pmatrix}
\begin{pmatrix}
    \epsilon_{t}^{Res \ Supply} \\
    \epsilon_{t}^{Treas \ Supply} \\
    \epsilon_{t}^{FF \ Specific} \\
    \epsilon_{t}^{Other \ Z}
\end{pmatrix}.
\]

We motivate our ordering based on the structure of Treasury auctions. Aside from cash management auctions, Treasury bill auctions have historically followed a regular schedule where the auction is announced on Tuesday and settled on Thursday. Treasury auction announcements provide details about what is on offer, including the maturity, amount, and even the Committee on Uniform Security Identification Procedures (CUSIP) number. This

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4We also include a constant and dummy variables in the VAR to absorb typical month-, quarter-, year-end as well as holiday dynamics. We use the AIC to select the number of lags, which generally chooses 4 lags.
enables immediate trading and pricing of the new securities on a “when-issued” basis (Garbade and Ingber, 2005). However, winning bidders from Treasury bill auctions settle with Treasury up to one week after the announcement. For example, if the winning bidder is a depository institution, the Federal Reserve—in its role as the fiscal agent for the U.S. Treasury—settles the auction by debiting the depository institution’s reserve account and crediting Treasury’s General Account. The implication is that changes in reserve supply due to Treasury bill issuance occur at settlement, whereas the response of interest rates and asset prices, more generally, can occur when the auction is announced.

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. Thus, we make two primary identifying restrictions to separate reserve adjustments emanating from balance sheet runoff and reserve adjustments ensuing from Treasury issuance. First, we assume that until September 2019, when the FOMC ended its balance normalization program, the Federal Reserve did not adjust the pace of reserve reductions week-to-week in response to developments in money markets or broader financial conditions. This assumption is consistent with the description in Yellen (2017) of the Federal Reserve’s balance sheet normalization strategy. The second key assumption we make 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. This second assumption enables a clean separation of the financial market effects of balance sheet normalization from the effects of increased Treasury bill issuance.

5Gorodnichenko and Ray (2018) combine Treasury futures data with the time lag between Treasury 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.

6To use a recent Treasury auction as an example, consider the 4-Week Bill auction announced on Thursday, Oct. 4, 2018. The Oct. 4 press release details that $40 billion of these bills were auctioned on Tuesday, Oct. 9, and then issued on Thursday, Oct. 11, which is when the winning bidders transferred payment to Treasury. Importantly, this implies that any fluctuations in reserves between Wednesday, Oct. 3, and Wednesday, Oct. 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 would first appear in the Wednesday, Oct. 17 H.4.1 release.

7Our identifying restriction is also consistent with changes in repo rates for reasons other than Treasury issuance, so long as the change in repo rates is unrelated to contemporaneous changes in reserves. However, 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 weeks and months.
Finally, increases in the federal funds rate (relative to the IOR rate) could also prompt changes in broader financial conditions. Potential effects could be driven by shifts in the liquidity management practices of Federal Home Loan Banks who serve as the primary lenders in the federal funds market. Another channel through which these (relative) federal funds rate adjustments could materialize stems from adjustments in bank demand for federal funds loans from foreign banks around month-, quarter-, or year-end, as well as holidays. Importantly, we assume that these shifts in loan supply and demand are idiosyncratic to the federal funds market and are not associated with any contemporaneous shifts in reserve balances nor Treasury repo rates. We implement this assumption by including the FF-IOR spread in our VAR model and ordering it after reserve balances and the SOFR-IOR spread.

4.2 The Dynamic Effects of Balance Sheet Normalization on Financial Conditions

Our structural VAR estimates shed light on the effects that reserve reductions—consistent with balance sheet normalization—have on the general climate of financial markets. Our VAR is positioned to speak to the effects of balance sheet normalization both narrowly—within repo markets and the federal funds market—and more broadly over the stringency or slackness of overall financial conditions. Finally, we leverage the parsimonious structure of the Goldman Sachs Financial Conditions Index to provide a more granular view of the cross-asset movements that materialize when unwinding the balance sheet.

