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The financial market effects of unwinding the Federal Reserve's balance sheet☆

A. Lee Smith[a], Victor J. Valcarcel[b],*

[a] Federal Reserve Bank of Kansas City 1 Memorial Dr. Kansas City, MO 64198
[b] University of Texas at Dallas 800 W. Campbell Rd. Richardson, TX 75080

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ABSTRACT

Twice in a brief 12-year period between 2008 and 2020, central banks turned to asset purchase programs to combat a global economic downturn. While balance sheet expansions have become familiar and been widely studied, balance sheet normalization is less well understood. 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 unwinding past asset purchases tightens financial conditions. However, we show that these effects cannot be merely portrayed as *quantitative easing in reverse*. In particular, we find that balance sheet normalization generally lacked the large announcement effects that characterized quantitative easing. Instead, the effects of normalization manifested upon implementation and surfaced, in part, through larger liquidity effects than were evident during various phases of balance sheet expansion.

1. Introduction

Central bank balance sheets now play a central role in monetary policy. The COVID-19 pandemic serves as a case in point. In March 2020, as the coronavirus spread across the globe, the Federal Open Market Committee (FOMC) initiated Treasury and agency mortgage-backed securities (MBS) purchases at a rapid pace. Other central banks, including the European Central Bank, the Bank of England, and the Bank of Japan, carried out similar actions. While balance sheet reduction has proven less common, several central banks 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.
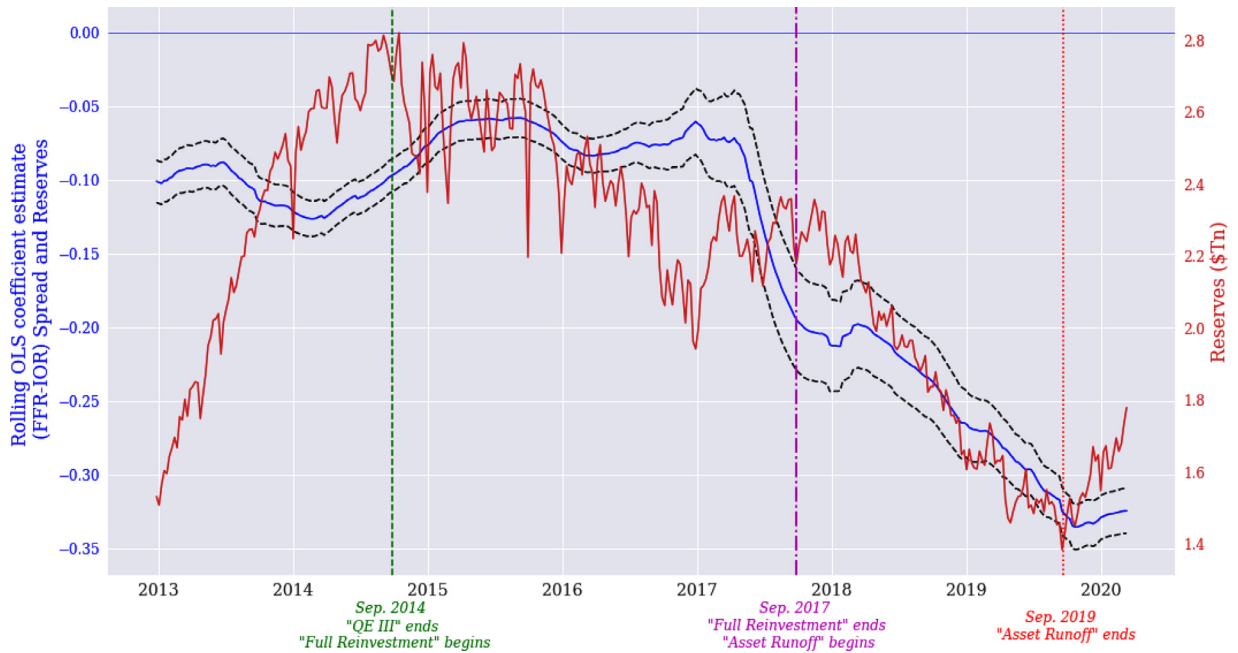
Fig. 1. The Changing Liquidity Effect Between Reserves and the (FF-IOR) Spread. *Note:* The (solid) blue line denotes the rolling regression estimate of the liquidity effect obtained by regressing the spread between the federal funds rate and the interest rate paid on reserves on a constant and the natural log of reserve balances. This estimate is flanked by a 90% 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. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Despite its importance, there is scant empirical analysis of the broad 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 event study estimates, if the effects of expanding and shrinking the central bank's balance sheet were symmetric then we could assume that reducing the central bank's balance sheet has no effect on short-term interest rates but increases longer-term bond yields. Based on the existing QE literature, one may further assume that these yield increases materialize upon the announcement of policymakers' plans for reducing its balance sheet.

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 effects 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 2009–2014 balance sheet expansion. This period is marked by the natural lower bound that zero placed under short-term interest rates despite rapid growth in reserves. Nevertheless, during the QT period from October 2017 through August 2019 bank reserves declined from more than $2.0 trillion toward $1.4 trillion amid a more than $650 billion reduction in the Federal Reserve's asset holdings. It is during this period that the magnitude of the liquidity effect roughly doubles.

In addition to differences in the liquidity effect, we also show that the large announcement effects that accompanied asset purchases were largely absent from the Federal Reserve's balance sheet normalization effort. This asymmetry appears to stem in part from the concerted effort of the FOMC to divorce expectations of future rate increases from unwinding the balance sheet, especially after the "taper tantrum" episode. This resulted in signaling effects being mostly absent from QT announcements, a sharp contrast from QE announcements that typically contained a large signaling component (Krishnamurthy and Vissing-Jorgensen, 2011). Numerous other differences amplify the distinction between the Federal Reserve's balance sheet expansion and unwind. Balance sheet reduction ensued at a materially slower pace than balance sheet expansion since assets were not actually sold but rather allowed to mature without replacement. Moreover, balance sheet normalization took place against a backdrop of relative calm, whereas asset purchases were carried out amid severe financial strains. And, unlike QE episodes where central banks were easing in unison, QT 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 unwind. To assess the importance of announcement effects regarding QT, we first carry out a high-frequency event study on the financial market impact of Federal Reserve communication related to normalizing its balance sheet. We then employ a novel structural vector autoregression (VAR) identification scheme, which leverages weekly Federal Reserve balance sheet data, to detect the effects of balance sheet normalization on financial markets that may have manifested upon implementation. The Federal Reserve's sequencing of policy actions leads us to focus on two distinct periods. From 2014-Q4 through 2017-Q3, the Federal Reserve reinvested proceeds of maturing securities. This *Full Reinvestment* phase resulted in declining reserves without a commensurate decline in asset holdings. Then, beginning in 2017-Q4 until 2019-Q3, the Federal Reserve purchased fewer assets than were maturing. This *Asset Runoff* phase resulted in declines of both reserves and asset holdings.

Time-varying and constant-parameter structural VAR models reveal evidence that during the *Asset Runoff* sample, reductions in reserve balances and asset holdings led to tighter financial conditions. This tightening is characterized by relatively large liquidity effects on short-term rates, higher yields on Treasury notes, mortgage securities, and corporate bonds, as well as an appreciation in the foreign-exchange value of the dollar, which gradually fade over several months. We conclude that—even in the absence of announcement effects—unwinding the Federal Reserve's balance sheet tightened financial conditions. However, this tightening transmits in a different fashion than merely a QE policy in reverse.

2. Balance sheet unwind transmission channels

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. Figure 2a and b 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 mortgage securities acquired through various QE programs.

Further normalization of the balance sheet required adjustments in reserves management and asset reinvestment policy. 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, as a fraction of maturing securities were allowed to runoff each month, reserves began to decline along with the size of the balance sheet. These reserve dynamics are illustrated in Fig. 2a. From October 2017 through August 2019, asset holdings declined by roughly $650 billion with reductions in both Treasury and agency debt as well as MBS holdings, as illustrated in Fig. 2b. The multiple dimensions across which the balance sheet was evolving during this period suggests financial markets could be affected in a number of ways.

Reductions in reserves may 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 primary mechanism behind that conclusion is arbitrage incentives, which should drive the federal funds rate toward 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. Arbitrage appears to be costly, leading to persistent and sometimes negative spreads between the federal funds rate and the IOR rate. Moreover, Smith (2019) and Martin et al. (2019) find evidence that this spread correlates negatively with reserves, indicating that liquidity effects remained under the Federal Reserve's post-2008 operating framework. However, the question remains whether liquidity effects strengthened after reserve balances stopped growing and began to decline.

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:

$$FF_t - IOR_t = \alpha + \beta * 100 * log(RES_t) + \varepsilon_t. \tag{1}$$

The magnitude of the coefficient β in this regression provides a reduced-form measure of the strength of the liquidity effect.[1] 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 the coefficient on reserves 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 Fig. 1. Figure 3 scatters the FF-IOR spread against bank reserves across these two samples and corroborates a visible strengthening of the pass-through from reserves to the federal funds rate spread during balance sheet normalization.[2]

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[1] From December 2008 through August 2019, shifts in aggregate reserve balances were not effectively targeting the federal funds rate (FF_t). Therefore, regressions of this form are unlikely to be biased by endogeneity concerns.

[2] Importantly, the increases in the liquidity effect that we document here and in our structural VAR models were building well ahead of the visible and highly-publicized liquidity-driven rise in repo rates that occurred in September 2019. Several recent studies have focused on the factors contributing

