A Skeptical View of the Impact of the Fed's Balance Sheet

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ABSTRACT/EXECUTIVE SUMMARY

We review the recent U.S. monetary policy experience with large scale asset purchases (LSAPs) and draw lessons for monetary policy going forward. Most previous studies have found that quantitative easing (QE) lowered long term yields, with a rough consensus that LSAP purchases reduced yields on 10-year Treasuries by about 100 basis points. We argue that the consensus overstates the effect of LSAPs on 10-year yields. We use a larger than usual population of possible events and exploit interpretations provided by the business press. We find that Fed actions and announcements were not a dominant determinant of 10-year yields and that whatever the initial impact of some Fed actions or announcements, the effects tended not to persist. In addition, although the Fed began the transition to a smaller balance sheet sooner than the market had expected, the announcements and implementation of the balance-sheet reduction do not seem to have affected rates much. These observations lead us to conclude that the effects of LSAP are likely more modest than generally claimed. Going forward, we expect the Federal Reserve's balance sheet to stay large. This calls for careful consideration of the maturity distribution of assets on the Fed's balance sheet. Our conclusion is that the most important and reliable instrument of monetary policy is the short term interest rate, and we discuss the implications of this finding for Fed policy going forward.

In this paper we review the recent U.S. monetary policy experience with large scale asset purchases and use our review to draw lessons for monetary policy going forward.

In response to the financial crisis and the Great Recession, the Federal Reserve instituted a series of rate cuts that lowered the overnight rate effectively to zero in December 2008. With a perceived need for further loosening, and with the overnight rate stuck at the zero lower bound, the Federal Reserve turned to unconventional policy. One of its major unconventional tools involved large scale asset purchases (LSAPs) of long term Treasuries and other securities. A voluminous literature has found that such purchases affected long term yields. Perhaps a consensus figure is that the programs lowered the 10 year Treasury yield by about 100 basis points (for example, see Borio and Zabai (2016)).

The Federal Reserve has recently begun to scale down the size of its balance sheet. This raises the question of whether downsizing will have effects comparable in magnitude, but opposite in sign, to the effects associated with expansion of the balance sheet. And quite apart from transitional effects, there is the issue of whether LSAPs should play a regular role as a monetary policy tool.

Recent reviews of the impact of LSAP programs include Borio and Zabai (2016), Dell'Ariccia et al. (2017) and Kuttner (2017). We build on these studies by providing new evidence on the overall importance of LSAPs in driving real and nominal 10-year bond yields.

Our paper is organized roughly chronologically. Sections 2 and 3 review the theory of conventional and unconventional monetary policy. Sections 4 and 5 present new evidence on the U.S. experience with QE programs, with Section 4 focusing on expansion of the balance sheet and Section 5 on the period from the first hints of tapering to the initial stage of unwind. Section

6 considers the future evolution of the balance sheet, both empirically and theoretically, as well as some linkages to fiscal decisions. Section 7 makes policy recommendations.

In more detail:

We begin our paper (Section 2) by reviewing how monetary policy worked before the financial crisis. Our view is similar to the standard textbook version–raising or lowering the overnight rate leads to changes in long term yields, including real private borrowing rates. We also note that considerable econometric evidence indicates that such adjustments in the overnight rate have persistent effects on long rates.

Section 3 reviews the theory of unconventional monetary policy. In our view, negative interest rates have limited potential. And forward guidance, which is powerful in theory, is not easy to implement effectively in practice. Forward guidance aside, large scale asset purchases (LSAPs) can work through a portfolio balance channel. This channel is ruled out in many standard economic models, but could arise under some formulations of preferred habitat or other market imperfections. How effective LSAPs might be in practice is very much an empirical question. The cross-country and historical evidence suggests that the monetary authority is able to influence long rates through LSAPs. The relative contribution of forward guidance versus portfolio balance is unclear, as is the magnitude of the effect.

Section 4 takes a closer look at the effectiveness of the Fed's LSAP programs. We note that we are not commenting here on the potential effectiveness of the emergency loans that the Fed initiated in September and October of 2008, but begin our analysis with the large-scale purchases of Treasury and mortgage-backed securities that came later. In event studies such as Gagnon et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011), the researcher studies a

handful of key dates where the Fed clearly moved the markets. We argue that this is useful for finding "clean" experiments, but is less useful for gauging the sustained, full impact of LSAPs.

We instead adopt two more comprehensive approaches. First, we examine changes in yields on "Fed News Days"—all days of FOMC announcements, release of minutes and policy-related speeches by the Fed Chair. The sum of these should capture the general impact of the Fed over time, along with some noise for days on which the Fed didn't matter much. Second, we look at any day on which there is a one-standard deviation change in bond yields, and use the Reuters bond market wrap up to label the cause of the bond market move that day. We use "Reuters Fed News" as a label for a day in which bond yields change by one standard deviation and Reuters attributes the change in part to news about Federal Reserve statements or actions. We use labels such as "macro data" and "Europe news" for Reuters attributions on other one standard deviation days. We focus on days where there was at least a one standard deviation change in bond yields on the assumption that it is easier for Reuters to identify the cause of market moves when the move is large.

Skeptics of QE point out that yields generally rose during the implementation of each round of QE—QE1, QE2 and QE3. Consistent with that finding, our analysis produces smaller policy impacts than in event studies focusing on big announcements. In particular, we find that yields tend to rise on "Fed Days" and "Reuters Fed News" days that are subsequent to the big surprise days. We do not attempt to establish why this is the case. One possibility is that market participants eventually decided that the initial response represented an overreaction, or they had anticipated a subsequent flow of announcements that never materialized. Another is that some responses in non-Fed days were so strongly colored by market views of Fed policy that, despite the Reuters attribution, those responses should be properly be counted in part as a "Reuter Fed

News" day. A third possible factor, as noted in Hamilton and Wu (2012) and Greenwood, Hanson, Rudolph, and Summers (2016), is that the Treasury unexpectedly undercut the Fed's programs, thereby muting any possible portfolio balance effect. We note that our finding is consistent with studies such as Swanson (2017) that find that the effects of forward guidance die out very quickly.

Section 5 begins our discussion of the exit from unconventional policy by analyzing events from the first talk of tapering through the early stages of balance sheet normalization in 2017. Our procedure attributes most of the bond market sell-off during the 2013 "taper tantrum" to better economic news rather than to changing expectations for the end of balance sheet expansion. And even when plans for exit were gelling, a comparison of January 2017 survey answers with actual outcomes reveals that the Fed was more hawkish than market participants expected (for example, starting shrinkage sooner than expected). Nonetheless, there did not seem to be much of a market reaction – a phenomenon we describe as the "shrinkage shrug." Consistent with the conclusions from Section 4, the implication would seem to be that movements in the balance sheet, and surprise decisions about the balance sheet, have modest and uncertain effects on yields.

Section 6 looks ahead at the evolution of the balance sheet. Because of normal growth in the economy and changes in operating procedures, we expect the balance sheet to start to expand again after a few years, even if the Fed follows its planned unwind over the nearer term. Some Federal Reserve documents (for example, Federal Reserve Bank of New York, 2017) present a scenario in which the average reserve balance ends up around $100B. We think this is unrealistic absent a significant change in the Fed's current operating procedures. Among other

factors, Treasury balances and reverse repurchase agreements are so large and volatile that offsetting them with small reserve balances could produce big spikes in interest rates.

On a related but distinct topic, Section 6 also considers policy aspects of the duration of assets on the balance sheet. We endorse recent Treasury moves to make its decisions about the weighted average maturity of the debt more predictable and model driven. This would allow the Fed to be last mover, making it less likely that Fed and Treasury actions will work at cross purposes when the Fed is adjusting its balance sheet. We also note some of the tradeoffs involved in the Fed's decisions about duration.

Section 7 makes policy recommendations. The starting point is our view that LSAPs have uncertain effects. The most important and reliable instrument is control of the short term interest rate. In terms of the balance sheet, we recommend a "Treasuries first" policy, with the Fed perhaps holding a small amount of MBS to signal that purchases of MBS are not completely out of the question. The Fed should mostly hold short term Treasury securities. Finally, in terms of the ongoing unwind, the Fed should consider larger and looser caps on the amount of redemptions.

Our overall conclusion is that the size of the Fed's balance sheet is less potent in moving the bond market than as perceived by many and should not be viewed as a primary tool of monetary policy going forward.

2. Monetary policy goes from conventional to unconventional

Let us begin with an overview of conventional monetary policy transmission, as practiced in the pre-crisis period. Suppose the monetary authority—from now on, the Fed—wishes to stimulate the economy. Then it lowers the target rate for federal funds rate. When the target rate

falls, in general, so, too, does the whole spectrum of interest rates, on private as well as public loans, and on loans of all maturities. This, in turn, triggers a general easing of financial conditions. Because prices and expected inflation are sticky, this fall in nominal rates also lowers real rates. This stimulates interest-sensitive private sector expenditures such as home construction..

Needless to say, the lags from interest rate adjustment to economy-wide response are long and variable. The transmission mechanism to the macroeonomy is not within the scope of our paper, however, and we henceforth abstract from such transmission and focus on movements of long term interest rates in response to monetary policy decisions.

A number of studies have concluded that Fed actions had significant effects on long-term yields during the pre-2008 period (see among others Cook and Hahn, 1989 and Kuttner, 2001). These papers find that yields on Treasuries of all maturities move in the same direction as that of the target rate, with the effect monotonically declining with horizon. There is variation in the response in different decades. But, to oversimplify, these papers indicate that a 100 basis point surprise cut in the target rate results on impact, in roughly a 50-75 basis point decline in Treasuries with less than one year to maturity. The impact effect diminishes with maturity, with 20 or 30 year Treasury yields falling by roughly 10-20 basis points.

The previous paragraph inserted the word “surprise” before “cut.” The empirical literature finds a difference between expected and surprise components of changes in target rates. This is consistent with models of the term structure of interest rates. Long term rates are the sum of two components, the average of expected future short term rates, and a term premium. Changes in an overnight rate such as the federal funds rate can potentially affect the path of both components. But to the extent that the change in the target rate is anticipated, the actual

adjustment of the interest rate will cause little to no adjustment of the path of expected future rates and hence have a diminished impact: market participants will incorporate anticipation of the Fed's future target for the short rate into the pricing of current long-term yields. Changes in current or expected future short-term rates could affect market risk premia. An example of an empirical study that concludes that adjustments in short rates affect both expected future short rates and term premia is Hanson and Stein (2015).

This conventional view overlooks forward guidance that stands apart from an interest rate adjustment, a distinction we do make in our discussion of unconventional policy below. It also abstracts from a possible direct effect of Fed words or actions on bank balance sheets or on asset prices other than bonds. Nonetheless, we take our description to capture a central element of how monetary policy affects the economy in periods such as the pre-crisis era.