Our sample encompasses two phases in the policy normalization efforts of the Federal Reserve. During the first phase, between 2014-Q4 and 2017-Q3, the Federal Reserve ceased net asset purchases and instead bought just enough securities to replace those that matured each month. The result of this Full Reinvestment phase was a steady decline in reserve balances but without an associated decline in asset holdings. In contrast, beginning in October 2017, the Federal Reserve conducted a structured and deliberate Asset Runoff using a pre-specified cap on the amount of securities that could be redeemed without replacement, with the cap rising gradually over time. Therefore, negative supply shocks could, in principle, elicit different effects across these two phases in the balance sheet normalization process. The runoff ceased in September of 2019 when the Federal Reserve began repo operations to raise reserve balances amid volatility in short-term money markets. In light of this sequencing of policy actions, we estimate our VAR specifications across two sub-samples: the Full Reinvestment.

8We include dummies in the VAR models for these events, but these shocks can capture, among other forces, larger-/smaller-than-usual calendar effects.
sample of September 2014 - September 2017 and the Asset Runoff sample of October 2017 - August 2019. Although our VAR contains no explicit information on the Federal Reserve’s asset holdings, our delineation between these two phases of asset reinvestment/runoff policy opens the door to an analysis of the differential effects of changes in liability composition versus joint adjustments in liability and asset holdings.

We generally find that negative reserve supply shocks in the Full Reinvestment period only transmitted to short-term funding markets but did not propagate further to broader financial conditions. The left column of Figure 7 shows impulse responses to a negative one-standard-deviation reserve supply shock from our VAR specification, which includes the FCI officially released by Goldman Sachs as the fourth variable. We find negative reserve supply shocks lead to positive and persistent effects on the FF-IOR, as well as the Repo-IOR, spreads. These responses are consistent with a strong liquidity effect. However, the response of financial conditions more broadly is not precisely estimated. Given that higher values of the GS FCI indicate tightness in financial markets, a positive response would mean that a negative shock in the supply of reserves has an adverse impact on financial conditions—whereas a negative response portends a beneficial effect. The ambiguity of the response of the GS FCI suggests that changes in the composition of Federal Reserve liabilities from 2014-Q4 to 2017-Q3 with no concurrent shift in asset composition had little bearing on the financing conditions facing households and firms.

In stark contrast, we find evidence that reserve reductions prompted a persistent tightening in financial conditions during the Asset Runoff period. The right column of Figure 7 shows that during this latter period, negative reserve supply shocks prompted large and persistent increases in repo as well as federal funds rate spreads. The estimated liquidity effect here is notably larger and more persistent in this latter sample. A possible explanation for this dynamic is that average reserve balances declined from $2.4 trillion during the Full Reinvestment sample to $1.9 trillion during the Asset Runoff sample. In particular, if the demand for reserves is non-linear, as the estimates in Carpenter and Demiralp (2006) suggest, then the liquidity effect would increase when reserves are less abundant. This tightening in money market conditions ultimately permeates with some lag to a rise in the GS FCI, corresponding to a tightening in broad financial conditions. Figure 8 shows the same split-

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9 Although we specify an implicitly nonlinear (log-demand) for reserves, the demand for reserves may be nonlinear in ways that this simple transformation may not capture. In the next section, we turn to a more flexible model that could accommodate other nonlinearities and, in that model, we continue to find evidence of amplified liquidity effects during the Asset Runoff period.
sample estimates with an alternative measure of financial conditions, the Bloomberg FCI.\(^{10}\)
Both measures show evidence of a sharper tightening in financial conditions during the Asset Runoff period compared to the Full Reinvestment period. These responses suggest that the unwinding of asset purchases reverses some of the easing effects of LSAP programs.

To gain insight into the scope and nature of the tightening in financial markets incited by unwinding past asset purchases, we take a more granular look at the components that comprise the GS FCI. In particular, in Figure 9 we display impulse responses for the overall GS FCI as well as the five yields/prices that comprise the index. We focus our attention on the Asset Runoff period for which we find evidence of a link between balance sheet normalization and a tightening of overall financial conditions.