(a) Federal Reserve Liabilities

(b) Federal Reserve Assets
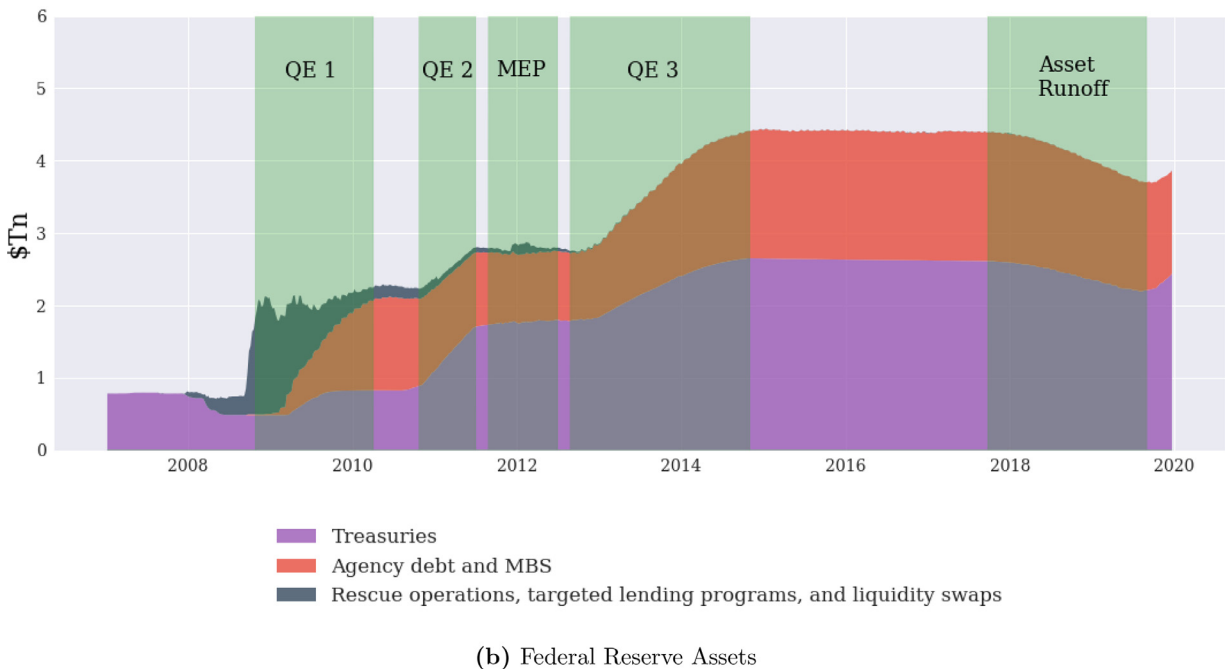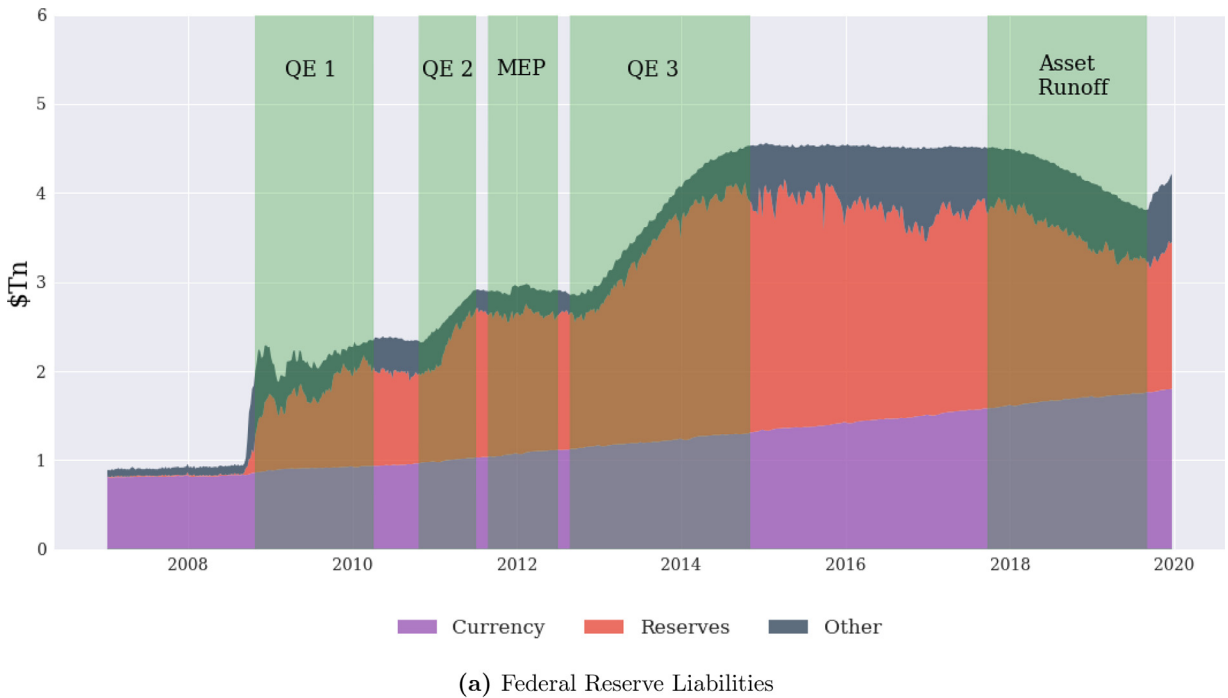
Fig. 2. The Federal Reserve's Balance Sheet: 2007–2019. *Source:* Federal Reserve Board.

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 perhaps be attributed to the

to that episode. Copeland et al. (2021) argue that reserve reductions among the 10 largest bank holding companies created payment timing stresses that contributed to the September 2019 repo rate spike. Anbil et al. (2021) document that market segmentation prevented arbitrage across repo markets, which somewhat accentuated the September 2019 repo rate spike. Finally, Afonso et al. (2020) argue that both lower reserve levels and costly arbitrage led to the September 2019 repo rate spike. We emphasize that our period of study ends ahead of the September 2019 repo rate spike, which we conservatively omit due to endogeneity concerns regarding aggregate reserve dynamics following that episode.

Fig. 3. The Liquidity Effect in Balance Sheet Expansions and Unwinds.

Federal Reserve's toolkit for managing short-term interest rates. Amid balance sheet expansion, multiple forces hemmed in the extent to which an explicit liquidity effect could be gleaned. These included the natura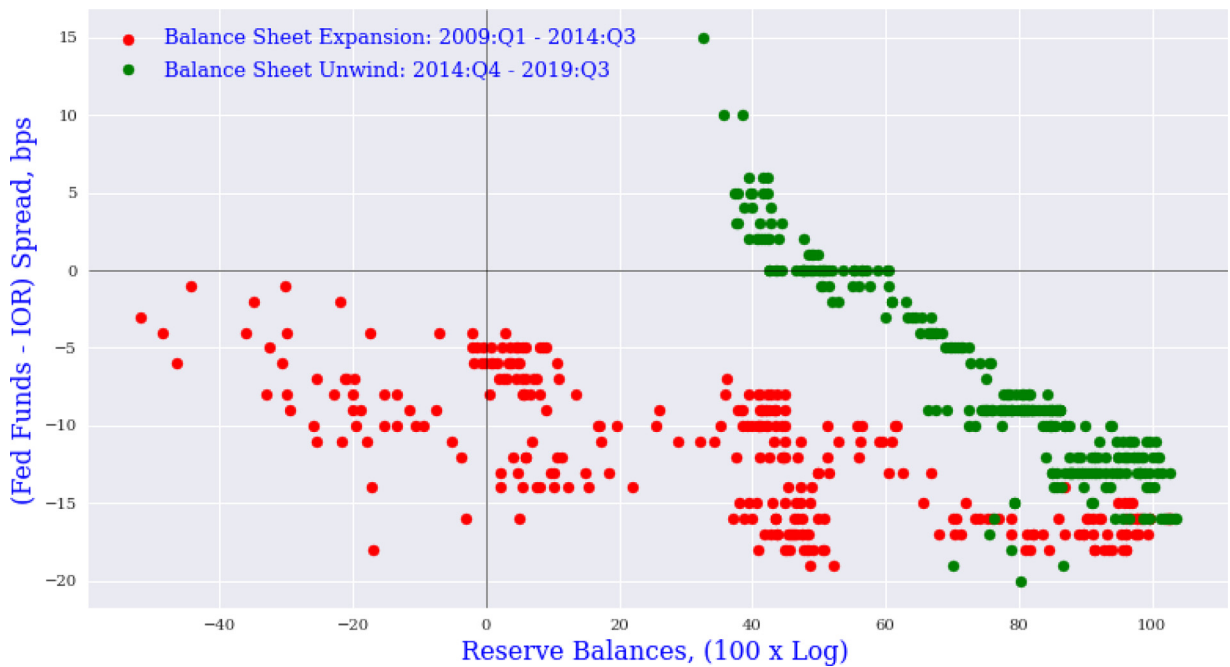l lower bound that zero placed under short-term interest rates and the Federal Reserve's deployment of the reverse-repo facility to support the federal funds rate from below. Throughout the period of balance sheet expansion, these forces limited the amount by which short-term interest rates could decline 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 throughout the balance sheet unwind period. This allows for a potentially larger degree of pass-through from reserves to interest rates, particularly from a lower base level of reserves, during a QT episode.

The reduction of asset holdings that accompanied declining reserve balances during balance sheet normalization could also affect asset prices via similar channels through which asset purchases are thought to primarily work, including signaling and duration channels. The signaling channel of asset purchases has been emphasized in Krishnamurthy and Vissing-Jorgensen (2011), Bauer and Rudebusch (2014), and Bhattarai et al. (2015). Krishnamurthy and Vissing-Jorgensen (2011) and Bauer and Rudebusch (2014), in particular, argue that the predominant factor driving the observed reductions in longer-term yields following QE announcements was downward revisions to expectations for the future path of policy rates. Therefore, shrinking the balance sheet could conversely signal that tighter policy is forthcoming and lead to higher longer-term yields due to upward revisions to expectations of the future path of policy rates.

Gagnon et al. (2011) instead interpret the observed reductions in Treasury, mortgage, and corporate yields around LSAP announcements as arising from broad duration effects. By purchasing a large amount of longer-term assets, the Federal Reserve reduced the amount of duration that the private sector was asked to bear. The runoff of assets from the Federal Reserve's balance sheet effectively transfers that duration back onto investors' balance sheets, which could increase risk- and term-premiums. Moreover, increasing the public supply of Treasury and mortgage securities could lead to a reversal of any portfolio rebalancing effects, a channel postulated by Vayanos and Vila (2021) in explaining the theoretical underpinnings for asset purchases. This mechanism was empirically emphasized by D'Amico et al. (2012), D'Amico and King (2013), Carpenter et al. (2015), and Ihrig et al. (2018). Thus, based on the arguments and evidence in favor of duration-associated portfolio rebalancing effects, reducing the balance sheet and transferring duration back into the private sector could increase longer-term interest rates across a range of assets.

However, there is also reason to believe that reductions in asset holdings would have smaller and more limited effects than did asset purchases. For instance, D'Amico and King (2013) predict that rebalancing effects could be attenuated upon normalization, if conducted in an environment of improved market functioning. Moreover, any effects that emerge from unwinding past asset purchases should be confined to those assets that the Federal Reserve purchased. In particular, Krishnamurthy and Vissing-Jorgensen (2013) propose that, aside from signaling effects, the relative transfer of Treasuries and MBS back into the hands of private investors should have concentrated effects on Treasury and MBS rates, with few spillovers to other assets.

Table 1

Quantitative Easing and Tightening Announcement Effects on Yields and Asset Prices.

	Cumulative Response to QE & QT Announcements (pp)		
	10-yr. Treas.	MBS	8-Qtr Eurodollar
QE Events[a]	-1.49***	-3.70***	-1.00***
	(0.20)	(0.34)	(0.25)
QT Events[b]	0.28	0.46	0.41
	(0.22)	(0.38)	(0.28)

[a] Coefficients β^{QE} from the regression: $\Delta y_t = \beta^{QE} QE_t + \beta^{QT} QT_t + \varepsilon_t$, where Δy_t is the two-day change in the yield and QE_t is a dummy variable, which takes a value of 1/9 on the nine QE dates described in Table 2. [b] Coefficients β^{QT} from the regression: $\Delta y_t = \beta^{QE} QE_t + \beta^{QT} QT_t + \varepsilon_t$, where Δy_t is the two-day change in the yield and QT_t is a dummy variable, which takes a value of 1/11 on the 11 QT dates described in Table 3. *Notes:* OLS standard errors are reported in parenthesis. Sample Period: January 2008 – December 2018. Observations: 4016. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 2

Quantitative Easing Announcements.