As an empirical matter, surprise adjustments of short rates importantly affected both shorter and longer rates not only on impact but persistently. The fact that movements in short rates are persistent is stylized fact in macroeconomics, often captured with a lagged interest term in a monetary policy rule. In term of longer rates, research includes Bernanke, Boivin and Eliasz (2005) and Gertler and Karadi (2015), who find 5 and 10 year yields still responding to monetary policy shocks one to two years after the shock (with mixed statistical significance).[1] As well, Bekaert, Cho and Moreno (2010) find that term structure variables respond persistently and significantly to monetary policy shocks for roughly a year, with monetary policy the dominant determinant of term structure factors. We shall suggest below that in the era of unconventional

[1] Gertler and Karadi's baseline results are for a sample that runs to 2012. Their robustness results indicate the cited result applies to a sample that ends in 2008. Ramey argues that in studies such as these magnitudes and even signs of responses may not be robust. However, inspection of her graphs indicates that persistence of response is a robust feature.

policy, it is not obvious that monetary policy decisions had a persistent and dominant effect on long rates.

For the transition from the pre-crisis era to the present, Exhibit 2.1 lists some key programs and events. The cut in interest rates in September 2007 was probably viewed by most as the usual beginning of an easing cycle. But the financial crisis brought forth a vigorous response that went well beyond interest rate cuts. The now-defunct programs such as those listed in line (2) of Exhibit 2.1 were intended to stabilize the financial system rather than provide the sort of stimulus that comes from lowering interest rates, and we shall not have occasion to say anything more about these programs.

Once the zero lower bound was reached in December 2008, lowering rates could not be accomplished by lowering the federal funds target. So various programs, labeled in Exhibit 2.1 --as QE1, QE2, the maturity extension program, and QE3 were introduced.[2] Such programs aimed to start the process of lowering the whole yield curve[3] by targeting rates on long maturity bonds. The logic is described in the next section. In terms of mechanics, those programs involved announcements and actions to purchase certain long maturity bonds.

Exhibit 2.2 displays the assets of the Federal Reserve since the end of 2002. These quintupled between 2007 and 2014 and stood at $4.5 trillion at the beginning of 2018. This balance-sheet expansion came in two distinct phases. The first came in the Fall of 2008 in the form of a variety of programs to provide emergency loans including Term Auction Credit, the Commercial Paper Funding Facility, and currency swaps. These are indicated by dark purple in Exhibit 2.2. As noted above, our paper does not address the potential efficacy of this first phase

[2] As discussed in the next section, precedents for these programs include "Operation Twist" in the U.S. (Swanson (2011)) and various programs in Japan (Michaelis and Watzka (2017)).
[3] And, in the case of MBS purchases, to specifically help the housing market.

of using the Fed's balance sheet. Our analysis instead focuses on the later expansion of Fed holdings of Treasury bonds (shown in pink) and mortgage-backed securities (MBS, in turquoise) purchased in QE1, QE2, and QE3. The pink and turquoise regions measure the par value of these securities. On average, the Fed paid a price slightly above par in acquiring these. The Fed does not report a breakdown of the premium on Treasuries versus MBS, so Exhibit 2.2 follows the convention of the H.4.1 release in treating unamortized premia net of discounts as a separate asset.

Exhibit 2.3 shows how these assets were financed in terms of the liability side of the Fed's balance sheet. Note that by definition, the cumulative height in Exhibit 2.3 is identical to Exhibit 2.2. Of the $4.5 T in assets at the start of 2018, about half were financed by deposits of financial institutions held at the Fed (purple), a little more than a third by currency in circulation (green), and most of the rest from the Treasury's Fed balance (in yellow) and reverse repos (orange). The latter can be thought of as collateralized loans to the Fed primarily coming from money market funds

3. The impact of unconventional policy

3.a. How unconventional policy works in theory

As noted in the previous section, traditional monetary policy operates through control of short-term interest rates. But the fed funds rate was brought essentially to zero by the end of 2008. There are three options available to the central bank to try to provide additional stimulus in such a situation. First, the central bank can try to push nominal interest rates into negative territory. Second, the central bank can use forward guidance to try to communicate its intended future path for the policy rate. Third, the central bank can purchase other assets (or "twist" its

asset holdings) to try to influence long-term interest rates or the exchange rate. Asset purchases can be further broken down in terms of the kinds of assets bought and the operating procedures within which the purchases are implemented. We now discuss each of these options in turn.

3.a.1. Negative interest rates.

The Federal Reserve has paid a modest positive interest rate on excess reserves since the fall of 2008. But the ECB and central banks of Sweden, Switzerland, Denmark, and Japan ended up imposing fees on some deposits held at the central bank, which can be viewed as a negative interest rate on those deposits. If a bank lends its central bank deposits to another bank overnight, it could avoid the fee, though this just passes the deposits to another bank. Banks are willing to pay another bank to take the deposits off their hands, and in equilibrium, the interest rate on interbank loans, like the interest rate on deposits held at the central bank, will be bid into negative territory.

An individual bank could also avoid the fee by purchasing a government security from another bank, sending its deposits to the other bank. Again, aggregate deposits with the central bank do not disappear as a result of such transactions. But the result will likely be that the interest rate on government debt becomes negative as well.

Exhibit 3.1 updates the analysis of Alsterlind et al. (2015) of the experience in Sweden. The Riksbank lowered its policy repo rate to -0.25% in March 2015 and had brought it down to -0.50% by February of 2016. The interest rates on 3-month loans between banks and 2-year government debt quickly became negative as well, and even the 2-year mortgage rate was negative by June of 2016. By driving the policy interest rate negative, the central bank thus has a tool with which it could encourage additional borrowing and spending.

Another way banks could avoid the fees is by withdrawing their deposits with the central bank in the form of cash. Hoarding cash is sufficiently costly and inconvenient that it has not been a major factor in the countries experimenting with negative rates, though it could become more important if the central bank tried to drive the interest rate deeper into negative territory. Moreover, retail customers might hoard cash to avoid even modest charges. This may be one reason that many banks have been reluctant to fully pass the charges along to customers, as seen in Exhibit 3.2. Studies by Heider, Saidi, and Schepens (2016) in the Euro Area and Eggertsson, Juelsrud, and Wold (2017) in Sweden found distinctly less pass-through of the policy rate into aggregate lending rates once the policy rate became negative.

To the extent that the negative rates are not fully passed through to customers, the policy amounts to a tax that decapitalizes banks at a time when maintaining the health and stability of financial institutions may be a key policy goal. Heider, Saidi, and Schepens (2016) and Eggertsson, Juelsrud, and Wold (2017) found that the more important customer deposits were as a source of bank funding, the slower the growth in lending from the bank once interest rates become negative. Eggertsson, Juelsrud, and Wold (2017) noted that as a result of this effect, the net consequences of negative interest rates on aggregate spending could actually be contractionary, a possibility also demonstrated by Brunnermeier and Koby (2016).

The net stimulatory potential of bringing the policy rate from 0 down to -0.50% thus is likely not very large, and it's probably not possible to go much below this without encouraging more widespread unproductive hoarding of cash. Some authors, including Goodfriend (2016) and Rogoff (2016) noted that additional measures could be considered to utilize negative rates more aggressively, such as banning large-denominational currency to further raise the cost of

hoarding cash. In the absence of such institutional changes, the potential stimulus from negative interest rates seems very limited.

3.a.2. Forward guidance.

When the federal funds rate reached its effective lower bound, everyone expected that one day the U.S. would eventually return to a regime of positive interest rates. If the Fed can effectively promise to keep rates low for a longer period, this could potentially be a source of stimulus even while interest rates are still at the lower bound. For example, anticipation of higher inflation in 2016 could in principle influence the spending decisions of consumers and firms in 2009. In many economic models, if one takes the anticipation of policy in the distant future as something that can be arbitrarily changed, adjusting those expectations turns out to be a powerful tool for stimulating the economy at the zero lower bound (ZLB). Indeed, this tool is predicted by theory to be so powerful that some researchers have developed doubts about the theoretical models themselves; see for example Del Negro, Giannoni and Patterson (2012) and McKay, Nakamura and Steinsson (2016).

The Fed made its first stab at forward guidance at the August 9, 2011 FOMC meeting, issuing the following statement:

> "The Committee currently anticipates that economic conditions–including low rates of resource utilization and a subdued outlook for inflation over the medium run–are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013."

Swanson and Williams (2014) noted that in the month prior to this FOMC statement, the Blue Chip consensus was that the fed funds rate would not be raised until 3 more quarters. After the statement, the estimate jumped to 7 or more quarters (see Exhibit 3.3), demonstrating that the Fed indeed has the power to influence market expectations with statements like this one.

But what exactly was the Fed communicating? Campbell et al. (2012) noted two possibilities, both inspired by stories from Greek mythology. In "Odyssean forward guidance," the Fed with announcements like this is committing itself to a future course of action, like Odysseus bound to the mast of his ship, even though the Fed might later wish it could make a different choice. By contrast, in "Delphic forward guidance," the Fed, like the Oracle of Delphi, is simply communicating information it has that the market does not. Such information could either be about the Fed's own preferences—you may not know it, but we're really doves at heart, and that's why we're not about to raise interest rates—or about the Fed's superior knowledge of the state of the economy—the economy is in much worse shape than you think, and that's why we're not about to raise rates. The former would presumably serve as an expansionary Delphic signal, whereas the latter could lead to further pessimism and actually make the situation worse. Empirical analysis by Campbell et al. (2012) and Nakamura and Steinsson (forthcoming) concluded that the second Delphic channel, operating through the Fed's superior information about weak fundamentals, accounts for a significant component of the market's reaction to Federal Reserve communication of its future intentions. Bhattarai, Eggertsson and Gafarov (2015) presented an alternative model in which LSAP is effective because it generates a credible signal of low future real interest rates in a time-consistent equilibrium.

3.a.3. Large scale asset purchases.

The other main policy tool that the Fed relied on during the period of exceptionally low interest rates between 2009 and 2014 was open-market purchases of securities in very large volume. In contrast to the potentially strong role for forward guidance in many macroeconomic models, large-scale asset purchases (LSAP) for an economy at the zero lower bound would have no effect on inflation, nominal interest rates, or any real variable in most standard models. The

reason is that if the public's demand for high-powered money is already saturated, purchasing any asset with newly created Federal Reserve deposits does not change the pricing kernel that determines any asset price or private spending decision (see for example Eggertsson and Woodford, 2003). As Ben Bernanke put it just before he stepped down as Chair of the Federal Reserve, "the problem with QE is it works in practice, but it doesn't work in theory."[4] Here we consider different possible channels whereby the purchases might have an effect by distinguishing between the kind of securities purchased and the way the program is implemented.

Large-scale purchases of Treasury Securities. A Federal Reserve purchase of a long-term Treasury security essentially swaps one liability of the U.S. government (for example, a 10-year Treasury note) for a very short-term liability (interest-bearing overnight deposits with the Federal Reserve). While a Modigliani-Miller Theorem (for example, Wallace, 1981) might suggest that the maturity composition of outstanding government debt does not have any real effects, in practice the Treasury pays a premium when it issues long-term debt instead of short, apparently willingly compensating bond holders for absorbing a state-contingent risk that the Treasury or the Fed would otherwise have to bear. For example, if a higher fraction of publicly held Treasury debt is of short duration, in some states of the world the Treasury might be forced to raise distortionary taxes or the Fed tolerate higher inflation in a situation where they would prefer not to be forced to do so. Hamilton and Wu (2012) and Eggertsson and Proulx (2016) proposed this as one possible mechanism whereby LSAP could end up exerting real effects, essentially as a form of Odyssean state-dependent forward guidance which could potentially influence long-term interest rates through both an expectations component and the term premium.