Figure 9 shows that reserve reductions during the Asset Runoff period imposed tightening effects across most financial markets. The federal funds rate response increases sharply in the first month after the reserve reduction and remains persistently elevated thereafter. This increase in short-term interest rates passes through to longer-term Treasury rates as evident by the similar shape of the impulse responses for the federal funds rate and the 10-year Treasury rate. While Treasury yields retrace their rise after a couple of weeks, corporate bond rates remain persistently higher for months after the initial reduction in reserves. Turning to foreign exchange markets, the decline in reserve balances leads to a protracted appreciation in the U.S. dollar against a broad basket of currencies. Finally, and in contrast to these other asset classes, the S&P 500 shows essentially no response to declining reserve balances.

The responses across asset markets during the Asset Runoff period contrast in meaningful ways with what might have been expected based on available estimates of the effects of LSAPs. For instance, unlike the LSAP period when short-term rates had little room to fall due to the zero lower bound, short-term rates had no corresponding upper bound during the balance sheet unwind. This allows for a larger degree of pass-through from reserves to short-term interest rates. This asymmetry suggests that liquidity effects may play a more prominent role during the balance sheet unwind than they did during the balance sheet expansion. The similarity of the shape of the impulse responses for the federal funds rate and the 10-year Treasury yield suggests that long-term rates may have been partly influenced by this liquidity-driven rise in short-term rates. This mechanism may explain why we find a more delayed response of long-term Treasury yields compared to what the LSAP event-study literature typically reports.

\(^{10}\)Here again we take the daily values on Wednesday to align with our week-ending-Wednesday.
On another point of departure, Gagnon et al. (2011); Krishnamurthy and Vissing-Jorgensen (2013); Swanson (2018); and Swanson (2020) find evidence, based on announcement effects, that LSAPs widened the spread between corporate bonds and the 10-year Treasury as they gave rise to sharper declines in Treasury rates compared to risky corporate bond rates. However, we find evidence that unwinding these purchases actually widened—rather than compressed—corporate borrowing spreads. Policy divergence could be a salient factor that explains this lack of symmetry. The Federal Reserve’s balance sheet expansion took place amid easing actions by other major central banks. Conversely, the U.S. unwound these purchases while other central banks were still growing their respective balance sheets. Therefore, policy divergence across countries during the U.S. balance sheet unwind period may have led global investors to shift into U.S. Treasuries. This explanation could explain the short-lived rise in 10-year Treasury rates and the persistent rise in the dollar exhibited in Figure 9.\footnote{Chari, Dilts-Stedman and Lundblad (2020) present evidence generally consistent with this as they find that money flowed from emerging market countries into the U.S. when the Federal Reserve tapered its pace of asset purchases.}

To the extent that corporate bonds did not receive similar degrees of demand, this policy divergence channel could also explain the widening in corporate spreads that we observe during the balance sheet unwind.

Our samples include a period when reserve reductions were driven both by changes in the liability composition of the Federal Reserve’s balance sheet as well as outright asset reductions. Overall, evidence from our structural VAR specifications suggests reserve contractions driven solely by changes in liability compositions seem to have exerted little effect on financial conditions beyond short-term funding markets, whereas contractions in reserves associated with asset reductions significantly tightened financial conditions. And, in contrast to popular opinion, we find little evidence that the balance sheet normalization weighed on equity returns. Our evidence appears to be consistent with the Swanson (2018) finding that LSAP programs had no statistically significant effect on equity prices. However, other facets through which balance sheet normalization operates in tighter financial conditions may differ from what one might have predicted given the available evidence on the effects of LSAPs. Specifically, unlike the evidence from other studies on LSAPs, we find liquidity effects are pronounced. Longer-term Treasury yields respond with a delay, and corporate bond rates are more sensitive than are longer-term Treasury rates. Therefore, unwinding the balance sheet does not entirely appear to be a QE policy in reverse, which perhaps underscores the importance of the global economic and financial backdrop against which these actions were taken.
In the next section, we relax our imposition of the date of structural change \textit{a priori}, and we turn to a model capable of capturing a richer evolution in the dynamic effects of reserve shocks. In particular, we estimate a more flexible time-varying parameter model to study the changing nature of the effects of unwinding the Federal Reserve’s balance sheet across the different phases of balance sheet normalization.