Date	Announcement	Event	Source
No. 25, 2008[a]	QE 1	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2011)
Dec 1, 2008[a]	QE 1	Speech	Krishnamurthy and Vissing-Jorgensen (2011)
Dec 16, 2008[a]	QE 1	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2011)
Jan 28, 2009[a]	QE 1	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2011)
Mar 18, 2009[a]	QE 1	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2011)
Aug 10, 2010[a]	QE 2	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2011)
Sep 21, 2010[a]	QE 2	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2011)
Sep 21, 2011[b]	MEP	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2013)
Sep 13, 2012	QE 3	FOMC Meeting	Krishnamurthy and Vissing-Jorgensen (2013)

[a] See also Woodford (2012) for a description of these events. [b]*Note:* MEP denotes Maturity Extension Program.

Our preliminary evidence suggests that the strength of these signaling and duration effects were indeed less pronounced during QT compared with QE. Importantly, both signaling and duration effects emphasize the role of expectations and, therefore, the evidence in favor of these channels primarily stems from event studies around policy announcements. Table 1 presents comparative evidence of the response of Treasury, MBS, and Eurodollar-implied interest rate expectations following QE and QT announcements. Consistent with the QE literature discussed above, we find QE announcements led to meaningful cumulative declines in longer-term Treasury and MBS rates across a select set of nine QE announcements, outlined in Table 2. Moreover, accompanying declines in Eurodollar futures-implied interest rates also took place around these QE announcements, consistent with prior evidence of signaling effects.

Conversely, dynamics surrounding the QT period stand in stark contrast. We select a set of 11 QT announcements in which the Federal Reserve publicized plans and timelines for slowing and ultimately unwinding asset purchases. No significant cumulative increases—in longer-term Treasury yields, MBS rates or Eurodollar futures rates—are observed across these QT dates. This prima-facie evidence of asymmetric effects is striking as it suggests that announcement effects differed meaningfully across QE and QT episodes. This is supportive of the notion that QT transmits differently to financial markets than merely QE in reverse.

While this analysis does not constitute incontrovertible proof, it does provide a strong indication of asymmetry—in both liquidity and announcement effects—across expansions and unwind episodes. This observation motivates the rest of our paper. We aim to complement the large literature on the effects of central bank asset purchases with an empirical examination of the financial market effects of unwinding the Federal Reserve's balance sheet.

3. Were there announcement effects during the balance sheet unwind?

We begin our analysis with an event study to detect announcement effects stemming from balance sheet normalization. While the results in Table 1 suggest that announcement effects were absent from the QT episode, our focus on the cumulative decline across all QT events could mask some degree of heterogeneity across announcement effects. Therefore, we now proceed with a more detailed analysis of individual QT announcements. We scrutinize possible differences in announcements regarding tapering or slowing purchases as distinct from unwinding past purchases, and provide some narrative interpretation for our findings.

Our event study follows a large literature that isolates the financial market effects of the Federal Reserve's QE programs by studying the responses of asset prices in small windows around Federal Reserve announcements (including Gagnon et al.,

Table 3
Quantitative Tightening Announcements.

Date	Announcement	Description
May 22, 2013[a]	Taper	Bernanke says tapering could begin "in the next few meetings"
Jun 19, 2013[b]	Taper	Bernanke states that tapering could be appropriate "later this year"
May 21, 2014[c]	Unwind	Minutes signal beginning of balance sheet normalization planning
Jul 9, 2014[c]	Unwind	Minutes discuss gradual approach to ceasing asset reinvestments
Aug 20, 2014[c]	Unwind	Minutes offer details on balance sheet normalization planning
Sep 17, 2014[c]	Unwind	FOMC releases *Policy Normalization Principles and Plan*
Jan 12, 2017[d]	Unwind	Three Fed speeches discuss normalizing the balance sheet
Apr 5, 2017[c]	Unwind	Minutes signal phasing out reinvestments "later this year"
May 24, 2017[c]	Unwind	Minutes detail plan for phasing out reinvestment
Jun 14, 2017[b]	Unwind	FOMC releases asset runoff plan, announces that runoff will begin "this year"
Sep. 20, 2017[b]	Unwind	FOMC announces that asset runoff will begin next month

[a] *Source:* The Economic Outlook Congressional Hearings, 113th Congress, Joint Economic Committee. [b] *Source:* FOMC Meeting Meeting calendars, statements, and minutes (2016-2021). [c]*Source:* Federal Reserve History of the FOMC's Policy Normalization Discussions and Communications. [d]*Source:* Ben Bernanke's Brookings Blog Shrinking the Fed's balance sheet.

2011; Krishnamurthy and Vissing-Jorgensen, 2011; 2013; Swanson, 2020, among others). Identification of such announcement effects on financial markets is premised on the assumption that markets are efficient and forward looking and, thus, expectations of policy are reflected in asset prices before policymakers make any announcement. Under this assumption, the change in asset prices following the announcement predominantly reflects the revision of policy expectations by investors and, consequently, the change in asset prices around the announcement embodies the surprise component of monetary policy. We specifically study the announcement effects on Treasury yields, MBS and corporate bond yields, as well as the foreign exchange value of the dollar, the S&P 500 index, and Eurodollar futures-implied interest rates.

We follow Krishnamurthy and Vissing-Jorgensen (2011) and study the change in bond yields and other asset prices in a two-day window around Federal Reserve announcements and extend the analysis to communication related to both tapering and unwinding asset purchases. The two-day window allows for late-in-the-day announcement effects to fully reflect through to asset prices the following trading day. As Hanson and Stein (2015) argue, empirical evidence suggests that it especially takes time for longer-term yields to fully react to FOMC announcements. The set of events we focus on is largely outlined by the Federal Reserve Board's chronology of Federal Reserve communication related to balance sheet normalization.[3] We augment this timeline of events with two key announcements related to the tapering or slowing of asset purchases. Strictly speaking, these two announcements were not necessarily focused on shrinking the balance sheet per se. Nevertheless, they may have shaped expectations about the ultimate normalization effort. Table 3 outlines the 11 dates that constitute our QT event study set. The first two events of May 22, 2013 and June 19, 2013 correspond to tapering announcements when the Committee revealed intentions to slow the pace of its asset purchases. The remaining nine events encompass the release of FOMC meeting minutes, FOMC statements, and speeches that publicized the Committee's discussions and plans specifically related to reducing the balance sheet.

In parallel to the results we show in Table 1, we generally find a limited response of Treasury yields to Federal Reserve announcements related to QT. Table 4 shows the two-day change in Treasury yields over the 11 QT event days across the 1-, 3-, 5-, 10-, and 30-year sections of the yield curve with the bottom rows registering the cumulative response across different types of events. The cumulative change across all events elicited no significant response outside of the 5-year Treasury note. However, the tepid cumulative effect across all events masks considerable heterogeneity across announcement types. The first two announcements, which were focused on the tapering of asset purchases, showed much larger responses than did any of the announcements related to normalizing the balance sheet. For some benchmark, over the January 2008 through December 2018 sample, the standard deviation of the two-day change in the 10-year Treasury yield is 0.07 percentage points. This represents a threshold that none of the nine balance sheet unwind dates reach and only the two tapering announcements exceed. The cumulative differences between taper and unwind announcements are clear in the last two rows, which show that taper announcements led to meaningful upward revisions across much of the yield curve. However, the overall effect of unwind announcements is quantitatively small and qualitatively ambiguous across the 1-, 3-, 5-, 10-, and 30-year sections of the yield curve.

Additionally, we find no significant announcement effects of quantitative tightening on broader financial markets. Table 5 duplicates the analysis of Table 4, extending it to the two-day change in MBS and corporate bond yields, as well as the foreign exchange value of the dollar, S&P 500 index, and Eurodollar futures-implied interest rates. The cumulative change in all of these yields and asset prices is statistically insignificant across all 11 events. Notably, just as we saw for the Treasury market, there is considerable heterogeneity in the response across announcement types. The tapering announcements exacted higher mortgage and corporate borrowing rates, a stronger dollar, and lower equity prices. These movements were all

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[3] This chronology is available at: https://www.federalreserve.gov/monetarypolicy/policy-normalization-discussions-communications-history.htm.

Table 4
Quantitative Tightening Announcement Effects on Treasury Yields.

		Two-Day Change in Yields (pp)				
Date	Announcement	1-yr.	3-yr.	5-yr.	10-yr.	30-yr.
May 22, 2013	Taper	0.00	0.03	0.07	0.08	0.06
Jun 19, 2013	Taper	0.01	0.14	0.24	0.21	0.15
May 21, 2014	Unwind	0.00	0.03	0.04	0.04	0.05
Jul 9, 2014	Unwind	-0.01	-0.06	-0.04	-0.03	0.00
Aug 20, 2014	Unwind	-0.01	0.05	0.05	0.01	-0.02
Sep 17, 2014	Unwind	-0.01	0.06	0.07	0.03	0.00
Jan 12, 2017	Unwind	0.00	0.01	0.01	0.02	0.03
Apr 5, 2017	Unwind	0.02	-0.02	-0.01	-0.02	0.00
May 24, 2017	Unwind	0.02	-0.03	-0.06	-0.04	-0.03
Jun 14, 2017	Unwind	-0.01	-0.02	-0.03	-0.05	-0.09
Sep 20, 2017	Unwind	0.00	0.04	0.05	0.03	-0.01
		Cumulative Response (pp)				
Event Study Regressions		1-yr.	3-yr.	5-yr.	10-yr.	30-yr.
All Events[a]		0.01	0.23	0.39*	0.28	0.14
		(0.12)	(0.19)	(0.22)	(0.22)	(0.21)
Only Taper Events[b]		0.01	0.17**	0.31***	0.29***	0.21**
		(0.05)	(0.08)	(0.09)	(0.10)	(0.09)
Only Unwind Events[c]		0.00	0.06	0.08	-0.01	-0.07
		(0.11)	(0.17)	(0.20)	(0.20)	(0.19)

[a] Coefficients β^{QT} from the regression: $\Delta y_t^n = \beta^{QT} QT_t + \varepsilon_t$, where Δy_t^n is the two-day change in the n-year constant maturity Treasury yield and QT_t is a dummy variable, which takes a value of 1/11 on the dates listed above. [b] Coefficients β^{QT} from the regression: $\Delta y_t^n = \beta^{QT} QT_t + \varepsilon_t$, where Δy_t^n is the two-day change in the n-year constant maturity Treasury yield and QT_t is a dummy variable, which takes a value of 1/2 on the first two dates above that were related to tapering. [c] Coefficients β^{QT} from the regression: $\Delta y_t^n = \beta^{QT} QT_t + \varepsilon_t$, where Δy_t^n is the two-day change in the n-year constant maturity Treasury yield and QT_t is a dummy variable, which takes a value of 1/9 on the last nine dates above that were related to unwinding past asset purchases. *Notes:* OLS standard errors are reported in parenthesis. Sample Period: January 2008 – December 2018. Observations: 4016. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 5
Quantitative Tightening Announcement Effects on Other Assets.