[4] See https://www.ft.com/content/3b164d2e-4f03-11e4-9c88-00144feab7de.

Woodford (2012) noted that Fed purchases of Treasury securities could also have real effects by influencing a possible safety premium. Financial institutions use certain safe assets like Treasury securities as collateral in repo transactions, which gives these securities value beyond that associated with their state-contingent pecuniary returns alone. Central-bank purchases or sales of long-term Treasury securities might be able to affect the size of the safety premium, and thus affect long-term yields even in the absence of any change in the expected path of short rates. The theoretical model in Caballero and Farhi (2017) provided one way to represent such effects.

More generally, LSAP could have real effects whenever some investors have preferences for bonds of certain maturities or are limited in the set of securities they are willing to buy. If this is the case, a decrease in the supply of a particular security (for example, if the Fed buys up a significant fraction of outstanding long-term Treasury bonds) would increase the price of those securities and depress the yield on those bonds relative to others. This channel is typically described as a "portfolio balance effect," an extreme version of which assumes that certain institutions are completely unable to hold certain securities. Theoretical models incorporating versions of this idea include Chen, Curdia and Ferrero (2012), and Greenwood and Vayanos (2014).

Large-scale purchases of other securities. In addition to purchasing Treasury securities, the Federal Reserve also bought large quantities of mortgage-backed securities, a strategy sometimes referred to as "targeted asset purchases" or "credit easing." Again this would have no impact on mortgage rates in models like Eggertsson and Woodford (2003), but portfolio-balance effects could allow these purchases to affect yields as in Curdia and Woodford (2011) and

Gertler and Karadi (2011). Some of the empirical evidence surveyed below suggests that purchases of MBS had a stimulatory effect over and above that of the Treasury purchases.

Using LSAP to target exchange rates or interest rates. Large-scale asset purchases could in principle be specified in terms of quantities (buy so many billions of long-term Treasuries, for example) or in terms of fixed price targets (keep on buying until the 10-year yield reaches a specified target). Again, unless the central bank can somehow commit to a particular policy rule once the economy escapes from the zero lower bound, no volume of purchases could achieve a specified target for the 10-year yield under the assumptions in Eggertsson and Woodford (2003).

In September 2017, the Bank of Japan adopted a version of this in the form of yield curve targeting, announcing its intention to purchase Japanese government bonds (JGB) so that the 10-year JGB yield would remain at around zero percent. One could argue that the policy so far has been successful. The 10-year JGB yield has remained around 7 basis points since the Bank's announcement, a period when 10-year German yields rose 20 bp and 10-year U.S. Treasuries rose by 50 bp. However, it may be that yield curve control only works if interest rates and inflation expectations are already low. Yield curve control came after years of low interest rates and deflation, making it easier to maintain the peg.

The Swiss National Bank tried to commit to a target exchange rate, but gave up in January 2015. When it did give up, the franc appreciated 30% against the euro in a day, leading to a capital loss to the Bank of 50 billion francs. Svensson (2003) argued a binding commitment to price level target path, a currency depreciation with a crawling peg, and an exit strategy could produce a "foolproof" way to avoid a deflationary spiral for an economy stuck at the zero lower bound. However, it's not clear how real-world policymakers can or should bind themselves to such commitments. Continuing to make ever larger purchases in an effort to achieve a target that

might prove to be fundamentally infeasible sets the central bank up for an arbitrarily large capital loss when it eventually capitulates.

3.b. Empirical evidence of the effects of large-scale asset purchases

There are now a large number of academic studies that try to estimate empirically the effects of unconventional policy. Our review in this section supplements many previous surveys of this literature including Williams (2014), Fischer (2015), Gagnon (2016), Borio and Zabai (2016), and Kuttner (forthcoming).

3.b.1. Pre-ZLB evidence on the relation between debt supplies and interest rates.

A number of researchers have looked at data prior to the ZLB for evidence that the maturity composition of outstanding Treasury debt has an effect on the yield curve. One natural experiment came in 1961 with "Operation Twist", in which the Treasury and Fed made a concerted effort to lower the fraction of long-term Treasury debt held by the public. Modigliani and Sutch (1966) found no evidence in quarterly data that Operation Twist had any effect on the term structure. But Swanson's (2011) high-frequency analysis of changes in interest rates on key announcement days concluded that Operation Twist may have lowered long-term yields by 15 basis points. Swanson noted that relative to the size of the economy, the magnitude of Operation Twist was comparable to the changes implemented in QE2, suggesting that QE2 perhaps also reduced long-term yields by 15 basis points. Hamilton and Wu (2012) found in monthly data over 1990-2006 that the maturity structure of Treasury debt had predictive power for bond yields, which they interpreted using a no-arbitrage affine model of the term structure of interest rates. Their empirical estimates suggested that if the Fed in 2006 had sold off its entire holdings of Treasury bills (about $400 B at the time) and used those funds to retire all of the outstanding Treasury debt longer than 10 years in duration, investors would have been willing to surrender

all of that long-term debt to the Fed if the 10-year yield fell by about 13 basis points. Other studies that found a historical empirical relation between the maturity structure of Treasury debt and long-term interest rates include Roley (1982), Bernanke, Reinhart, and Sack (2004), Gagnon et al. (2011), Li and Wei (2013), and Greenwood and Vayanos (2014). Our reading of this evidence is that the Fed has some ability to influence long-term yields through this channel, but the magnitude of the effect is modest.

Another test of the preferred-habitat view comes from looking at changes in yields in narrow windows associated with Treasury auctions. Since the auctioned supplies are known well in advance, observed changes in yields at the time of the auction must result from shifts in demand for specific securities. Gorodnichenko and Ray (2017) concluded from the correlations between volumes and yields that a $30 B increase in the demand for a particular security would be associated with a 3.3 basis-point decline in its yield.

Fieldhouse, Mertens and Ravn (2017) suggested that another natural experiment comes from exogenous regulatory changes over 1967-2006 in the quantities of MBS that Fannie and Freddie were allowed to purchase and hold for their own account. The authors concluded that a 1% increase in mortgage originations purchased by the GSE's would lead to a 10-15 bp drop in mortgage rates.

3.b.2. Cross-sectional differences in response to LSAP.

Several papers have used panel data to study how responses of individual banks or mortgages differed under various LSAP regimes. QE1 and QE3 included purchases of MBS whereas QE2 did not. Moreover, the MBS purchases covered only mortgages that qualified for securitization by Fannie or Freddie. Di Maggio, Kermani, and Palmer (2016) found that originations of qualifying mortgages tripled under QE1 whereas there was little change in other

mortgages. By contrast, they found no difference between qualifying and nonqualifying mortgage origination during QE2. Rodnyansky and Darmouni (2017) found that banks with more MBS holdings increased lending during QE1 and QE3 relative to banks with less MBS exposure, but did not find a statistically significant difference for QE2. Chakraborty, Goldstein, and MacKinlay (2016) found that a bank's loan originations were statistically predicted by an interaction term between the bank's exposure to MBS and the previous year's Fed purchases of MBS in a panel regression that included year fixed effects.

3.b.3. Event studies.

The most common methodology to try to assess the effects of LSAP and forward guidance relies on event studies. Unconventional monetary policies were a response to deteriorating economic fundamentals. Thus when one finds a correlation between the policy measures and lower interest rates, there is a potential ambiguity as to whether the low interest resulted from unconventional monetary policy or from weak fundamentals. The idea behind event studies is that if we look at a sufficiently narrow window around the time of the announcement of a new policy, the announcement by the central bank itself is likely the factor responsible for the market response.

The most dramatic example comes from the March 18, 2009 FOMC announcement of its intention to purchase an additional $300 B in long-term Treasury securities, $100 B in agency debt, and $750 B in agency mortgage-backed securities by year end. The yield on the 10-year U.S. Treasury fell by nearly 50 bp within minutes of the announcement (see Exhibit 3.4).

There is little doubt that the Fed's announcement was the cause of the market response. But it's not clear exactly how we should interpret this response. Was there a forward guidance component to the Fed's announcement, with the decision to purchase securities underscoring its

commitment to keep the rate low for an extended period? And could some of the market response be due to a Nakamura and Steinsson (forthcoming) Delphic effect in which the market was responding to the Fed's communication that the economy was in an even more dire condition than private analysts had perceived. Alternatively, was the market interpreting the announcement as a signal of even more aggressive measures to come? We will explore the market response to Fed announcements these in detail in Section 4.

The typical event study collects a series of dates of announcements like that on March 18 and looks at the change in yields in narrow time windows around those announcements. Gagnon et al. (2011) proposed 8 dates on which key QE1 announcements were made. Other researchers have used subsets or expansions of this set of dates. Exhibit 3.5 lists the first 5 dates, which formed the basis for the analysis by Krishnamurthy and Vissing-Jorgensen (2011). These include four statements prior to the March 18 announcement that communicated the likelihood of large-scale asset purchases. Exhibit 3.5 describes these statements and summarizes the change in 10-year Treasury yields on the day of each announcement, the cumulative change on the day of and the day after the announcement (Krishnamurthy and Vissing-Jorgensen's preferred measure), and the change within 30 minutes of the announcement (a tighter window than that used by many subsequent researchers). The 10-year yield fell a total of 100 basis points on the 5 days when the Fed's willingness to conduct QE1 was revealed, with half of this move coming in response to the March 18 announcement alone. Other analysts have then divided this cumulative change by an estimate of the total volume of securities purchased to come up with an estimate of how much the Fed can reduce the 10-year yield by purchasing another $100 B in long-term securities. For example, Fischer (2015) calculated that in all of QE1, the Fed purchased $1,250 B in MBS, $172 B in agency debt, and $300 B in Treasuries for a total QE1 purchase of $1,722

B, which might suggest that an additional $100 B in LSAP could lower yields by 100 bp/17.22 = 5.8 bp.

Krishnamurthy and Vissing-Jorgensen (2011) added three key announcement dates associated with QE2, which are also summarized in Exhibit 3.5. The third, when QE2 was actually announced, might seem to be the most important of these, though Krishnamurthy and Vissing-Jorgensen omitted this from some of their summaries on the grounds that the announcement was widely anticipated, and that if there was any surprise it was that some traders were expecting even larger purchases.

Other researchers have used additional dates in their event studies. For example, Gagnon et al. (2011), Glick and Leduc (2012), and Bauer and Rudebusch (2014) added Aug 12, Sep 23, and Nov 4, 2009 to the 5 QE1 dates in Exhibit 3.5 to measure effects of contractionary QE1 announcements in addition to the expansionary announcements. Glick and Leduc (2012) and Rogers, Scotti and Wright (2014) added speeches by Fed Chair Bernanke on Aug 27 and Oct 15, 2010 as additional important announcements about QE2. Wright (2012) and Swanson (2017) added every FOMC statement release to the set of relevant announcements.

Clearly the dates one uses and how they are used strongly influences the conclusions one draws, an issue that we will revisit in detail in Section 4. Three recent summaries have concluded that LSAPs lowered rates by about 100bp, a consensus view that we question in the next section.