5 The Time-Varying Effects of Balance Sheet Normalization

Given the evidence that regime change might have had a first-order effect on the transmission of balance sheet normalization to broad financial conditions, we now turn to a time-varying parameter approach. The potential change in dynamics could be addressed in a number of ways. Event studies are a popular technique to elucidate potential discontinuities in the effects of interest to the researcher. However, they remain largely impracticable for our analysis in light of the Federal Reserve’s carefully orchestrated communication around normalizing the balance sheet. Other approaches for regime change, such as Markov Switch, GARCH or sub-samples estimated across structural break tests at unknown dates, could prove useful. We, however, opt for a time-varying approach because it does not preclude the possibility that the change in dynamics may not occur suddenly. The Federal Reserve emphasized the gradual nature of the unwind. And while it may be straightforward to connect a policy announcement with an explicit date, it is far less tractable to pin down an exact date for a change in the effect, transmission, or implementation associated with that policy action. In particular, the sub-sample investigation in the previous section suggests that the nature of reserve reductions evolved between the Full Reinvestment and Asset Runoff periods. However, we now relax the strong assumption about an explicit date-break and, instead, let the data inform our views on when the dynamic effects from unwinding the balance sheet unfold.

We maintain our structural identification outlined in Section 4.1 implied by the ordering of the variables in the system \( x_t = [(100 \times \log(RES_t)); (SOFR_t - IOR_t); (FF_t - IOR_t); Z_t]' \), where \( Z_t \) is an indicator of financial conditions, along with a lower-triangular impact matrix. However, our specification is now expanded by allowing both the parameters and the covariance matrix of the VAR to vary over time.
5.1 Econometric Framework

Consider the following VAR process:

$$\theta_t(L)x_t = e_t,$$  \hspace{1cm} (3)

where $x_t$ is an $n$-vector of endogenous time $t$ variables; $\theta_t = I_n - \theta_{1t}L - ... - \theta_{pt}L^p$ is a $p$-th order lag polynomial in which each $\theta$ is a time-varying matrix of autoregressive coefficients and $e_t$ is an $n$-vector of mean-zero VAR innovations. We allow for time variation in the variances of the shocks in the VAR model, all of which are summarized in the time-varying covariance matrix $R_t$. Let $\Theta_t$ represent the stacked vector of all coefficients in $\theta_t(L)$, and assume it evolves according to:

$$\Theta_t = \Theta_{t-1} + u_t, \hspace{1cm} (4)$$

where $u_t$ is a Gaussian white noise process with zero mean and constant covariance $Q$, independent of $e_t$ at all leads and lags. A seminal application of modern time-varying structural VARs by Cogley and Sargent (2005) and a comprehensive treatment by Primiceri (2005) rely on the Bayesian single-move technique of Jacquier, Polson and Rossi (2002) to estimate stochastic volatilities. We follow a variant of the multi-move stochastic volatility construct of Kim, Shephard and Chib (1998) to allow for time variation in the underlying VAR model.\footnote{Del Negro and Primiceri (2015) argue for an alternative algorithm that allows for a more efficient implementation of Kim, Shephard and Chib (1998) over Jacquier, Polson and Rossi (2002). It involves a reorganization of the steps in the Gibbs sampler where the history of the volatilities is sampled after—rather than ahead of—the mixing indicators for each parameter for every period $t$.}

We decompose the covariance matrix of system (3) as follows. Let $E(e_t e_t') = F_t H_t F_t'$, where $F_t$ and $H_t$ are given by:

$$F_t = \begin{bmatrix} 1 & 0 & \ldots & 0 \\ f_{2t} & 1 & \ldots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ f_{nt} & \cdots & f_{nt-1} & 1 \end{bmatrix}$$

and

$$H_t = \begin{bmatrix} h_{1t} & 0 & \ldots & 0 \\ 0 & h_{2t} & \ldots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & h_{nt} \end{bmatrix}.$$
respectively. The diagonal elements of $H_t$ are independent univariate stochastic processes that evolve according to the following:

$$ln(h_{jt}) = ln(h_{jt-1}) + \xi_t \quad \forall j = 1, 2, \ldots, n$$  \hspace{2cm} (5)

Stacking all the off-diagonal elements of $F_t^{-1}$ into a vector $\gamma_t$, we further assume that this vector evolves according to the following drift-less geometric random walk:

$$\gamma_t = \gamma_{t-1} + \zeta_t$$  \hspace{2cm} (6)

where $\xi_t \sim iid(0, \Xi)$ and $\zeta_t \sim iid(0, \Psi)$. We assume $u_t \perp \xi_t \perp \zeta_t$ with a block-diagonal covariance matrix $\Psi$ to prevent non-zero covariance of the coefficients among different equations.