		Two-Day Change in Yields (pp) and Asset Prices (%)				
Date	Announcement	MBS	BBB	Dollar Index	S&P 500	8-Qtr Eurodollar
May 22, 2013	Taper	0.19	0.04	0.05	-1.12	0.05
Jun 19, 2013	Taper	0.29	0.20	1.71	-3.85	0.27
May 21, 2014	Unwind	0.02	0.05	0.03	1.05	0.03
Jul 9, 2014	Unwind	-0.05	-0.01	-0.01	0.05	-0.07
Aug 20, 2014	Unwind	-0.01	-0.03	0.25	0.54	0.05
Sep 17, 2014	Unwind	0.02	0.01	0.29	0.62	0.09
Jan 12, 2017	Unwind	0.03	0.01	-0.86	-0.03	0.02
Apr 5, 2017	Unwind	-0.02	-0.01	0.01	-0.11	-0.04
May 24, 2017	Unwind	-0.04	-0.02	-0.28	0.69	-0.03
Jun 14, 2017	Unwind	-0.03	-0.08	0.22	-0.32	-0.04
Sep 20, 2017	Unwind	0.03	-0.01	0.29	-0.24	0.07
		Cumulative Response (pp or %)				
Event Study Regressions		MBS	BBB	Dollar Index	S&P 500	8-Qtr Eurodollar
All Events[a]		0.46	0.21	1.91	-2.72	0.41
		(0.38)	(0.21)	(1.46)	(4.67)	(0.28)
Only Taper Events[b]		0.48***	0.30***	1.97***	-4.97**	0.32***
		(0.16)	(0.09)	(0.62)	(1.99)	(0.12)
Only Unwind Events[c]		-0.02	-0.09	-0.07	2.25	0.09
		(0.35)	(0.19)	(1.32)	(4.22)	(0.25)

[a] Coefficients β^{QT} from the regression: $\Delta y_t = \beta^{QT} QT_t + \varepsilon_t$, where Δy_t is the two-day change in the yield or percent change in asset price and QT_t is a dummy variable, which takes a value of 1/11 on the dates listed above. [b] Coefficients β^{QT} from the regression: $\Delta y_t = \beta^{QT} QT_t + \varepsilon_t$, where Δy_t is the two-day change in the yield or percent change in asset price and QT_t is a dummy variable, which takes a value of 1/2 on the first two dates above that were related to tapering. [c] Coefficients β^{QT} from the regression: $\Delta y_t = \beta^{QT} QT_t + \varepsilon_t$, where Δy_t is the two-day change in the yield or percent change in asset price and QT_t is a dummy variable, which takes a value of 1/9 on the last nine dates above that were related to unwinding past asset purchases. *Notes:* OLS standard errors are reported in parenthesis. Sample Period: January 2008 – December 2018. Observations: 4016. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

statistically significant. In contrast, announcements related specifically to unwinding past asset purchases caused no similar tightening. Changes in mortgage and BBB corporate bond rates were unremarkable around the nine unwind announcements. Turning to MBSs, a market which had the potential to be directly impacted by partially unwinding the Federal Reserve's MBS holdings, the two-day change in MBS rates around any of the nine unwind events fails to exceed the sample standard deviation of the two-day change in MBS yields of 0.12 percentage points. More broadly, foreign exchange and equity markets also appeared to be unfazed by the Federal Reserve's communication around unwinding its balance sheet.

This event study reveals that—while announcements related to tapering asset purchases led to a tightening in financial conditions—announcements related to shrinking the balance sheet and unwinding past purchases had no observable impact on financial markets. This disparity appears to be explained, at least in part, by differences in signaling effects. The last column of Table 5 shows the response of expectations for future short-term interest rates, as implied by the 8-Qtr ahead Eurodollar futures contract, to each announcement in our event set. We find the taper announcements incited large revisions to the expected path of future policy rates. In fact, the 0.32 percentage point movement in interest-rate futures is similar in magnitude to the 0.29 percentage point movement in 10-year Treasury yields. Therefore, the taper announcements appear to have had large financial market effects, in part, because they led to an upward revision to expectations about future policy rates, consistent with the discussion in Bernanke (2017). In contrast, the unwind announcements had no statistically significant effect on interest rate expectations, as evident from the last row of Table 5.

The lack of signaling effects, and more general announcement effects, from communication regarding unwinding the balance sheet appears to have been by design and was largely an objective of Federal Reserve officials. On June 14, 2017, one of the nine balance sheet unwind event dates we inspect, the Federal Reserve unveiled its plan for shrinking its balance sheet and announced intentions to implement the plan, "this year." However, in a concerted effort to mitigate any market reaction to this announcement, Federal Reserve Chair Yellen described the Federal Reserve's balance sheet normalization plan in the post-FOMC meeting press conference as follows (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 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)

As this quote suggests, and unlike when the Federal Reserve announced plans to expand its balance sheet, communication around unwinding past asset purchases was largely framed as an independent aspect of the policy stance. It was not intended to signal a broader shift in the path of monetary policy. For instance, in September 2017 when the Federal Reserve announced that it would begin reducing its balance sheet in October, Federal Reserve Chair Yellen took great care to outline that, "[…] changing the target range for the federal funds rate is our primary means of adjusting the stance of monetary policy. Our balance sheet is not intended to be an active tool for monetary policy in normal times." The dichotomy the Federal Reserve created between shrinking its balance sheet and adjusting the path of the federal funds rate may play an important role in accounting for the discrepancy in announcement effects across expanding and shrinking the Federal Reserve's balance sheet.

Signaling effects aside, other differences in communication provide added context in explaining the diverging effects of announcements across both regimes. Asset purchase programs were typically introduced with explicit disclosures of a precise amount of assets the Federal Reserve intended to purchase over a given period. Conversely, communication around balance sheet reductions were far less concrete. For instance, the June 14, 2017 *Policy Normalization Principles and Plans* vaguely stated that, "the Federal Reserve's securities holdings will continue to decline in a gradual and predictable manner until the Committee judges that the Federal Reserve is holding no more securities than necessary to implement monetary policy efficiently and effectively." Therefore, unlike announcements that accompanied balance sheet expansions, communication surrounding balance sheet reductions may have been too nebulous to meaningfully shape expectations regarding the evolution of the balance sheet.

The importance of unwind announcements might have further been hampered by the foregone conclusion that unwinding past asset purchases was always anticipated to take place. As early as 2008, then Chair Bernanke clearly signaled that asset purchases would be unwound in the future (Bernanke, 2008). Conversely, QE announcements —particularly those related to QE 1 for which the event study literature has found the largest financial market effects —were largely unexpected. Consequently, a common challenge to event studies could be biasing our estimates since QT was not an entirely unexpected proposition.[4]

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[4] Greenlaw et al. (2018) instead argue that the absence of any meaningful market reaction to quantitative tightening announcements suggests that changes in expectations over the size of the balance sheet have little effect on financial markets. This seems consistent with our findings if one attributes the differences across QE, taper, and unwind announcement effects to differences in rate signaling.

Given the dearth of signaling, the lack of specificity accompanying unwind announcements, and the anticipated nature of unwinding the balance sheet, any effects from unwinding past asset purchases may not have manifested themselves upon announcement. Instead, these effects more likely materialized upon implementation, an issue we turn to next.

4. Implementation effects surrounding balance sheet unwind

We pursue a flexible time-series approach to quantify financial market effects upon the implementation of balance sheet normalization. Unlike announcement effects, implementation effects can diffuse gradually over time. Event studies may be less well-suited to measure slow propagating effects. Accordingly, we employ both time-varying and constant-parameter structural VAR models. While identification is more challenging in this setting, compared with an event-study scheme, a strength of our framework is that it allows for both immediate and delayed effects from balance sheet adjustments. This is likely necessary in order to accommodate the Federal Reserve's deliberate strategy for a gradual normalization of its balance sheet in this period. Another advantage of the approach includes its ability to inform how persistent any financial market effects from unwinding asset holdings may have been. The persistence of the effects of the Federal Reserve's asset purchases has been an area of focus of several studies, with no clear consensus emerging (D'Amico and King, 2013; Swanson, 2020; Wright, 2012).

Implementation effects from reducing the Federal Reserve's balance sheet may emanate from reductions in reserve balances, through liquidity effects for instance. They may also ensue from reductions in asset holdings, such as those identified in Kandrac and Schlusche (2013), D'Amico and King (2013), and Christensen and Gillan (2022) upon the implementation of asset purchases. We incorporate both Federal Reserve liabilities and asset holdings into our structural VAR model to encompass the numerous possible aspects through which the implementation of balance sheet reduction may impact financial markets.

We, however, orient our structural identification around the dynamics of reserve balances, a Federal Reserve liability. This decision primarily reflects the FOMC's own approach to balance sheet normalization. The June 14, 2017 *Policy Normalization Principles and Plans* noted that: "The Committee expects to learn more about the underlying demand for reserves during the process of balance sheet normalization." Therefore, balance sheet normalization was guided by how the relationship between reserve balances and short-term money market rates would evolve. Reinforcing this point, the end of the balance sheet unwind process culminated on a material increase in money-market rates amid sharp reductions in reserve balances in September 2019. In response to this tightening in money markets, the Federal Reserve initiated repo operations and outright purchases of Treasuries to once again begin increasing the supply of reserves. This marked the end of the balance sheet reduction process we study. To capture these apparent linkages between reserves and short-term interest rates, we include in our structural VAR model measures of short-term secured (repo) and unsecured interest rates: the secured overnight financing rate (SOFR) and the federal funds rate.

Our consideration of these rates serves a dual purpose. First, they should help capture any liquidity effects upon normalization. Second, they provide a safeguard against the possibility that the dynamics we seek to study are contaminated by other developments shaping the Federal Reserve's balance sheet and financial markets. In addition to the approximately $700 billion 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 (Copeland et al., 2021). For instance, in a June 2018 press conference, Federal Reserve Chair Powell attributed the upward rate pressure not to declining reserve balances but instead noted:

> *I 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 toward IOER.* – (Powell, 2018)

Figure 4 shows that during the 2017–2019 *Asset Runoff* period, Treasury bills outstanding increased by nearly 30%. As Treasury supply increased, Treasury's general account (TGA) balance with the Federal Reserve also increased, which would result in reserve reductions that mimic, yet are distinct from, balance sheet reduction dynamics. Namely, increases in bill supply could increase money market rates and increase TGA balances while reducing reserve balances.[5]

We next turn to our strategy for identifying reserve supply shocks and a discussion as to why we associate reductions in reserve supply with the unwinding of the Federal Reserve's balance sheet.