- Gagnon (2016) argues that "QE can be especially powerful during times of financial stress, but it has a significant effect in normal times with no observed diminishing returns." (p. 1) He tabulates the results from 18 studies, including 11 event studies, for the US. He concludes that that the median estimates suggest that US QE programs

reduced 10 year yields by about 1.2 pp (p. 4). It is worth noting that the median from his table is heavily influenced by studies of QE1, which is by far the dominate focus in studies of US QE.

- Borio and Zabai (2016) argue that "there is general agreement that large-scale asset purchases did have sizable effects on financial conditions." Their rough estimate of the impact of all the Fed programs on ten year yields is "on the order of -100 basis points" (p. 13). Averaging across studies, yields were pushed down 76 bp under QE1, but only 28 and 7 bp respectively for QE2 and QE3. As we discuss in the next section, this raises the question of whether the impacts diminished over time or became more anticipated and hence harder to see.
- A third summary comes from a speech by Vice Chair Fischer at the U.S. Monetary Policy Forum event in 2015. He cites a somewhat smaller set of studies, noting that QE1 lowered yields by as much as 100 bp, while acknowledging that the "documented effects" of "subsequent programs are generally smaller." He concludes that asset purchases "provide meaningful stimulus."

3.b.4. Interpreting event studies using structural models.

Changes in interest rates in narrow windows around these announcements have also been used in combination with various structural models to arrive at a more detailed interpretation of the effects of LSAP and forward guidance. Bauer and Rudebusch (2014) used an affine term structure model to decompose the change in the term structure of interest rates on any given announcement day into a component that reflected expectations of future short term rates and a term premium in the hopes of measuring the relative importance of forward guidance and preferred habitat effects. They found that more than half of the observed effects on long-term

yields could be attributed to the expectations component, suggesting that the Fed may have been using LSAP as a way to communicate more effectively its intention to keep interest rates low after liftoff. Swanson (2017) considered two- or three-variable principal-component representations of the response of the yield curve to monetary policy announcements, and argued that one particular linear combination of these factors could be interpreted as forward guidance news and another as LSAP. He concluded that both components had substantial and highly statistically significant effects on medium-term Treasury yields, stock prices, and exchange rates. Zhang (2017) interpreted the changes in the term structure on announcement days using an empirical adaptation of the Gertler and Karadi (2011) model. She found that LSAP and forward guidance made comparable contributions to interest rates, though in terms of that theoretical model, the implications for output and inflation of the LSAP were more important than the forward guidance.

3.b.5. Structural vector autoregressions.

Other researchers have sought to estimate the effects of unconventional monetary policy using vector autoregressions in which shocks to LSAP are partially identified on the basis of sign restrictions; examples include Baumeister and Benati (2013) and Hesse, Hofmann and Weber (2017). Alternatively, Stock and Watson (2012) and Gertler and Karadi (2015) showed how responses of interest rates in a narrow window around monetary policy announcements could be used as part of a structural vector autoregression to estimate the effects of forward guidance and LSAP.

4. Event studies and the expansion of the Fed's balance sheet

4.a. Introduction

Clearly event studies are central to assessments of the effectiveness of unconventional policy. In this section we take a critical look at the literature and offer our own evidence on how 10-year Treasury yields—both nominal and real—respond to Fed news.

- First (Subsection 4.a.1 below), we look at the usual process for selecting events in these studies. As we just noted, many studies focus on only a few key events since their objective is to explore the transmission mechanism using a "clean" experiment. However, if the objective is to measure the size and duration of the effects, this narrow focus could be a serious problem. If news arrives gradually over time, or if there is a rethinking in the market, the narrow focus on a few days could be misleading.
- Second (Subsection 4.b), we step back and look at the "population" of potential events and show that that on average during important "Fed Days"—all FOMC announcements, releases of minutes and policy-relevant speeches by the Chair—bond yields tended to move in the "wrong" direction, rising when the Fed was in expansion mode (2009-12) and falling as the Fed signaled tapering and moved toward the exit (2013-17).
- Third (Subsection 4.c), we present a new event study approach where we allow the business press to tell us what factors moved the market each day rather than choosing the dates ourselves. This captures more of the flow of Fed news and allows us to control for other factors that moved the markets. In our view, this approach is more consistent with the way a transparent central bank conveys its intentions to the market. Again, we find many days in which Fed news was associated with a reversal of some of the bond market movement that occurred on the big announcement days.
- Fourth (subsection 4.d) we adopt a more narrative approach and look more closely at QE1—the episode that seems to offer the strongest evidence of QE effectiveness. We argue

that initial big moves on the two key announcement days probably exaggerate the sustained impact.

Subsection 4.e presents our conclusions. We do not attempt to distinguish between portfolio balance or signaling or other channels. We do read the evidence as indicating that while unconventional policy works, the impacts are more modest and uncertain than some summaries of the literature suggest. In particular, we are skeptical about relying too much on the average "bang for the buck" estimates from recent reviews of the literature.

4.a.1 Finding events

Event studies depend on the ability to measure the size of the surprise. For economic data releases, it is generally assumed that the consensus of economists represents expectations in the market.[5] For policy rate announcements, expectations are measured by looking at what is priced into forward markets. Presumably that is a relatively good measure, at least for participants in the federal funds market. For unconventional policy changes, however, measuring the surprise is much more difficult. Surveys of market participants can help. To our knowledge, there are only a handful surveys from the business press of market participants balance-sheet expectations in the run-up to QE1. More recent episodes have more detailed surveys and the Federal Reserve Bank of New York has had a comprehensive survey of primary dealers since January 2011. However, it is impossible to construct a complete time series on unconventional policy expectations. We argue that the lack of an objective measure of what is priced in can create a bit of circularity in the identification of surprises: the researcher may find the event in part by looking for big market responses that are consistent with priors.

[5] This is not as good as it seems. A common question prior to data releases is "what is the whisper number?"—that is, which way is the market leaning going into the number. "Market" expectations and the consensus of economists are not always the same.

In a world of "policy transparency" the challenge to event studies is even greater. A transparent central bank will endeavor to avoid surprising the markets. Rather, they strive to "teach" the markets what their reaction function is so that markets can price in the policy change as economic and other pertinent news arrives. They also try to steer markets through testimonies, speeches, minutes, press conferences and other more informal communication. In a perfectly transparent policy world, formal policy announcements should be small events or even nonevents. Shocking the markets with a formal policy announcement would be a sign of poor communication.

The event study literature has tended to use as a starting point dates used in the pioneering studies, sometimes with a few modifications. We described above two pioneering studies, the Gagnon et al. (2011) study of QE1 and Krishnamurthy and Vissing-Jorgensen (2011) which added QE2 dates. Those authors recognized the importance of choice of dates. For example, Gagnon et al. (2011) used a set of eight baseline events and a broader set of 23 days. For their baseline events, bond yields moved down a total of 117 bp on five of the eight days and up 25 bp on the other three days for a net decline of 91 bp.[6] For their broader set of events, the net decline in yields was only 55 bp.[7] Krishnamurthy and Vissing-Jorgensen (2011) acknowledged that they may be missing other "true" events, but argue that "for the objective of analyzing through which channels QE operates, omitting true event dates does not lead to any

[6] Presumably there is on 1 bp rounding error.

[7] The authors are careful to acknowledge the limits of what they are doing. "we examine changes in interest rates around official communications regarding asset purchases, taking the cumulative changes as a measure of the overall effects. In doing so, we implicitly assume that: 1) our event set includes all announcements that have affected expectations about the total future volume of LSAPs, 2) LSAP expectations have not been affected by anything other than these announcements, 3) we can measure responses in windows wide enough to capture long-run effects but not so wide that information affecting yields through other channels is likely to have arrived, and 4) markets are efficient in the sense that all the effects on yields occur when market participants update their expectations and not when actual purchases take place." (p 48)

biases" (p226). They also note that "for estimating the overall effect of QE, omitting potentially relevant dates could lead to an upward or downward bias" (p226). As we shall see, our results underscore the sensitivity of results to choice of dates and of the importance of the caveats noted in these two papers.

4.a.2 A three pronged approach

With these concerns in mind, let's go back to square one and take a deeper look at unconventional events. One inconvenient fact cited by skeptics of QE like Woodford (2012) and Cochrane (2017) is the fact that bond yields rose during each round of QE (Exhibit 4.1).[8] Note that for these, and subsequent charts, we have included shaded areas for the period of buying under the three QEs. This is meant to orient the reader rather than imply that the impact of QE comes during the implementation phase rather than the announcement phase. Of course, the rise in nominal yields during QE expansions could be consistent with the idea that QE boosts inflation expectations. The rise in real yields is harder to justify but could reflect the fact that QE was priced in before it started and that other news dominated the bond market as the actual buying took place. Nonetheless, this is an optical challenge for fans of QE.

4.b First prong: looking at the unconventional population

Digging deeper this seems to be more than an optical problem. Our first step is simply to look at the "raw data"—the evolution of bond yields on three kinds of "Fed Days": FOMC policy announcements, the release of minutes and policy-relevant speeches by the Fed chair from late 2008 to the end of 2017.[9] These days capture announcements related to the balance sheet

[8] Interestingly, a similar chart for the S&P 500 suggests a very high correlation between the growth in the balance sheet and the rise in stock prices. This relationship has disappeared in the last few years as the equity market continues to rally even as the Fed exits.

[9] We include all days where the Chair spoke or testified about the economy or monetary policy. The Board website includes PDFs for the prepared remarks. Note that our bond yield data comes from Bloomberg. Using Federal Reserve data does not alter the results.

(including both buying and maturity extension) and forward guidance on interest rates, as well as dovish or hawkish language from the Fed that helped signal potential policy changes. Focusing on these days should give a sense of whether the "population" of most of the days that event studies draw on is likely to produce supportive results. Of course, this includes days where the Fed did not signal anything new. It also misses occasional market-moving signals from FOMC officials other than the Chair. Finally, as with all event studies, it does not capture the market's endogenous recalibration of Fed expectations in response to changing economic news. Note that the bond market was open on 2374 days over this period and there were 255 Fed Days.

Focusing on these days, we would expect bond yields to move in line with dovish and hawkish shifts at the Fed. In particular, yields should drop on average on Fed Days during the period where the Fed was expanding its unconventional policies, and yields should rise on Fed Days during the period of tapering and subsequent exit from QE. Other news on these Fed Days, such as data releases, should more or less wash out.[10]

Exhibit 4.2 shows the cumulative market moves on Fed Days. In particular, the chart shows the moving sum of the change in yields, with the actual change in yields on Fed Days and with zeros for all other days. The raw data show the challenge in finding major cumulative QE effects. Bond yields fell on Fed Days at the start of QE1, but the cumulative sum of moves on Fed Days trends higher through the rest of the period of expanding policy. Of course, some of the rising trend might be due to the Fed disappointing the market by not being sufficiently expansionary. Even if so, the implication is that Fed Days did not on net lower yields. Similarly, during the exit period, starting in 2013, bond yields initially rose when Bernanke's May 21, 2013, talk triggered the taper tantrum, but have drifted lower since, including this year

[10] In theory, the Fed news on these days could be a reaction to other news that day; in practice, the Fed rarely responds on the same day to news.

as the Fed warned and then announced balance sheet shrinkage. Looking at these broad periods, the market only moved strongly in the "right direction" at two big turning points—the two surprise announcements of QE1 and the surprise signal of tapering.