We assume the underlying structural shocks ($\epsilon_t$) are a time-varying transformation of the reduced-form innovations ($e_t$) as follows:

$$e_t = P_t \epsilon_t \quad \forall t,$$  \hspace{2cm} (7)

where $P_t$ is a non-singular matrix that satisfies $P_t P_t' = R_t$. Given this mapping, changes in the contributions of different structural shocks to the volatility in innovations in the underlying variables of interest are captured by changes in $P_t$.

Let the companion form of (3) be given by:

$$X_t = \Pi_t X_{t-1} + D e_t,$$  \hspace{2cm} (8)

where $X_t = (x'_t, x'_{t-1}, \ldots, x'_{t-p+1})'$, $D = (I, 0, \ldots, 0)'$, and $\Pi_t$ is the companion matrix containing the time-varying autoregressive coefficients in (3). With these elements in hand, a standard local projection of (8) can be defined by:

$$\frac{\partial x_{t+h}}{\partial \epsilon_t} = s_{n,n} (\Pi_t^h) \quad \forall t, h = 1$$  \hspace{2cm} (9)

where $s_{n,n} = D' \Pi_t^h D$ selects the upper left n-by-n sub-matrix from the larger matrix. A simple application of the chain rule obtains impulse responses at an arbitrary $h$-th horizon:

$$\frac{\partial x_{t+h}}{\partial \epsilon_t} = \frac{\partial x_{t+h}}{\partial e_t} \frac{\partial e_t}{\partial \epsilon_t} = s_{n,n} (\Pi_t^h) P_t \quad \forall t, h = 1.$$  \hspace{2cm} (10)

Here we follow the same specifications as those described in Section 4.2 aided by the same identification strategy as in Section 4.1. Therefore, in our specification with $n=4$ variables, the last variable in the order ($x_t$) is an index of financial conditions where $t$ is the value of each variable as of Wednesday each week.
5.2 Discussion of Results from the Time-Varying Approach

We estimate two separate TVP-VARs. One for the GS FCI and another for the Bloomberg FCI, both placed fourth in our ordering. For both specifications, we employ a training sample of 65 weeks for estimation of a standard VAR whose reduced-form parameters are used to initialize the Gibbs sampler algorithm. Thus, our estimates range from October 2015 to October 2019. We obtain impulse response function-point estimates for each week within our sample (200 periods across the $t$-dimension) and for every week following the specified shock (20 horizons across the $h$-dimension.)

In the interest of clarity in our presentation of results, we report the responses to negative supply shocks for every period $t$ while averaging the responses across horizons. Figures 10 - 12 show the last week of the month-responses for every week between October 2015 and October 2019 with error bands produced within the 16-84% credible set. The top panel of these figures report the first-horizon responses post-shock (the first-week responses). The middle panels show the first month responses (averages for horizons one through four). The bottom panels display the second-month responses (averaging week five through week eight responses post shock). Finally, we append a vertical line, labeled September 2017, to each of these charts, which constitutes a line of demarcation between the two phases of the balance sheet unwind: Full Reinvestment and Asset Runoff.