4.1. Structural VAR identifying restrictions

There have been many investigations of the effects of changes in central bank reserves on interest rates, financial markets, and the broader economy (see Christiano et al., 1996; Curdia and Woodford, 2016; Demiralp et al., 2019; Iwata and Wu, 2006; Strongin, 1995, among many others). While many approaches, particularly those employing structural VAR 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.

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[5] The settlement of Treasuries purchases ultimately involves debiting a reserve account and crediting the TGA account. Indeed, TGA fluctuations have been used as an instrument for exogenous changes in the supply of reserve balances to isolate liquidity effects in the Federal Reserve's pre-crisis regime for implementing monetary policy (Hamilton, 1997).
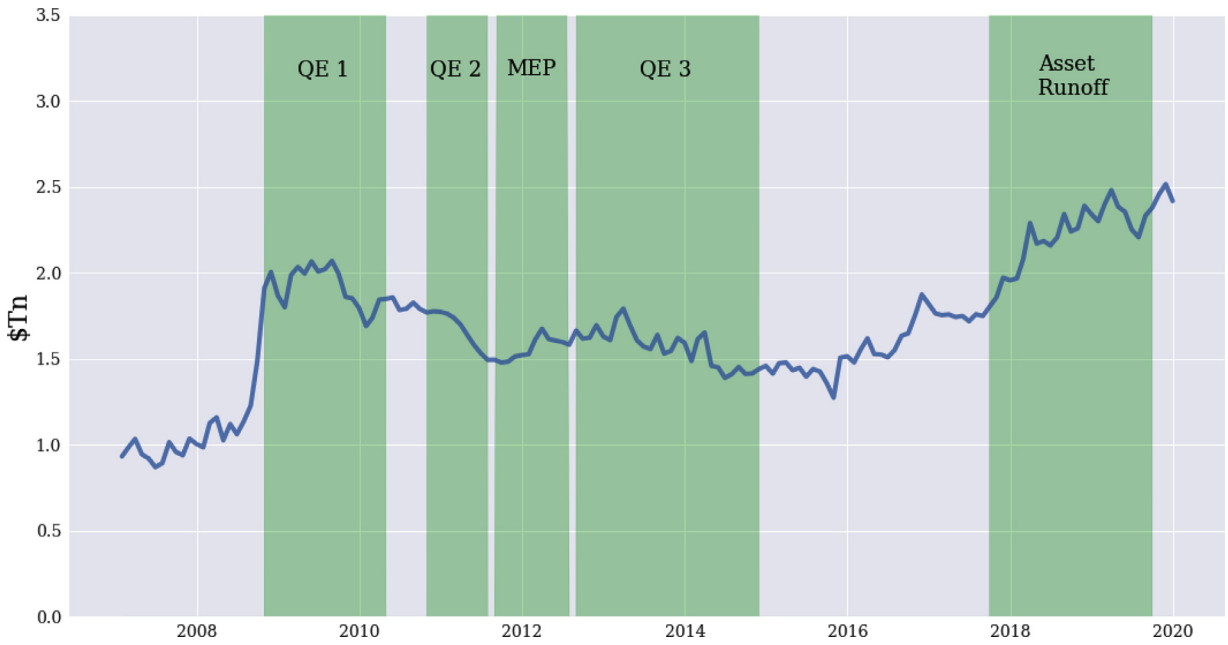
Fig. 4. Marketable Treasury Bills Outstanding: 2007–2019. *Source:* U.S. Treasury.

We pursue a similar approach by combining the Federal Reserve's approach to reserves management during balance sheet normalization with the Federal Reserve Board's week-ending-Wednesday balance sheet data. Our strategy in particular aims to isolate effects of reserve supply shocks, which are inextricably linked to the Federal Reserve's balance sheet unwind, from other forces, including fluctuations in Treasury bill supply. We achieve this distinction by assuming a block-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 formulation whereby our focus of attention—an exogenous shock in the supply of reserves—is placed first in our VAR ordering. An assumption we now defend on the basis of both the Federal Reserve's approach to implementing monetary policy as well as institutional aspects regarding the timing of Treasury auctions.

Specifically, we order reserves ahead of: the secured overnight financing rate net of the interest on reserves; the spread between the effective federal funds rate and IOR; either an index of financial conditions or the price/yield of a particular asset, denoted by Z_t; and the Federal Reserve System Open Market Account (SOMA) holdings. We denote the VAR variables by $x_t = [(100 * log(RES_t)); (SOFR_t - IOR_t); (FF_t - IOR_t); Z_t; (100 * log(SOMA_t))]'$ where t is the value of each variable as of Wednesday each week. We model these variables as a time-varying parameter VAR(p):

$$\theta_t(L)x_t = e_t \tag{2}$$

where $\theta_t(L) = I_5 - \theta_{t,1}L - \cdots - \theta_{t,p}L^p$ is a pth order lag polynomial and e_t is a mean zero vector of reduced-form VAR residuals with time-varying covariance matrix R_t.[6] We recover the underlying structural VAR by specifying the linear mapping, $e_t = P_t\epsilon_t$, between e_t, the reduced-form VAR residuals, and ϵ_t, the structural shocks of interest, where P_t is block lower-triangular. We provide further details of our implementation of the the time-varying parameter VAR model in the next section and we now turn to our restriction scheme.

We motivate our identifying assumptions based on two factors: (i) the Federal Reserve's approach for implementing monetary policy and managing reserves during balance sheet normalization as well as (ii) the structure of Treasury auctions. Regarding the first factor, until September 2019, when the FOMC ended its balance sheet normalization program, the Federal Reserve did not adjust reserve balances 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. This allows us to treat the supply curve for reserves as perfectly inelastic (vertical) within the week. However, shifts in this supply curve week-to-week could stem not only from balance sheet runoff but also from changes in Treasury bill supply which, through changes in the TGA, can feed through to reserve balances. This could ultimately affect repo markets as well as broader financial conditions.

In principle, changes in Treasury bill supply could introduce a confounding factor in our restriction scheme. However, institutional aspects of the management of Treasury auctions severely limits the ability for the Treasury bill supply to con-

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[6] We also include a constant and we use the AIC to select four lags.

taminate our identification strategy. Specifically, 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 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 TGA. 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 within 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).[7]

Based on these two factors, we interpret innovations to reserves in our specification as "reserve supply shocks" stemming from the unwinding of the Federal Reserve's balance sheet. Our sample encompasses two phases in the policy normalization efforts of the Federal Reserve. During the first phase, between September 2014 and September 2017, 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 without an associated decline in asset holdings. Thus, in this early sample, a negative reserve supply shock could arise from tax payments, an increase in outstanding reverse repos, or unexpected asset redemptions, such as more mortgage pre-payments, relative to what the trading desk at the New York Fed anticipated. In any event, the result is the same: a decline in the supply of reserves available to banks. This allows us to infer the response of interest rates and other asset prices to reductions in reserve balances since, unlike in previous operating regimes, the Federal Reserve was not attempting to counteract these reserve fluctuations (Ihrig et al., 2020). By not offsetting reserve declines, the Federal Reserve was effectively unwinding the large reserve balances accumulated from past asset purchases.

Beginning in October 2017, the Federal Reserve conducted a structured *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, in this later sample, what we identify as a negative reserve supply shock may arise from the aforementioned sources but should predominantly reflect asset redemptions related to the unwinding of the federal reserve's SOMA portfolio. To this point, SOMA holdings and reserve balances both declined by about $700 billion dollars.[8] It is in this later sample that one can glean the financial market effects of joint declines in the supply of reserves available to banks *and* reductions in the Federal Reserve's asset holdings.

4.2. The time-varying dynamics of balance sheet unwind

In light of the aforementioned changes in reinvestment policy, we allow—but do not impose—that changes in the nature of reserve reductions had a first-order effect on the transmission of balance sheet normalization to broad financial conditions. We begin our structural VAR analysis by studying the effects of negative reserve supply shocks on our core VAR variables discussed in previous sections along with a broad index of financial conditions to measure the net effect on overall financing conditions. While many such indexes are available, the Goldman Sachs Financial Conditions Index (GS-FCI) is one of the few available at a daily frequency. Figure 5 shows the time series of the weekly end-of-period (Wednesday) value of the index. The GS-FCI 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 (Hatzius and Stehn, 2018). After studying the responses of this broad GS-FCI, we then undertake a more granular analysis of the cross-asset price movements that materialize when unwinding the balance sheet.

While there was a discreet change in the Federal Reserve's reinvestment policy in October 2017, there were also gradual changes in the evolution of reserves and SOMA holdings before and after October 2017. For instance, to the extent that liquidity dynamics evolve with the level of reserve balances, we might expect a more continuous evolution of liquidity effects as reserve balances gradually declined from their 2014 peak. Moreover, while asset runoffs began in October 2017, the pace varied considerably as the Federal Reserve's caps on the amount of securities that were allowed to roll off the balance

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[7] To 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. Importantly, our identification 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.

[8] While we argue that declines in reserve balances were driven by reductions in SOMA holdings over this sample, we acquiesce to the possibility that a high degree of endogeneity may arise between reserves balances and currency in the longer run. However, we contend it is highly unlikely our reserve supply shocks, identified at a weekly frequency, could be confounded with currency demand shocks during the QT period. First, while the ratio of reserves-to-total-checkable-deposits (R/TCD) exhibits wide fluctuations around a sustained decline during the balance sheet unwind period (an almost 65% reduction between 2014 and 2019), the currency/TCD ratio remains essentially flat (less than 0.7% decrease) over the same period. Moreover, even bi-weekly movements in currency are practically dwarfed by high-frequency fluctuations in reserves, where the latter's standard deviation is 14 times larger than the former in our sample. Consequently, high-frequency currency movements would seem largely uninformative for any discernible dynamics in reserves between 2014 and 2019.
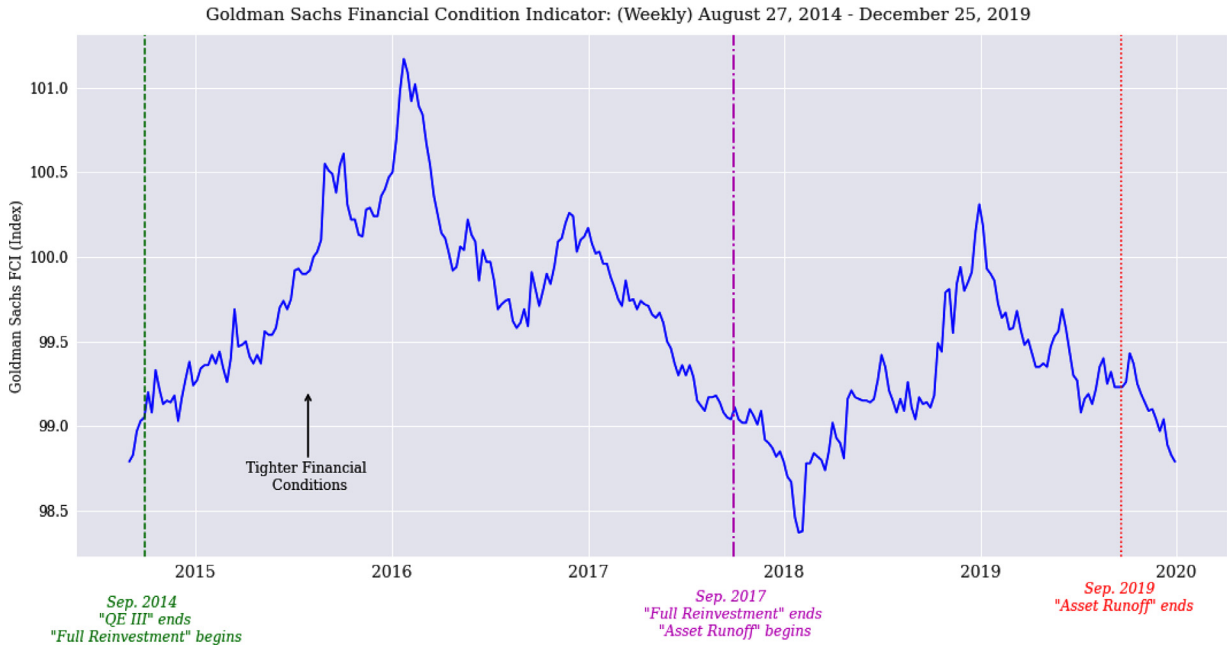
Fig. 5. Financial Conditions Before/During/After Quantitative Tightening Period. *Note:* Higher values of the GS-FCI correspond to a tightening in financial conditions. Conversely, low values indicate a loosening.