Exhibits 4.3, 4.4 and 4.5 show the three kinds of Fed Days separately. We attribute to Fed meeting announcements a roughly neutral effect over the course of policy expansion. The days when minutes were released seem particularly hawkish over this period. This may reflect the fact that the minutes represent the whole Committee, including some nonvoting hawks.[11] Bond yields tended to rise on days when the Chair spoke about the economy and/or monetary policy. None of the subsets of Fed Days looks very promising for finding strong balance sheet effects with the right sign.

Exhibit 4.6 cumulates all non-Fed Days. On a somewhat discouraging note, this chart looks like one would hope to see on Fed Days—a cumulative drop of 200 to 300 bp over the period of policy expansion. Obviously other things are going on here: as we argue later, the big drop in yields in the middle of the sample can be attributed mainly to the crisis in Europe. However, this underscores the fact that yields tended to rise on Fed Days even during a period where yields were under downward pressure on other days.

As a final step, Exhibit 4.7 decomposes the net change in yields into days where yields went up or down. The third and fourth rows show the period of expanding policy from November 2008 to just before the taper tantrum in 2013. During this phase, bond yields went up

[11] Both the "Street Economists" on this paper, Greenlaw and Harris, maintain hawk-dove charts as part of their research product. They tend to rate the regularly voting governors as more dovish than the regional presidents who rotate on and off the Committee.

on more days than they went down. The big down move days—consistent with policy "working"—are not really representative of the overall "population" of Fed Days.[12]

In our view, these raw results suggest two kinds of challenges for event studies. First, the population of "events" that some of these studies draw on looks quite puzzling. We don't think the answer is to throw out the seemingly "counter intuitive" days because they are necessary to gauge the sustained net impact of unconventional policy. For example, at times the markets overshoot in terms of their expectations from the Fed, and correct on later days when the Fed issued subsequent statements. The second challenge is that empirical estimates of the cumulative impact of policy signals clearly will be very sensitive to exactly which dates are chosen. In other words, the danger of choosing a misleading sample is very high.

4.c Second prong: a systematic selection process

As we noted above, some event studies have relied on a handful of key dates to identify "Fed news." We propose a more systematic approach. At the end of each trading day, news outlets publish summaries of what moved the market that day. The reports are generally based on interviews with market participants. We use news reports from Reuters to pinpoint the trigger for large market movements for every day during the period. In particular, we look at all days in which 10-year Treasury yields moved more than one standard deviation.[13] This eliminates small wiggles in the market that are hard to ascribe to specific events. We then looked at the Reuters market wrap-up for each of those days and allowed the reporter (and his or her sources) to

[12] The results get more "perverse" if we include the taper tantrum period—from May 2013 to the end of QE3 in December—in the expansion phase. It could make sense to include this period in the expansion phase if you view the taper tantrum as the market adjusting to the reality that QE3 would not go on indefinitely. Using this extended period suggests even less of a net bond market stimulus during the Fed expansion period.

[13] Specifically the threshold fell from 6 bp (October 2008- December 2010), to 5 bp (January 2011- December 2015) and 4bps (January 2016 – present). This is designed to adjust for the decline in volatility over time.

identify the cause of the move. If more than one story drove the markets, we apportion credit equally to each story. The sample uses daily data from November 2008 to December 2017.

As Exhibit 4.8 shows, we identify 1125 "events." Fed news moved the markets 161 times, including 83 times due to balance sheet news and 80 due to interest rate guidance. We call these two kind of days "Reuters Fed News" days. These 161 Reuter Fed News days exclude 16 additional days where Reuters said the implementation of balance sheet expansion moved the market.[14] Almost a third of the market moves are due to data releases. Interestingly, European news—including political events, economic data and monetary policy developments—was a major persistent driver of the US bond market during this period. Some of the Reuters stories also didn't match the kind of thing economists look for in event studies, including a variety of technical stories and continued reactions to previous day's events.

Our approach has both advantages and drawbacks. On a negative note, the identification is only as good as the reporter and sources used in the story. Indeed, this is why we decided to only focus on days with significant market moves when the reported cause of the move is more likely to be accurate. As a double check on this, when the story is unclear we looked at market summaries from Bloomberg as well as Reuters. Nonetheless, an informed observer could certainly find some of the attributions wrong. As well, the attributions can be correct as far as they go but incomplete. For example, the story may not recognize that a response attributed to economic news was importantly shaped by previous Fed announcements or actions or by expectations of future Fed announcements or actions. That is, subtle effects of Fed expectations

[14] There were three days where Fed news moved the market, but it was difficult to assign to either interest rate or balance sheet news. These included two days with announcements of liquidity facilities and one story about the prospect of a new Fed governor. In addition, on some Reuters Fed News days the press report does not identify whether the Fed was signaling balance sheet or interest rate policy. This occurred when the Fed made general comments about the economy and the policy stance. In these cases we gave half credit to balance sheet and half to interest rate guidance.

may fly below our radar. Indeed, as with all event studies, we miss most of the "endogenous" pricing of policy expectations in response to other macro news. Reuters sometimes includes this connection in its write-ups (for example, "weak data signaled more potential Fed easing…") but often does not. We view our approach as a supplement, rather than a substitute for focusing on a limited number of big dates. Despite these drawbacks, for ease of exposition, we generally write as if the Reuters explanations can be taken at face value, even as we are aware that those explanations can be wrong or incomplete.

We see four advantages in our approach. First, by looking at all days with significant market moves we can sort through a range of competing explanations for the evolution of the market. This is particularly important on days where the Fed was not the only story or when the Fed sent a signal on both forward guidance and the balance sheet. Second, we can track the changing views around policy between the big event days. "Shock and awe" is likely not a normal part of the Feds tool kit and we want to see how policy impacts the market under more normal situations. We will argue that the outsized response to QE1 and the taper tantrum probably in part reflect technical factors that kick in when the market is caught completely off guard. Third, we can use the press reports to get a better sense of why the market moved. For example, there are a number of instances where the market move reflected both new data and the new thinking on the Fed that came with that data.

Finally, we think our approach reduces the risk of several potential biases in event impact estimates:

1. If the study only focuses on days in which the market moved dramatically in the "right" direction, it might suffer selection bias.

2. A similar problem arises if the markets move in the "wrong" direction on the day of the news. Should this be interpreted as evidence that a stronger policy signal was expected, or should it be included as part of the cumulative impact of the run-up to the announcement?
3. A third potential problem is if there is conflicting news in the run up to the announcement. Suppose one set of news suggests a 50% chance of QE, a second set of news lowers the probability to 25% and the third is the actual announcement for QE. Then the correct estimate of the impact must include all three events—if it includes only the first and last event the cumulative impact will be overstated.

The plots for Reuters Fed News days look similar to the Fed News Day plots. Exhibit 4.9 shows the cumulative move in nominal bond yields on Reuters Fed News days and other Reuters News Days. The good news, for QE fans, is that a lot of the rise in yields during the actual implementation of QE (shown in shaded areas) is attributed to non-Fed news. The bad news is that the bond market only rallied on Reuters Fed News days in the early stages of QE1 and briefly in the run-up to QE2. On other Reuters Fed News days the market on average sold off. Over the whole period late 2008 to the end of 2017—including the "entrance" through 2013 and the partial "exit" thereafter—the cumulative change in 10 year yields was effectively zero.

For completeness, Exhibit 4.10 shows the cumulative market move in days that did not make it into our sample because the market move that day was too small to reach our threshold. On net the market rallied on these days: it appears that no (major) news was good news to the bond market. This may have reflected ongoing disappointment with the pace of the recovery and inflation, along with smaller bits of negative news from overseas.

Exhibit 4.11 breaks out the Reuters Fed News days into two kinds of news: signals around the balance sheet (BS) and around interest rates (IR). Over the full sample period, bond

yields have risen on Reuters Fed Balance Sheet Days. In contrast, interest rate news pushed yields down about 50 bp during QE1 and has been roughly neutral since.

Finally, what about other major market moving news (Exhibit 4.12)? Two kinds of news stand out. First, according to Reuters, macroeconomic news releases tended to depress US bond yields in the early part of the sample, but pushed up US bond yields since late 2011. Perhaps the biggest, most persistent driver of US yields has been news from Europe, including central bank actions, macro news and political news. Over the entire sample, European news has pushed US yields down by roughly 150 bp. In other words, Reuters attributes to such news a much larger and more persistent role than to Reuters Fed News days.

Part of the story here might be that "what the Fed giveth the Treasury can taketh away." Greenwood, Hanson, Rudolph and Summers (2016) (GHRS) highlighted the possible role of Treasury debt management in offsetting some of the market effects of QE. While the Fed's asset purchases were absorbing duration risk from the bond market, putting downward pressure on bond yields and term premiums, the Treasury was increasing the average maturity of their issuance and possibly offsetting the market effects of some of the Fed's actions. GHRS concluded that, as of mid-2014, a little more than one-third of the impact of Fed QE on bond yields was offset by the increase in the average maturity of issuance and the steady rise in Treasury debt outstanding (Exhibit 4.13). If one were to apply, without necessarily endorsing, their methodology to updated data, the proportion of Treasury offset would rise to 60% by the end of 2017. Note that our event study approach would not capture these effects, except on days where the Treasury made formal announcements that were covered in news reports.

Before we take a closer look at QE1, we offer a few thoughts on the Maturity Extension Program (MEP). This program helped bridge the gap between QE2 and QE3 and it is captured in Reuters Fed News days. There were three relevant signals:

1. At the August 9, 2011 FOMC meeting, the Committee announced further interest rate guidance (holding interest rates near zero "at least through mid-2013"), but also hinted at renewed buying at the long end, saying it "is prepared to adjust those holdings as appropriate."
2. On September 21, 2011 the Fed announced that it would buy $400 B of Treasuries with maturities of 6 to 30 years, funded by selling securities with remaining maturities of 3 years or less.
3. On June 20, 2012 the Fed announced it would extend the program through the end of 2012, implying another $267 B in maturity transformation.

How effective was the MEP? Ehlers (2012) found a big cumulative 46 bp drop in response to the first two announcements (the paper came out before the third). However, he focuses on both the day of the announcement and the day after. Our Reuters Fed News variable finds that most of the second day moves were unrelated to the Fed.[15] Overall, our Reuters Fed News variable credits 15 bp of the rally around the MEP to balance sheet signals, another 3 bp to interest rate guidance and the remainder to other news. Given the extreme volatility in the markets in this period, pinning down the exact impact of MEP is difficult to say the least.

4.d Third prong: a closer look at QE1

[15] According Reuters, the drop on August 10th was due to European news: "buyers rushed to Treasuries as concern over the French banking system intensified and investors sought safety in U.S. debt." There is no mention of the Fed's announcement on the previous day. On September 22nd, the rally was only partly an extension of the prior day: "downbeat economic data out of Europe and China revived global slowdown concerns and added fuel to a bond rally that started when the Federal Reserve announced plans to reallocate $400 billion of its bond portfolio into long-term Treasuries."