Figure 10 shows the time-varying response of the GS FCI to a negative shock in the supply of reserves. A negative reserve supply shock elicits no significant response of financial conditions prior to September 2017. Thereafter, during the second phase of balance sheet normalization — when asset runoff was the primary driver of reductions in the balance sheet of the Federal Reserve — reductions in reserves elicit an adverse effect on financial conditions. This tightening in financial conditions becomes significant early in 2018. These time-varying effects of balance sheet normalization substantiate conclusions drawn from our SVAR model. Figure 11 shows a similar pattern of time-variation in the response of financial conditions, now measured by the Bloomberg FCI, following a reduction in the supply of reserves. While the responses are slightly more muted in the Bloomberg specification, we again find that negative reserve supply shocks show indications of a significant tightening in financial conditions after the initiation of the asset runoff policy.\textsuperscript{13}

\begin{footnote}{13}{We also considered two other financial condition indicators produced by the Federal Reserve Banks of Chicago and St. Louis. We do not report these responses because of the reporting frequency of these Federal Reserve indices. While the daily frequency of the GS and Bloomberg indexes of financial conditions are preferable for our purposes, these weekly Federal Reserve measures may provide a materially different}

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The TVP-VAR models further suggest that time variation in the strength of liquidity effects is an important source of the time-varying response of financial conditions to reserve supply shocks. In particular, Figure 12 shows the time-varying responses of the FF-IOR spread following a 1 standard deviation reduction in the supply of reserves. The magnitude of FF-IOR spread responses increase roughly three-fold in the Asset Runoff period compared to the Full Reinvestment period. The error bands prior to 2017 tend not to overlap with those after 2018. This suggests that the responses of short-term interest rates to reserve supply shocks are meaningfully more significant, both economically and statistically, after 2018 than before 2017. These conclusions are largely consistent with the analogous responses in Figure 7 and Figure 8. Taken together, our evidence shows a more binding liquidity effect taking place in the latter part of the balance sheet unwind period, which is also when we generally obtain evidence of a tightening of financial conditions following reductions in the supply of reserves.

Overall, a preponderance of evidence—from the SVAR as well as the TVP-VAR models—suggests that outright reductions in the size of the Federal Reserve’s balance sheet from late 2017 through much of 2019 strained financial conditions. However, absent corresponding reductions in asset holdings prior to the Asset Runoff phase, reductions in reserve balances did not appear to inflict similarly adverse effects. This underscores the differential effects that reserve supply shocks exert on financial conditions across these two phases of balance sheet normalization. We find liquidity effects were also markedly different. In the early sample, the repo- and federal funds rates responses to reserve reductions are considerably more muted when compared to the later sample. We conclude that, despite the avoidance of announcement effects by the Federal Reserve, the combination of reductions in the asset holdings and declining reserve balances from lower base levels appears to have tightened U.S. financial conditions.

perspective of financial conditions. Despite this, we found similar dynamics of the St. Louis Federal Reserve FCI response to those of the GS and Bloomberg FCIs. Negative reserve supply shocks exert significant stress in the St. Louis Fed FCI after 2017. The response was positive prior to 2017 but not statistically significant. In contrast, we found an adverse response of the Chicago Fed’s FCI throughout the sample, suggesting that Chicago Fed’s FCI seems to tighten following negative reserve supply shocks during both the Full Reinvestment and Asset Runoff phases of balance sheet normalization.
6 Conclusion

The Federal Reserve, the European Central Bank, the Bank of England, and the Bank of Japan have all taken actions to expand their balance sheets amid an unprecedented global economic contraction incited by the COVID-19 pandemic—all the while constrained by a dearth of available conventional policy space. At this time of economic hardship, we stipulate that balance sheet normalization remains a distant thought. However, central banks will presumably confront the eventual desire to normalize their balance sheets. Therefore, to fully appreciate the costs and benefits associated with asset purchases, a better understanding of the ramifications of exiting from these unconventional policies is necessary. However, prior to this study, there has been little empirical analysis of the consequences of balance sheet normalization. This leaves central bankers with limited guidance on the realities of unwinding past asset purchases. Our aim in this paper is to shed light on this important, but less well understood, dimension of balance sheet policy.