sheet gradually increased over time. Therefore, we allow the flexibility of the time-varying-parameter VAR to inform our views on how gradual were the effects from unwinding the balance sheet. We opt for this time-varying approach because it does not preclude the possibility that the change in these dynamics may not occur suddenly.[9] Consider the following VAR process:

$$\theta_t(L)x_t = e_t, \tag{3}$$

where x_t is an n-vector of endogenous time t variables; $\theta_t = I_n - \theta_{1t}L - \ldots - \theta_{pt}L^p$ is a pth order lag polynomial in which each θ 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 Θ_t represent the stacked vector of all coefficients in $\theta_t(L)$, and assume it evolves according to:

$$\Theta_t = \Theta_{t-1} + u_t, \tag{4}$$

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 et al. (2002) to estimate stochastic volatilities. We follow a variant of the multi-move stochastic volatility construct of Kim et al. (1998) to allow for time variation in the underlying VAR model.[10]

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

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

---

[9] Nonlinear dynamics in the transmission of reserve management and financial conditions could be modeled in a number of ways. Event studies, such as those we employ in our analysis in previous sections, are a popular technique to elucidate potential discontinuities. Other approaches for regime change, such as Markov Switch, GARCH or sub-samples estimated across structural break tests at unknown dates, could prove useful as well. However, we opt for a time-varying VAR approach because it allows for the possibility that these transmissions in question may have proceeded gradually.

[10] Del Negro and Primiceri (2015) argue for an alternative algorithm that allows for a more efficient implementation of Kim et al. (1998) over Jacquier et al. (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.

and

$$
H_t = \begin{bmatrix} h_{1t} & 0 & \ldots & 0 \\ 0 & h_{2t} & \ldots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \ldots & 0 & h_{nt} \end{bmatrix},
$$

respectively. The diagonal elements of H_t are independent univariate stochastic processes that evolve according to:

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

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

$$
\gamma_t = \gamma_{t-1} + \zeta_t \tag{6}
$$

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 Ψ to prevent non-zero covariance of the coefficients among different equations.

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

$$
e_t = P_t \epsilon_t \qquad \forall t, \tag{7}
$$

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:

$$
X_t = \Pi_t X_{t-1} + De_t, \tag{8}
$$

where $X_t = (x_t', x_{t-1}', \ldots, x_{t-p+1}')'$, $D = (I, 0, \ldots, 0)'$, and Π_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:

$$
\frac{\partial x_{t+h}}{\partial e_t} = s_{n,n}(\Pi_t^h) \qquad \forall t, h = 1 \tag{9}
$$

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 hth horizon:

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

In our specification with $n=5$ variables, the second-to-last variable in the order is an index of financial conditions where t is the value of each variable as of Wednesday each week. And the last variable is the week-ending-Wednesday (log transformed) SOMA balances. However, what is practically important for our block-triangular structure is that reserve balances are ordered first.

4.3. Discussion of results from the time-varying approach

We estimate a TVP-VAR with the GS-FCI placed fourth in our ordering. 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 responses to negative reserve supply shocks for every period t while averaging the responses across horizons. Figures 6–8 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 panels of these figures report the first-month responses to a negative shock in reserves (the first variable in our ordering). We collate these responses by averaging the first through the fourth week responses post shock. The middle panels show the second-month responses (averages for horizons five through eight). The bottom panels display the third-month responses (averaging week nine through week 12 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 6 shows the time-varying response of the GS-FCI to a negative shock in the supply of reserves. A negative reserve supply shock generates 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
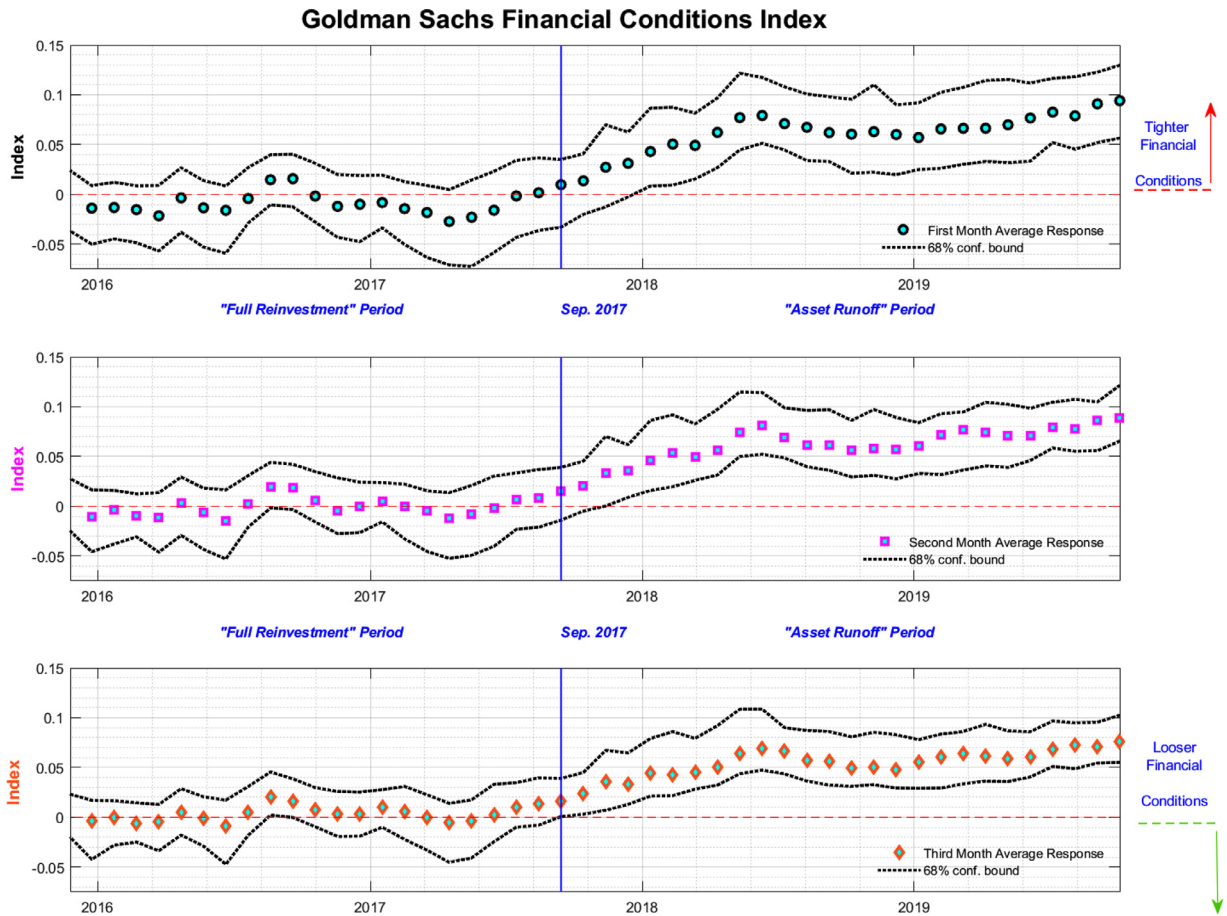
Fig. 6. Time-Varying Responses of the GS-FCI to a Negative 1 sd Reserve Supply Shock. *Note:* Each point estimate reflects: the mean response over the first four weeks (top panel), the mean response between the fifth and eighth weeks post shock (second month response in the middle panel), or the mean response between the ninth and twelfth weeks post shock (third month response at the bottom panel) for each month in the sample. An increase in the GS-FCI 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.

becomes significant early in 2018.[11] Though not shown, the response of reserves is relatively stable over time, underscoring that the increased sensitivity of financial conditions to reserve reductions after September 2017 does not simply reflect larger percent reductions in reserves.