Our third approach is to take a more detailed look at QE1, the episode that has provided the strongest support for QE effectiveness. This allows us to understand a bit better the challenges of pinning down the impact of QE. In particular, we can look more closely at complications that bias the estimated impact in both directions. On the one hand, we can get a better sense of how much of QE was already priced into the markets, suggesting that the full impact may be much bigger than the market move on the day of the big announcement. On the other hand, we can explore how the market took back some of its initial response, suggesting the sustained impact may be smaller than previous studies suggest.

4.d.1 Surprise, surprise, surprise?

On the surface, the first round of QE provides a clean natural experiment for measuring the bang for the buck from unconventional monetary policy. After all, the Fed was the first major central bank to adopt QE in response to the global financial crisis, signaling $600 B in asset buying on 25 November 2008. And the news certainly came as a shock to the market. Indeed, even the second part of QE1—the announcement of an additional $625 B of purchases at the 18 March 2009 FOMC meeting—surprised the markets. The Financial Times wrote that the move "stunned investors" and Deutsche Bank economist Peter Hooper told them: "It appears that they wanted to give the market a jolt."

Was any element of QE1 already priced in before the announcement? QE was not new to the world: Japan had been experimenting for some time. Earlier in his career Bernanke had written extensively about unconventional policy options,[16] and given the extreme distress in the economy and markets some kind of policy action certainly seemed likely. According to Reuters,

[16] Bernanke, Reinhart and Sack (2004) for example laid out many options including expanding the balance sheet, changing its composition and forward guidance.

dovish minutes released the week before had already triggered a 21 bp drop in yields. Moreover, two weeks before the QE announcement, the Blue Chip survey added a new question, asking 50 business economists whether QE was likely "at some point" and 54.3% said yes.

Still, our sense is that considerably less than 50% of QE1 was pre-priced. While economists were thinking in general terms about an eventual policy announcement, it is unlikely that investors were pricing in such an uncertain, potentially distant, event. Certainly the timing was a huge surprise. Nonetheless, it makes sense to give QE expectations some "credit" for the bond market rally both that started before the announcement (Exhibit 4.14). Indeed, we started our sample at the end of October 2009 so that both our Fed Day and Reuters Fed News variables include the dovish signal from the November 19th minutes.

This is not the end of the story. As we noted earlier, Gagnon et al. (2011) yielded three possible estimates depending on the dates chosen: -117 if you only focus on the five days where the bond market rallied on Fed news, -91 bp if you add three other days in the Gagnon et al. "baseline" and -55 bp if all days are included in which the FOMC released a policy statement or meeting minutes. The estimated impact of QE can get even smaller if we take into account the fact that two of the big market moving events include interest rate guidance as well as QE.[17] Crediting half of those moves to interest rate guidance but otherwise taking the -55bp as given lowers the estimated impact of QE1 to -33 bp.

Our Fed Day and Reuters Fed News variables provide additional insight. On these days, from just before the first QE1 announcement until the end of the program, nominal yields fell 17

[17] In a speech on December 1, 2008 Bernanke offered a laundry list of possible future moves including bond buying, further interest rate cuts and other measures. 10-year yields fell 19 bp that day. After its December 16, 2008 FOMC meeting the Fed said it "stands ready to expand its purchases of agency debt and mortgage-backed securities … [and is] also evaluating the potential benefits of purchasing longer-term Treasury securities." However, they also said they expect "exceptionally low levels of the federal funds rate for some time." 10-year bond yields fell 26 bp on that day.

and 48 bp, respectively. The drop in real yields was bigger at 40 to 91 bp, respectively. These moves include the impact of all Fed news, including balance sheet news, interest rate news and news that related to both.

Let's look more closely. Exhibit 4.15 shows the change in the nominal 10 year yield for all days during this period where Reuters identified a balance sheet story. Note that some of these days the balance sheet news is not the only market mover. Consistent with our methodology we credit each driver that day equally for the move. Hence the portion of the move ascribed to balance sheet news is shown in dark blue. The labels on the chart distinguish four kinds of news: FOMC meetings (F), Bernanke speeches (B), speeches by other FOMC members (O) and minutes (M).

The interplay between Fed news and the markets was complicated. Three announcements caused major bond rallies: the first QE1 announcement (11/25), the next FOMC meeting in which the Fed cut rates and talked about doing more QE (12/16) and the second QE1 announcement (3/18). However, on most other days, balance sheet related news tended to be associated with an increase in yields. For example, yields jumped 14 bp on the day of the January 28, 2009 FOMC meeting as the Fed failed to announce a new program. Yields also rose on hawkish sounding speeches (relative to expectations), and on relatively optimistic statements about the economy by Fed officials. Putting it all together, based on the Reuters identification, balance sheet news lowered nominal and real yields by 23 and 61 bp respectively over this period.

Why the strong initial response followed by the reversal? Several explanations seem plausible. First, the market may have simply overreacted to an unusual event and then reassessed the situation over time. Second, the market may have assumed more Fed announcements would

come in short order. After all, if the Fed can double down on QE1, why not triple down? This tendency to extrapolate may explain why the response to the second announcement was much bigger—down 47 bp versus down 22 bp. Third, it could be that sustaining QE effects requires regular "fixes" for the market. Either way, the fact that the market went back up on subsequent Fed Days calls into question estimates in the literature that focus only on the initial announcements.

A number of economists argue that QE1 is not a good natural experiment for how QE works in normal times. After all, this was a period of severe market dislocation and illiquidity. Our results could be seen as validating that concern as we show that the markets seemed to reassess their initial reactions to big announcements on subsequent days.

4.e The surprising conclusion from our event study

The upshot of all of this is that QE looks less powerful and predictable than as stated in the summaries of the literature we cited above. Even "Exhibit A" of the literature—the market response to QE1—looks smaller and less clear on closer inspection. Modest and non-persistent effects stand in marked contrast to the effects of conventional policy in the pre-2008 era (see Section 2) As we noted above, possible explanations include initial market overreaction and the failure of the Fed to meet market expectations of further action. Another possible explanation, applicable if LSAPs work through a portfolio balance effect, is that Treasury actions offset Fed purchases. Whatever the explanation, our results are consistent with a literature that finds that the effects of QE were not persistent. For example, Swanson (2017) finds that the half-life of monetary policy actions during the relevant period is measured in weeks rather than months.

5. Fedexit: from taper tantrum to shrinkage shrug

While there has been considerable study of the impact of expansionary unconventional policy, there is relatively little on the impact of exiting. Here we look at how the Fed's exit signals have moved the bond market. This gives additional insight into the "bang for the buck" of QE and can also give hints about potential challenges in exiting.

Of course, the impact of entering and exiting are not necessarily symmetric. As we discussed in Section 3, announcement of a new buying program could have signaled to markets that interest rate hikes were even further off into the future. After all, a common refrain in the markets was that the Fed would not start hiking while it was still expanding its balance sheet. In other words, QE expansion might have moved markets both by reducing the supply of long dated debt and by signaling that rate hikes were further off.

Interestingly, once the funds rate moved off the zero lower bound, the signaling roles of rates and balance sheet were reversed. In particular, at the December 2015 meeting the FOMC announced that it would not start shrinking its balance sheet until the rise in interest rates was "well under way." In other words, starting at least in December 2015, news on the likely path of rate hikes tended to signal changes in the future path of the balance sheet.

5.a The end of QE

5.a.1 From QE infinity to tapering

In late 2012 the FOMC announced its QE3 asset buying program in two stages. First, in September it announced that it would purchase $40 B of MBS per month as long as "the outlook for the labor market does not improve substantially." Second, in December it extended the program to include open-ended purchases of $45 B per month in Treasuries for a total of $85 B per month. Thus, unlike previous programs there was no fixed end date or fixed amount.

There seems to have been considerable uncertainty and skepticism in the markets about the likely end date for QE3. In the business press a popular nickname for QE3 was “QE infinity.” After all, QE3 was the first open ended asset buying program. Moreover, the Fed had repeatedly extended existing programs and introduced new programs over the prior four years. Finally, the announcement included lots of forward looking language; including saying they would “initially” buy $45 B in longer term Treasuries per month. To many market participants, the Fed’s finish line seemed a long way off.

By early May 2013 talk of QE infinity had helped push 10-year yields to a low of 1.66%, causing an aggressive search for yield in both domestic and emerging markets (Exhibit 5.1). On May 22, Bernanke shocked the markets during Congressional testimony. Initially, the bond market rallied on relatively benign prepared remarks submitted by the Fed Chair. Then, in response to a question, he said “if we see continued improvement and have confidence that that’s going to be sustained, then we could, in the next few meetings, we could take a step down in our pace of purchases.” On June 19 he “doubled down” in the press conference following the FOMC meeting when he said “if the incoming data are broadly consistent with this forecast, the Committee currently anticipates that it would be appropriate to moderate the pace of purchases later this year,” and (again contingent on the data) “ending purchases around midyear.” On these two days alone, bond yields rose 28 bp.

Bond yields rose steadily over the summer as the markets became increasingly confident that the Fed would announce tapering at the September FOMC meeting. When the Fed failed to deliver the tapering announcement at that meeting, bond yields fell 16 bp, but then recovered into year end. Finally, the Fed announced tapering in December and bond yields ended the year

about 120 bp above where they were the day before Bernanke's first tapering talk (again, see Exhibit 5.1).

5.a.2 Talk versus action

How much of this sell-off was due to changing balance sheet expectations? Casual observers ascribe most of the rise in yields to tapering talk, but our data suggest otherwise. Let's look at what the Fed did relative to consensus expectations and what other factors moved the markets.

While the exact timing of the tapering talk was a big surprise, the ultimate outcome was not that different from consensus expectations coming into the period. In the spring of 2013 there was an ongoing debate about when the Fed would pull back on its purchases and whether there would be a slow taper or a more sudden exit. In the Fed's primary dealer survey that April, the median expectation was that purchases would end, rather abruptly, in Q2 2014. In Blue Chip surveys, the median expectation was that the Fed would taper in February/March 2014.[18]

Over the summer, the expected timing moved forward. Prior to the September meeting, primary dealers saw a greater than a 90% chance of tapering before year end, with better than even odds of a September announcement. The Blue Chip survey was similarly confident: 100% of those surveyed expected tapering before year end. However, when the Fed disappointed in September, the median expectation shifted out to March 2014. The actual start date was January 2014. In other words, the median expected end date moved only a few months in response to the Fed's evolving communications.

In Exhibit 5.2 we use the primary dealer survey to estimate the expected total buying under QE3, using median expectations of the starting date and speed of tapering. Despite all the

[18] Specifically, 37.0% of respondents expected tapering to start in 2H 2013, 41.3% in 1H 2014, 17.4% in 2H 2014, 4.3% in 1H 2015 and zero thereafter. The 50% dividing line is about a third of the way into the first half of 2014.

excitement in the market, the expected total remained fairly stable even as Bernanke warned of tapering. Then, when the Fed failed to taper in September, the market overshot modestly on its QE3 expectations. Why such small moves during the summer months? It seemed that participants started to expect an earlier start to balance sheet shrinkage, but at a slower pace, leaving the end size essentially unchanged. A rougher estimate using the Blue Chip survey found similar results: the expected size dipped a bit in the summer and then recovered.[19]

The surveys also give insight into the signaling channel of balance sheet policy. According to the Fed survey, from March to September primary dealers increased their median expected funds rate path. In the March Fed survey, the median dealer expected the funds rate to reach 3% by the second half of 2017 and by September that expectation had risen to 3.5%. Earlier tapering was seen as signaling faster rate hikes. Hence, shifting expectations for rate hikes share some of the "blame" for the taper tantrum.