Given important differences in the structure and global role of financial markets across various economies, the direct applicability of our quantitative findings to other central banks may be reasonably questioned. However, we find one widely applicable result worth highlighting: the consequences of unwinding past balance sheet expansions are unlikely to simply manifest as QE in reverse. Instead, stark differences in the nature of balance sheet unwinds versus expansions, together with important differences in the prevailing economic and financial conditions at the time of exit, are likely to culminate in markedly different dynamics than those that appeared upon implementation. Therefore, knowledge of the effects of LSAP policies alone appears rather insufficient to fully gauge the effects of balance sheet normalization, underscoring the need for further studies on this important monetary policy issue.
References


Figure 1: The Liquidity Effect Between Reserves and the (FF-IOR) Spread Before/During/After QT Period

Note: The (solid) blue line denotes the rolling regression estimate of the liquidity effect obtained by regressing the spread between the federal funds rate and the interest rate paid on reserves on a constant and the natural log of reserve balances. This estimate is flanked by a 95% confidence interval. For this regression estimate, the date on the x-axis denotes the end point of a 208-week rolling window. We choose 208 periods because we have roughly four years of data prior to the onset of the balance sheet normalization period. The first vertical (dashed) line corresponds with the end of the QE III period and the beginning of the Full Reinvestment phase of the balance sheet unwind period (2014-Q3). The (dashed-dotted) vertical line in the middle of the chart acts as a line of demarcation between the Full Reinvestment and Asset Runoff phases within the normalization period. The rightmost (dotted) vertical line denotes the end of the balance sheet normalization period.
Figure 2: The Federal Reserve’s Balance Sheet: 2007-2019

(a) Federal Reserve Liabilities

(b) Federal Reserve Assets

- Currency
- Reserves
- Other

- Treasuries
- Agency debt and MBS
- Rescue operations, targeted lending programs, and liquidity swaps
Figure 3: The Liquidity Effect in Balance Sheet Expansions and Unwinds
Figure 4: Duration of the Federal Reserve’s Asset Holdings

Source: Federal Reserve Bank of New York
Figure 5: Marketable Treasury Bills Outstanding: 2007-2019
Figure 6: Financial Condition Indicators (FCI) Before/During/After Quantitative Tightening Period

Note: Higher values of the Goldman Sachs FCI and the Bloomberg FCI (after normalizing) correspond to a tightening in Financial conditions.

Conversely, low values in both indices indicate a loosening of financial stress.
Figure 7: Responses of the GS FCI VAR specification to a Negative 1 sd Reserve Supply Shock

Note: The solid lines denote the empirical point estimate to a one standard deviation shock and the shaded areas denote the 16% - 84% probability interval of the posterior distribution.
Figure 8: Responses of the Bloomberg FCI VAR specification to a Negative 1 sd Reserve Supply Shock

Note: The solid lines denote the empirical point estimate to a one standard deviation shock and the shaded areas denote the 16% - 84% probability interval of the posterior distribution.
Figure 9: Responses of the Components of the GS FCI to a Negative 1 sd Reserve Supply Shock

*Note: The solid lines denote the empirical point estimate to a one standard deviation shock and the shaded areas denote the 16% - 84% probability interval of the posterior distribution.*
Figure 10: Time-Varying Responses of the GS FCI to a Negative 1 sd Reserve Supply Shock

Note: Each point estimate reflects: the first week response (top panel), the mean response over the first four weeks (middle panel), or the mean response over the second four weeks (bottom panel) for each month in the sample. For the GS FCI, an increase in the index represents a tightening of financial conditions. Therefore, any point estimate located above the zero line corresponds to a tightening of financial conditions in response to a negative reserve shock. Conversely, any estimate below the zero line represents a response consistent with an easing of financial conditions.
Figure 11: Time-Varying Responses of the Bloomberg FCI to a Negative 1 sd Reserve Supply Shock

Note: Each point estimate reflects: the first week response (top panel), the mean response over the first four weeks (middle panel), or the mean response over the second four weeks (bottom panel) for each month in the sample. We have normalized the Bloomberg FCI so that an increase in the index represents a tightening of financial conditions. Therefore, any point estimate located above the zero line corresponds to a tightening of financial conditions in response to a negative reserve shock. Conversely, any estimate below the zero line represents a response consistent with an easing of financial conditions.
Figure 12: Time-Varying Responses of the FF-IOR Spread to a Negative 1 sd Shock in the Supply of Reserves

Note: Each point estimate reflects: the first week response (top panel), the mean response over the first four weeks (middle panel), or the mean response over the second four weeks (bottom panel) for each month in the sample.