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, Fig. 7 shows the time-varying responses of the FF-IOR spread following a one-standard-deviation reduction in the supply of reserves. We find that negative reserve supply shocks lead to positive effects on the FF-IOR spread, consistent with our interpretation of these innovations as reserve supply rather than reserve demand. Moreover, the magnitude of FF-IOR spread responses increase roughly threefold in the *Asset Runoff* period compared with the *Full Reinvestment* period. The error bands prior to 2017 tend not to overlap with those after late 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 our reduced form analysis in Section 2. Taken together, our evidence shows a more binding liquidity effect taking place

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[11] We found a similar pattern of time-variation in the response of financial conditions, when measured by the Bloomberg FCI, following a reduction in the supply of reserves. While the responses were slightly more muted in the Bloomberg specification, we again found that negative reserve supply shocks show indications of a significant tightening in financial conditions after the initiation of the asset runoff policy. We also considered 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 not available daily, these weekly Federal Reserve measures may provide a materially different perspective on financial conditions. Despite this, we found similar dynamics of the St. Louis Federal Reserve FCI response to those of the GS-FCI. 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 seemed to contract following negative reserve supply shocks during both the *Full Reinvestment* and *Asset Runoff* phases of balance sheet normalization.
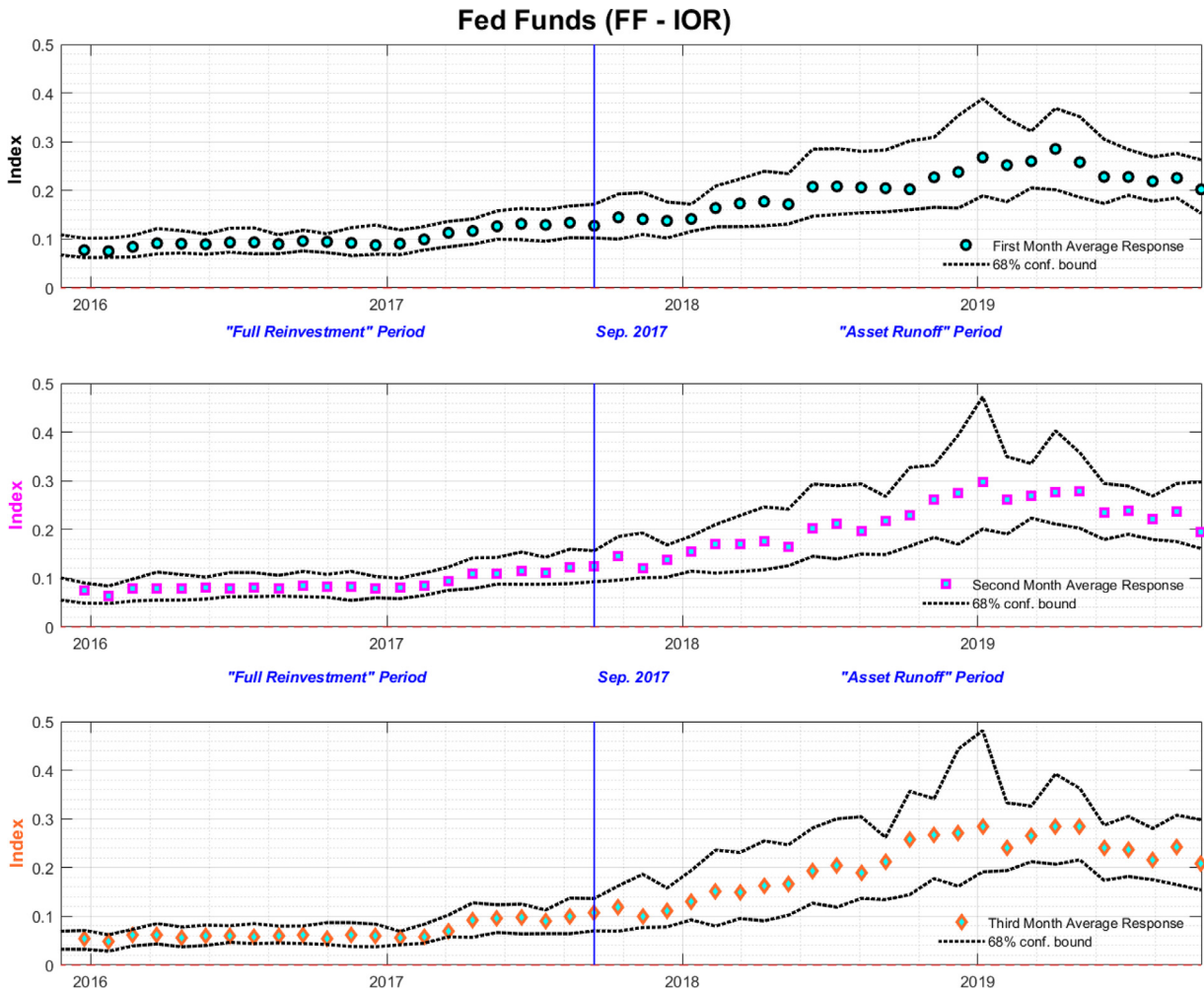
Fig. 7. Time-Varying Responses of the FF-IOR Spread to a Negative 1 sd Shock in the Supply of Reserves. *Note:* Each point estimate reflects: the first month response (top panel), the mean response over the second month (middle panel), or the mean response over the third month (bottom panel) for each month in the sample.

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.

Finally, Fig. 8 shows dynamics on the asset side of the Federal Reserve's balance sheet. The response of SOMA assets to negative reserve shocks during the *Full Reinvestment* period are small and imprecisely estimated. In contrast, the *Asset Runoff* period saw economically important reductions in SOMA holdings, compatible with our interpretation of negative reserves supply shocks emanating from asset redemptions during that phase of QT. These responses are generally consistent both in sign and magnitude with our analysis in previous sections. While it can be argued that these congruent effects on the asset and liability side of the balance sheet of the Fed could be simply mechanical, they provide for a sensible reality check on the suitability of our identification strategy. Given that SOMA assets are left wholly unrestricted and placed at the end of the VAR, these asset responses are completely driven by the data and bolster our conclusions and interpretations regarding the effects of reserve shocks on financial conditions.

Overall, these time-varying effects of balance sheet normalization support our interpretation of innovations to reserves as reserve supply shocks stemming from balance sheet normalization. In particular, our estimates show that the nature of the relationship between reserve reductions and financial conditions changed drastically after September 2017, precisely when the Federal Reserve began allowing assets to runoff of its balance sheet. The time-varying impulse responses suggest that after September 2017, declines in reserve balances arising from reductions in SOMA holdings tightened overall financial conditions. However, absent corresponding reductions in asset holdings prior to the *Asset Runoff* phase, reductions in reserve balances alone did not appear to inflict similarly adverse effects. We find liquidity effects were also markedly different across these two phases of balance sheet normalization. In the early sample, the repo- and federal funds rates responses to reserve reductions are considerably more muted when compared with the later sample. We conclude that, despite the avoidance
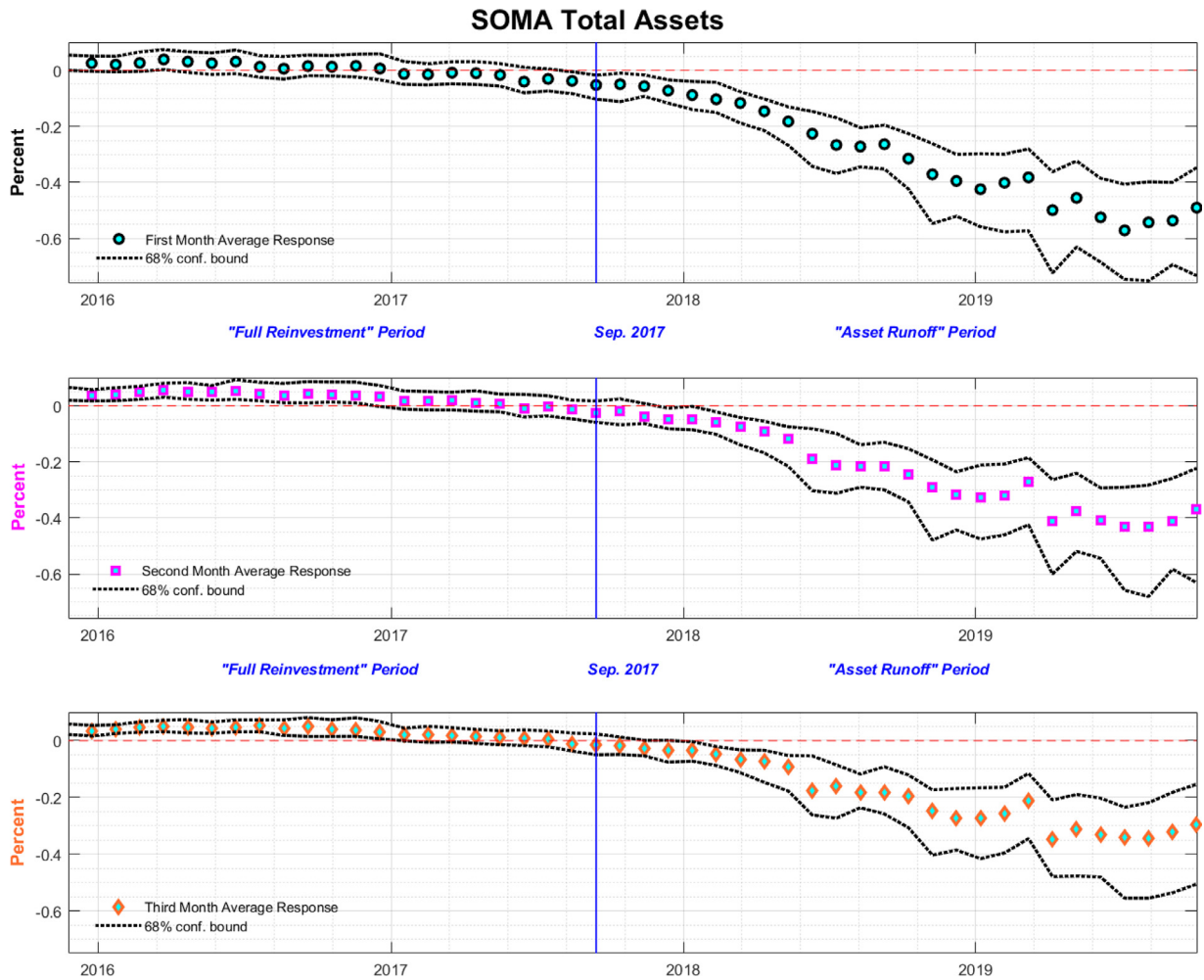
Fig. 8. Time-Varying Responses of SOMA Assets to a Negative 1 sd Shock in the Supply of Reserves. *Note:* Each point estimate reflects: the first month response (top panel), the mean response over the second month (middle panel), or the mean response over the third month (bottom panel) for each month in the sample.

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.

5. A granular look at quantitative tightening

To gain insight into the scope and nature of the tightening in financial markets, following the Federal Reserve's unwinding of past asset purchases, we now take a more granular look across asset classes. In addition, we perform a counterfactual analysis to quantify the overall effects of QT on longer-term Treasury rates. We maintain our structural identification outlined in Section 4.1 implied by the ordering of the variables in the system specified by x_t. The measure we chose for the variable Z_t embedded in x_t was the GS-FCI. We now model a constant-parameter SVAR and re-estimate our specification by rotating an indicator of financial conditions, or a particular yield or asset price in Z_t. We model these variables as a VAR(p):

$$\theta(L)x_t = e_t \tag{11}$$

where $\theta(L) = I_5 - \theta_1 L - \cdots - \theta_p L^p$ is a pth order lag polynomial and e_t is a mean zero vector of reduced-form VAR residuals with a constant covariance matrix R.[12] 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 ϵ_t, the structural shocks of interest, where P is block lower-triangular.[13]

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[12] We 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 four lags.

[13] We conduct inference on our estimated constant-parameter impulse responses from a Bayesian perspective assuming a non-informative natural conjugate prior for θ and Σ such that the posterior distribution of θ and R are centered at their OLS estimates. We closely follow Koop and Korobilis (2010) when implementing this prior.