5.a.3 Taper tantrum?: It's the economy stupid

Finally, our Reuters event data suggest an improving economy was much more important than Fed signals during this period. Exhibits 5.3 and 5.4 compare the overall move in nominal and real bond yields to the move explained by the Fed News Day and Reuters Fed News indicators. Note that our Fed indicators capture the 28 bp rise in yields on the two days that Bernanke warned of tapering. However, the cumulative impact of Fed news was relatively modest. From the day before Bernanke first spoke (May 21) to December 31, nominal and real

[19] Most of the above surveys only asked when the tapering of asset purchases would begin and not how quickly it would proceed. When the survey asked about ranges of dates we used the midpoint of each bucket. The chart assumes that respondents perfectly anticipated the speed of the Fed tapering, once the taper began. In other words, every month of delay in the start of the program added $85 B to the expected terminal balance sheet. Is this a reasonable assumption? The surveys published September through November also included questions about the expected speed of tapering. On average, respondents expected a slightly faster speed of tapering than the Fed actually enacted. Using the speeds suggested in the survey we find that the expected paths of tapering in September, October and November would have reduced the post-QE balance sheet size by $41 billion, $18 billion and $29 billion respectively, compared to the estimates in the chart.

bond yields rose a cumulative 110bp and 116bp respectively. However, the cumulative move on Reuters Fed News days was only 24 and 30 bp, respectively. The result for Fed Days was a bit bigger: 56 and 52 bp, respectively, for nominal and real yields.

Digging deeper, Exhibit 5.5 takes a closer look at other factors that moved the market. We have included just the variables that had a noticeable impact. If Reuters is right, the sell-off was mainly due to positive macro data news. For example, from May 21 to December 31 nominal and real bond yields rose a cumulative 110 and 116 bp, respectively, on days with major macro data news. Of course, as with all event studies, it is possible that the Fed moved the markets indirectly. For example, Bernanke's warnings may have made markets more sensitive to incoming data that confirmed a tapering was coming. So the move in yields that we attribute to "good economic news" may in a deep sense partly reflect a change in expectations about monetary policy. Nonetheless, as we noted above, over the course of the year the expected end point for the balance sheet did not change much.

Stepping back, several things emerge from the taper tantrum episode. First, the market impact of taper talk seems more related to the sudden arrival of the news, rather than a fundamental shift in the expected Fed balance sheet. While economists seemed on high alert for an end to QE expansion, markets seemed "wrong footed" after all the talk of QE infinity – especially with the taper talk coming close on the heels of a major bond rally. Second, some of the market impact probably resulted from changing expectations for the fed funds rate path. Third, macro news was a much bigger driver of the sell-off than Fed signals according to our Reuters News data.

Our results may also have forward looking implications. The good news is that the exit may not be as painful as might have been expected. The bad news is that this adds further

evidence to the idea that focusing only on big surprise days overstates the sustained impact of balance sheet policy on bond yields.

5.b The shrinkage shrug

In October 2014 the FOMC concluded its asset purchase program. It shifted to maintaining the par value of securities in the SOMA portfolio at approximately $4.25 trillion by reinvesting principal payments from its holdings of MBS and rolling over maturing Treasury securities at auction. Around that same time, the Committee issued a revision to their "Policy Normalization Principles and Plans." One of the most important aspects of this update involved a change in the sequencing of the normalization process. Back in June 2011 the FOMC had indicated that the first phase of normalization would be a gradual shrinkage in SOMA holdings. This would be followed, at some point, by rate hikes. But, the 2014 update reversed these steps – rate hikes would precede a change in reinvestment policy. The flip-flop seemed to be attributable to a higher degree of confidence in the ability to operate in an environment of abundant reserves along with a desire to start the policy tightening process using the more predictable component of the tool kit first.

In December 2015, the FOMC offered more insight into the timing of the exit plan. In announcing the first post-crisis rate hike, they also indicated that there would be no shrinkage in the SOMA portfolio "until normalization of the level of the federal funds rate is ***well under way***." This phrase was retained until the June 2017 meeting when the FOMC indicated that they expected "to begin implementing a balance sheet normalization program this year." Finally, at the September 2017 FOMC meeting the Fed announced the actual policy.

5.b.1 The shrinkage shrug: dovish expectations; hawkish reality

To assess the market impact of the Fed's policy, it is important to first understand what was priced into the market. In the run-up to the announcement, market participants grappled with

several questions. First, what level of the funds rate constituted "well under way?" Second, how fast would the Fed shrink its balance sheet once it started? Third, would balance sheet shrinkage be a substitute for rate hikes or a complement to rate hikes? In other words, would the Fed slowdown or stop its rate hikes and for how long? Finally, there was uncertainty regarding the extent to which the path would be pre-determined: would the Fed announce the whole exit in one go or would they suggest multiple steps with pauses to assess the impact?

Both the Blue Chip survey and the NY Fed survey of primary dealers offer useful insight into the evolution of the consensus view. Exhibit 5.6 compares the actual balance sheet announcement to median expectations among primary dealers and respondents to Blue Chip. Relative to expectations at the start of the year, the Fed was more hawkish than expected in all four respects: the shrinkage was earlier than expected (row one), the drawdown in the balance sheet a couple years out was larger than expected (row two), the Fed paused its rate hikes for only one press conference meeting when starting the shrinkage (row three), and the shrinkage was presented as very much a pre-programed plan (row four).

5.b.2 The market impact

Despite worry about another taper tantrum, the Fed's gradual hawkish shift did not seem to faze financial markets. To the contrary, most measures of financial conditions eased. For example, the Chicago Fed Financial Conditions Index moved to near record looseness (Exhibit 5.7). Even the 10-year term premium drifted lower last year despite more hawkish expectations for the Fed. Moreover, there was little indication that balance sheet shrinkage was seen as a substitute for rate hikes since the 1 year/1 year forward rate drifted higher (or held fairly steady) during the relevant period (Exhibit 5.8). Of course, the lack of any meaningful market hiccup

could have been attributable to other developments – for example, a moderation in core inflation, policies of foreign central banks, etc. Our Reuters data can help address this issue.

Our event study attributes little of the past year's bond market movement to the Fed's evolving exit plans. Exhibit 5.9 compares the cumulative yield in nominal yields over the year to our various Reuters news variables. In the Exhibit, our "US politics" variable captures some of the so called "Trump Trade" where yields rose initially on expectations of fiscal easing and growth friendly policies but then faded a bit as tax cuts and spending increases were delayed. Weak inflation readings pushed down yields in the second half of the year. Our Fed indicators show only small effects. The Reuters Fed News variable peaked at about 30 bp and ended with a cumulative gain of only 15 bp. The Fed News Day also has an up/down pattern, but perversely ends the year negative. In other words, last year the bond market on net rallied on days of FOMC announcements, the release of minutes and speeches by the Chair. The story for the term premium over the year is very similar (Exhibit 5.10). As the title of this section suggests, the change in the Fed's exit plans caused a collective shrug in the bond market.

5.b.3 More shrug than tantrum

Pulling together the taper tantrum and shrinkage shrug results, Fed exit signals appear to have had relatively little net impact on the market. Beyond the two big "Bernanke days," we attribute only a modest role to the Fed in the 2013 bond market sell-off. If anything, the more recent shrinkage stage has had even less impact and has not prevented a further decline of the term premium into negative territory. Again, this is mixed news for the Fed: perhaps exiting QE will be "like watching paint dry." However, that benign exit also means that we need to understand why there has been such a tepid response. One possibility is that balance sheet announcements only "work" if they truly shock the market. A second possibility is that the

markets have a prove-it-to-me attitude around the exit from QE. Finally, it may be that balance sheet expansion mainly works by signaling when and how fast rates will rise. Thus the taper warnings in 2013 pulled forward the expectations for funds rate increases. By contrast, learning the exact date that the shrinkage will begin by itself tells you little about the forward path of interest rates.

6. Where do we go from here?

Financial markets appear to have shrugged off the effects of Fed balance sheet normalization to this point. In this section, we take a look at the likely path of the balance sheet going forward from here and examine the policy linkage between movements in the Fed balance sheet and Treasury debt management policy.

6.a Fed balance sheet projections

The Fed plans to accelerate its balance sheet reduction during 2018, allowing principal payments to result in up to $20 B declines in its security holdings each month in the first quarter and up to $50 B monthly declines by the end of the year (see Exhibit 6.1). But Bonis, Ihrig and Wei (2017) observed that in practice under the current plans the actual declines will be significantly below these caps. For example, we know today that only $18 B of the Fed's Treasury bonds will be maturing in December of 2018, so the actual reduction in its Treasury holdings that month will be significantly below the $30 B cap. And although the MBS principal payments are difficult to anticipate, Bonis, Ihrig and Wei suggested that a reasonable guess is that the Fed's principal receipts on these will only be $12 B in December, well below the $20 B cap. Exhibit 6.2 compares the maximal reductions allowed under the Fed's current plan with the actual reductions anticipated by Bonis, Ihrig and Wei's calculations.

We took Bonis, Ihrig and Wei's anticipated reductions in the System Open Market Account each quarter and allotted 60% of this to Treasuries and 40% to MBS.[20] In addition, as bonds mature the unamortized premia will also run off the balance sheet with them.[21] The results of these calculations are plotted in Exhibit 6.3, which shows Fed assets falling to $3 T by the end of 2021.

Our projection in Exhibit 6.3, like those in Bonis, Ihrig and Wei (2017) and also the Federal Reserve Bank of New York (2017), has the Fed's balance sheet resuming its growth after a few years. As those reports note, the date at which growth resumes depends on the assumptions one makes on the liability side. One key assumption is the level of reserve deposits that is going to be the new normal once the balance sheet reduction is complete. One scenario considered in both those reports assumed an average reserve balance around $100 B.

Exhibit 6.4 shows why we believe that number is unrealistic in the absence of a significant change from the Fed's current operating procedures. Our projection of future Fed liabilities assumes that currency demand continues grow at 4% per year from current values. This appears to be the same baseline assumption used in Bonis, Ihrig and Wei (2017) and also the Federal Reserve Bank of New York (2017), though, as the latter notes, currency demand has grown significantly faster than 4% over the last three years, and if that faster growth continues it would result in an earlier date at which growth resumes. Four-percent annual growth would

[20] Bonis, Ihrig and Wei (2017) did not separately break down the contributions of Treasuries and MBS after 2019.
[21] For example, suppose the Fed pays $101 for a one-year bond with face value $100 and a coupon of $1. Next year it will receive $100 in principal payment and $1 in coupon payment, bringing $101 in reserve deposits back in and erasing both the par value of $100 and the unamortized premium of $1 from its assets. Alternatively, suppose it paid $101 for a bond with par value of $100 and coupon of $2. Next year it will receive $100 principal payment and $2 interest payment, bringing $102 in reserve deposits back in. The Fed will make a profit of $1 ($2 interest minus $1 capital loss) and turn this $1 over to the Treasury, for a net contraction of reserve deposits of $101. Thus once again after the profit remittance the Fed's assets and liabilities both decline by $101 as a result of the bond maturing. Our calculations in Exhibit 6.3 assume that unamortized premia decrease each quarter proportional to the amount of maturing securities.

mean a level of currency by the end of 2020 of $1.8 T; for this reason alone the Fed is never going to return to the $900 B balance sheet it had in 2007.