Based on the evidence from the time-varying parameter model that shows strong evidence of deep structural change across the *Full Reinvestment* and *Asset Runoff* periods, we now study the responses of various yields and asset prices to negative reserve supply shocks arising during the *Asset Runoff* period to better understand the forces that lead the balance sheet unwind to tightening overall financial conditions.[14] In Fig. 9 we display impulse responses for reserve balances, SOMA holdings, the GS-FCI, the 10-year Treasury yield (and its implied term premium), the BBB corporate borrowing rate, the 30-year Ginnie Mae current coupon MBS rate, the foreign exchange value of the U.S. dollar against a broad basket of currencies, as well as the S&P 500 price index. For each of these variables, we estimate a separate VAR with the yield or asset of interest in place of the financial conditions index. Each structural VAR is estimated over the *Asset Runoff* period.

Figure 9 shows that, during the *Asset Runoff* period, joint reductions in reserve balances and SOMA holdings imposed broad tightening effects across financial markets, as evident by the persistent increase in the GS-FCI. As we also witnessed in the impulse responses from the TVP-VAR model, reductions in reserve balances led to increases in short-term interest rates (SOFR and fed-funds rates), consistent with liquidity effects that would arise from a negative reserve supply shock. The 10-year Treasury yield also increases as reserve balances and SOMA holdings decline, contributing to the tightening in overall financial conditions.

The increase in the 10-year Treasury rate considerably outpaces the rise in the federal funds rate, suggesting that rising term premiums underlie the increase in longer-term Treasury rates. Along these lines, if we assume the VAR impulse responses of the federal funds rate proxies the response of the expected future path of short-term interest rates, we can calculate the impulse response for the VAR-implied 10-year term premium as the difference between the impulse response for this expected future path of short-term interest rates and the impulse response for the 10-year Treasury yield.[15] The resulting VAR-implied 10-year Term Premium responses show that nearly all of the increase in longer-term Treasury rates stems from increases in the term premium. This rise in longer-term Treasury yields permeates across bond markets to corporate bond and MBS rates in largely equal magnitudes. MBS yields rise for several weeks, decaying at a similar rate as the increase in Treasury yields, whereas BBB corporate bond yields remain elevated throughout the impulse response horizon. There are also persistent effects on the broad dollar index with a protracted appreciation of the dollar.[16] Consistent with a policy-induced tightening in financial conditions, the S&P 500 index declines, although the extent of the equity market effects are imprecisely estimated.

The responses in Fig. 9 provide circumscribed evidence on potential channels and the persistence of the financial market effects from unwinding past asset purchases. Despite the fact that the literature remains quite unsettled regarding the mechanisms through which LSAPs operate, we find evidence of broad—rather than narrow—effects across assets stemming from balance sheet reductions. For instance, while balance sheet normalization involved reductions in Treasury and agency securities, our evidence shows effects of similar magnitude on corporate borrowing rates. The rise in corporate borrowing rates does not seem to differ statistically from the movements in Treasury term premia—perhaps evocative of broad duration effects. While the LSAP literature is also divided on the persistence of the effects of asset purchases, the financial market effects from unwinding the balance sheet that we have identified appear to fade after several months. Although movements in corporate bond yields and the foreign exchange value of the dollar prove to be somewhat more persistent.

Our granular analysis also sheds light on the overall impact of the Federal Reserve's balance sheet runoff program on longer-term interest rates. The estimated structural VAR effects are not permanent "stock" effects of the sort implicit in an event study. Thus, a simple visual inspection of the response of the 10-year Treasury yield at a single horizon cannot be relied upon to extrapolate the overall consequences of the runoff of asset holdings over the 2017–2019 period. Instead, the structural VAR provides dynamic responses that peak in the first several weeks and then diminish over time. This implies that the effect of QT on the 10-year yield at any point in time also depends on the extent and speed of the past runoff.

In an effort to better quantify the effects of quantitative tightening, we simulate a counterfactual scenario from the structural VAR model to infer how much QT raised the 10-year yield. Specifically, in contrast to the realized sequence of reserve supply shocks that took place amid the runoff of SOMA holdings, we assume that the FOMC instead continued to fully reinvest maturing SOMA holdings, thereby counterfactually keeping reserve balances and SOMA holdings roughly constant over the Asset Runoff sample. The difference between realized data and this counterfactual reveals that the peak effect of the $650 billion reduction in asset holdings on the 10-year Treasury yield was about 40 basis points (occurring in mid-2018) and QT raised the average 10-year Treasury yield by about 8 basis points over the entire Asset Runoff period (Oct 2017 through August 2019).[17] To provide some perspective of this estimate in the context of federal funds rate changes, the conversion in Williams (2014) suggests that this is the same movement in longer-term rates one would expect from an increase in the federal funds rate of about 40 basis points.

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[14] In results available upon request, we confirmed that the pattern of insignificance and significance of impulse responses of the GS-FCI is maintained in the constant parameter VAR model across the two samples. Additionally, this standard VAR found substantially more muted responses of SOMA holdings, as well as Repo spreads, in the Full Reinvestment period—also consistent with results from the TVP-VAR counterpart.

[15] Specifically, for each impulse response horizon $h = 0, \ldots, 28$, we define the expected path of short-term interest rates over the next 10 years by $ExpectedPath_h = \frac{1}{520} \sum_{\tau=1}^{520} FF_{h+\tau}$. Then, we define the VAR-Implied 10-year Term Premium by $TP_h^{10-yr} = Treasury_h^{10-yr} - ExpectedPath_h$.

[16] Chari et al. (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.

[17] For comparison, Swanson (2020) reports that, based on the LSAP literature, $600 billion in medium- and longer-term Treasury purchases lowers the 10-year Treasury rate by 15 basis points. Therefore, our estimates of the effects of QT are within the range of estimates (and standard errors) from the LSAP literature.

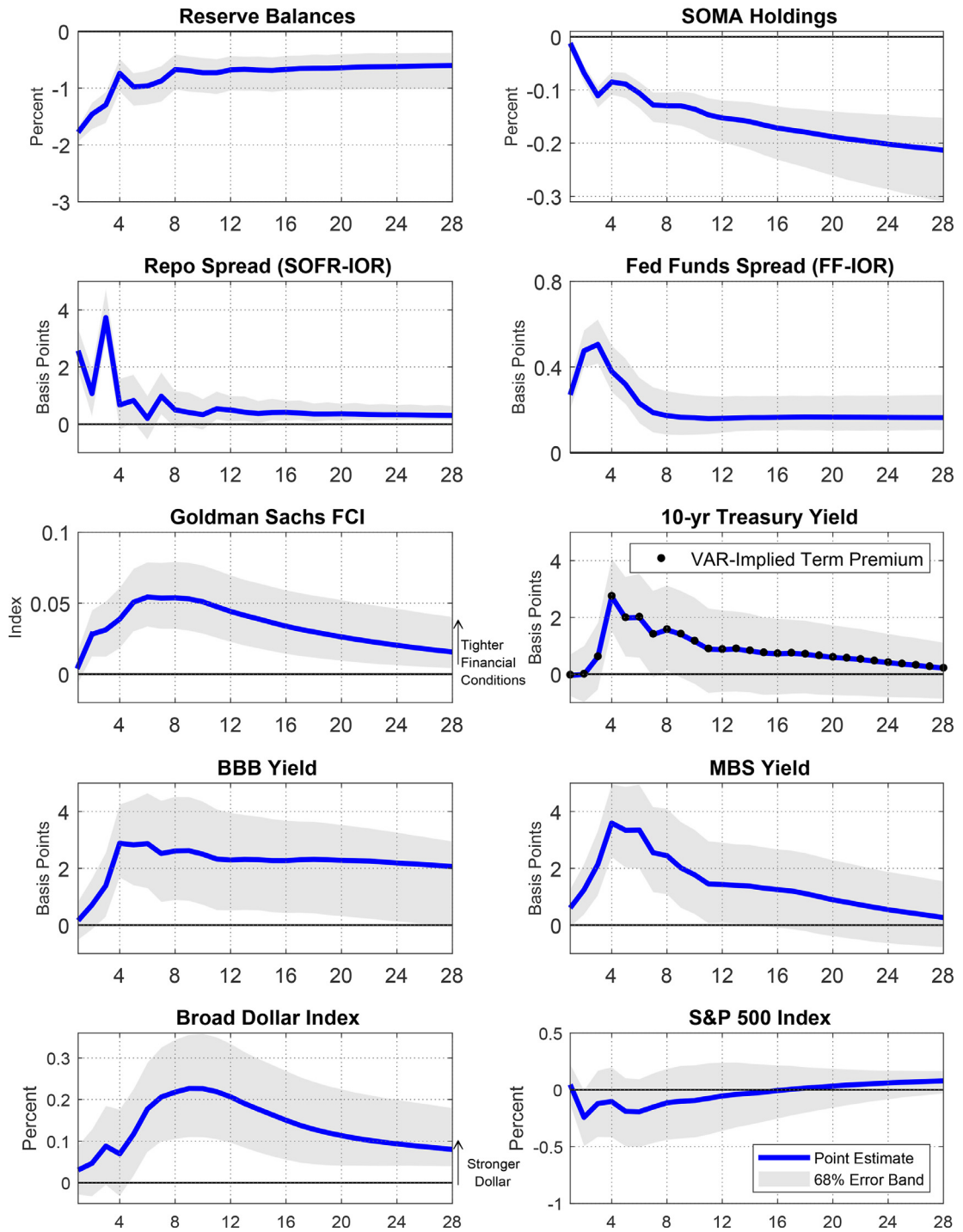## Asset Runoff Sample: 10/4/2017 - 8/28/2019

Fig. 9. Responses of Individual Yields and Assets to a Negative 1 sd Reserve Supply Shock. *Note:* Each subplot shows impulse responses from a separately estimated structural VAR model (with the exception of the Reserve Balances, SOMA Holdings, GS-FCI, Repo Spread, and the Fed Funds Spread responses, which are from a single VAR model). 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.

An interesting question that arises from these findings is: Given the known maturity date of Treasury SOMA holdings, what is it about the runoff of the balance sheet that raises longer-term Treasury rates?[18] One explanation may come from research showing that even largely anticipated events, such as Treasury auctions, can have a discrete effect on financial markets at the time of the event due to underlying frictions and slow-moving capital (Lou et al., 2013). Therefore, one implication of our work for central banks unwinding their balance sheets is that even a well-telegraphed reduction in asset holdings may nevertheless have tightening effects once executed.

6. Conclusion

The Federal Reserve, the European Central Bank, the Bank of England, and the Bank of Japan all took actions to expand their balance sheets amid an unprecedented global economic contraction caused by the COVID-19 pandemic—all the while constrained by a dearth of available conventional policy space. As central banks normalize their balance sheets, 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 financial market 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.

We provide a preponderance of evidence—from the TVP-VAR model as well as constant-parameter VAR models—that, despite the avoidance of announcement effects by the Federal Reserve, the combination of reductions in the asset holdings and declining reserve balances from late 2017 through much of 2019 strained financial conditions. 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 a QE policy 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. Consequently, 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 research on this important monetary policy issue.

Data availability

Data will be made available on request.

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[18] Even if the maturity of Treasury holdings is known, the runoff of MBS securities was stochastic as a result of unpredictable pre-payment patterns.

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