For projections of reverse repos and Treasury deposits, we have made a very simple assumption in order to be able to illustrate the issue graphically. We assume that the values for these two series each week over the next three years are exactly the same as was observed in the corresponding week over the last three years.[22] One sees clearly from such a simulation that the issue is not just the average values assumed for items like the Treasury balance and reverse repos, but also their volatility. Our simulation implies an average level of reserve balances of $400 B over 2022-2025, but the actual level of reserves is only $37 B in Dec 2025. To prevent a spike in interest rates from a scramble to maintain positive reserve balances, the resumption of growth in the Fed's balance sheet could begin no later than Jan 2022, at which point Fed assets would be around $3 T.

Under current operating procedures, both the Treasury balance and reverse repos are demand driven—the Treasury can choose to hold as much or as little as it wants each day, and money market funds are essentially allowed to do as large a volume of reverse repos they want at the Fed's offered rate. Of course, the Treasury balance was also demand driven before 2008. The Fed in those days adapted to this by using repos to add reserve balances temporarily when the Treasury's account was expected to grow or reverse repos to take them out if the account was expected to fall. Even so, the Fed would have misses in these calculations that occasionally produced spikes in interest rates (Hamilton, 1997). And in those days the fluctuations were on the order of a few billions of dollars.

[22] That is, the value for Jan 10, 2018 is exactly the number observed in Jan 14, 2015, while Jan 17, 2018 is the value from Jan 21, 2015. Our simulation cycles through the same set of numbers beginning again in Jan 6, 2021 and Jan 3, 2024.

In recent years, the Treasury has implemented some important changes to their cash balance policy, as can be seen in Exhibit 6.5. In response to an analysis of market disruptions in the wake of events such as 9/11 and Hurricane Sandy, Treasury decided it would be prudent to maintain a large enough cash balance to allow them to meet the government's obligations for a week or so (see U.S. Treasury, 2015). The result of this policy change is that, abstracting from normal seasonal swings, the cash balance target has been near $300 billion over the past few years. But, there have been significant deviations from this target. Indeed, debt ceiling constraints have often forced Treasury to carry a much lower balance for long stretches at a time and have added to the volatility associated with the elevation in the target level. Trying to offset fluctuations in the Treasury balance of recently observed magnitude with a relatively small average cushion of reserves could produce significant short-term volatility in interest rates.

Reverse repos pose an even bigger challenge. Exhibit 6.6 zooms in on their recent behavior. In some weeks the Fed has allowed over half a trillion dollars in these, and in daily data there are even bigger spikes than seen in this graph which only has Wednesday values. Much of this volatility is a result of window dressing by money market funds, which do not want to list their typical repo counterparty on dates when they give public reports of their assets, and so lend repos to the Fed on those days instead of their usual counterparties. If the Fed wants to reduce its balance sheet below $3 T, it will probably need to modify the way it is using this tool to put a floor under interest rates.

6.b A fiscal fret?

As noted in Section 3, the Treasury's debt management policies can play an important role in either reinforcing or offsetting the impact of Fed balance sheet changes. This may be particularly relevant today because – in response to SOMA run-offs, looming tax cuts,

prospective discretionary spending increases, rising entitlement spending spurred by demographic forces, and increased interest costs -- the Treasury appears to face a sizeable financing gap in coming years (see Exhibit 6.7).

However, it seems that Treasury has backed away from the debt management strategy that possibly offset some of the impact of Fed QE. At the November 2017 refunding announcement, Treasury indicated that they would no longer pursue a strategy to gradually increase the weighted average maturity (WAM) of the debt outstanding and would instead attempt to stabilize the WAM near its current level (see US Treasury, 2017). Exhibit 6.8 shows that the WAM of the outstanding stock of Treasuries has risen steadily in recent years and now stands at 70 months (the WAM excluding Fed holdings is lower because the SOMA consists of mostly longer dated maturities). The recent shift in debt management policy should lead to a flattening out of the WAM going forward which could help to mute the impact of Fed balance sheet normalization.

The Treasury's decision to alter their issuance strategy appears to at least partly reflect analysis recently done by the Treasury Borrowing Advisory Committee (2017). At the heart of the TBAC analysis is the notion that debt mangers can optimize the trade-off between the cost of issuance and the variability of that cost by concentrating issuance in the belly of the curve. Moreover, as the TBAC pointed out in their Report to the Treasury Secretary: "WAM is an outcome of the issuance strategy and not just a goal in and of itself." In the Committee's view, WAM is just one of several useful measures of funding risks.

Exhibit 6.9 is an excerpt from the TBAC report showing the results of a Monte Carlo simulation derived from a small scale macro model in which all new Treasury issuance over a 30-year period is concentrated in a single maturity. For example, if all new issuance is

concentrated in bills, the cost is low but volatility of that cost is quite high. Moving to a strategy of all 2-year note issuance has little impact on cost but results in lower volatility. The same pattern is evident as you move further out the yield curve to 3-year and (especially) to 5-year notes. However, as you extend to 7-year and 10-year maturities, the cost begins to rise with little accompanying change in volatility. Finally, an extension all the way to the 30-year maturity yields higher cost AND higher volatility. The increase in variability of debt service cost for the longer maturities reflects the higher cost of debt (attributable to higher term premiums) as well as the fact that the term premium tends to be volatile.

The results of this simulation reflect the correlation between economic growth, inflation, interest rates and the primary budget deficit. This particular simulation also relies on an important simplifying assumption – the concentration of all issuance in a single maturity point does not impact the yield curve. This assumption, which was made for illustrative purposes, is clearly unrealistic, but the report also shows that if a more realistic strategy is adopted and issuance is spread across various buckets of maturities with different weightings, the optimal trade-off between cost and variability is still achieved via a concentration of new issuance in the belly of the curve.

The TBAC work is preliminary in nature but the findings are broadly consistent with those of other studies of optimal sovereign debt management which have concluded that issuing in the intermediate part of the yield curve can be advantageous for the issuer (for example, see Bolder and Deeley, 2011 and OECD, 2005).

What would be the significance of the adoption of a new debt management model at the Treasury? One implication relates to the political economy of Fed and Treasury interaction. As mentioned earlier, GHRS (2016) argued that the Fed and the Treasury were working at cross

purposes during the crisis and went on to recommend increased coordination between the two bodies as a means of alleviating the potential for such conflict in the future. However, the notion that the Fed and Treasury should better coordinate their respective policy actions ignores important historical lessons. In particular, many blame undue political influence on the Fed for at least part of the run-up in inflation that occurred in the pre-Volcker era (Cummins, 2016). But there may be a middle ground. If Treasury debt management were to become less arbitrary and more model-driven, then the Fed – with last mover advantage – can simulate the Treasury model and account for likely shifts in debt management when determining the appropriate course for monetary policy. This would move policymakers closer to a consolidated balance sheet approach.

Moreover, a simulation of historical issuance utilizing a dynamic reaction function that attempts to optimize the cost-variability trade-off by adjusting the maturity mix of new issuance suggests that such an approach to debt management could have some important counter-cyclical properties. Exhibit 6.10 shows a comparison of the actual mix of issuance over the past decade versus an optimal mix strategy that is derived from the TBAC optimization model. Note that the recommended share of long-dated issuance declined dramatically during the Great Recession period. This outcome reflects the relative steepness of the term premium component of the yield curve during that timeframe. To the extent that, during an economic downturn, the term premium tends to be more elevated as you move further out the yield curve, the new optimization strategy would have counter-cyclical benefits (Exhibit 6.11). Indeed, from a consolidated balance sheet standpoint, it might make more sense for the Treasury, rather than the Fed, to extract duration from the bond market when policy accommodation is deemed appropriate.

6.c The end point for the Fed's balance sheet and fiscal linkages

An important consideration in assessing the long run impact of Fed normalization involves the make-up of the balance sheet. While the FOMC has not yet provided any details related to the long-run target size or composition of the SOMA, there is widespread expectation that it will be much larger than pre-crisis. The latest NY Fed survey of dealers and market participants indicates that respondents' median expectation for reserve balances in 2025 is $640 B, with a range of $240 B to $700 B. This is versus a pre-crisis level of approximately $10 B and a 2017 average of $2.25 trillion.

Assuming the Fed eventually wants to get to a portfolio consisting of primarily Treasury securities, as indicated in the 2014 "Policy Normalization Principles and Plans," what maturities should they buy once they start needing to replace maturing MBS and offset the normal growth in liabilities? There appear to be three options.

I) Mostly Treasury bills: in order to maximize the potential impact of balance sheet expansion in a ZLB environment, the Fed may want to maintain a normalized balance sheet that consists of very short duration securities. This would provide them with the ability to extract the maximum amount of duration possible from the market when confronting the ZLB. And, of course, there is recent research suggesting that the ZLB will be reached far more frequently going forward (see for example Kiley and Roberts, 2017).

II) Market neutral portfolio: if the Fed's objective is to avoid distorting markets in a normal policy environment, they could try to hold securities in the SOMA which roughly match the characteristics of marketable Treasury debt outstanding (based on WAM or some similar metric).

III) Liability matching: the Fed may choose to follow an ALM approach in managing their normal balance sheet. However, the appropriateness and practical implication of such a strategy is not entirely clear. The Fed is not really subject to the same type of interest rate risk as a bank (or other types of entities that use ALM). Moreover, it's not clear if currency (the major liability item on the balance sheet) represents a short duration or long duration liability.

The "T-bills" option seems the most appealing from a monetary policy standpoint but may involve considerable spillover effects on Treasury debt management. At present, the volume of Treasury bills outstanding in proportion to the overall supply of marketable Treasuries is the lowest it's been in more than 65 years (see Exhibit 6.12). And, it's worth noting that the Fed currently holds no Treasury bills whatsoever – having liquidated all of their bill holdings during the 2011-12 Operation Twist initiative. If the Fed is going absorb a large volume of an already low bill supply, the Treasury will probably want to compensate for this – especially since recent research suggests that there may be financial stability benefits associated with an elevated volume of Treasury bill issuance (see the discussion in Greenwood, Hanson and Stein, 2015).

There has been no official word yet from the FOMC regarding their long run plans for the balance sheet. While they have started to allow some Treasuries and MBS to roll off, the reinvestment policy for those securities that exceed the monthly redemption cap is unchanged – Treasuries get rolled into newly issued add-ons across the 2-year to 30-year maturity spectrum while maturing MBS get reinvested into new MBS. A decision regarding the long run composition of the SOMA portfolio does not seem to be near. Indeed, Fed officials and staff appear loathe to send any clear signals regarding their intentions and have merely been using

dealer survey results as inputs to their long run balance sheet simulations. The only glaring exception to this approach were the numerous references to a target range of $2.5 to $2.9 trillion by new Chair Powell during his confirmation hearing in late-November. Using the midpoint of the range that he provided (which, according to the NY Fed survey, is quite near the latest median expectation of primary dealers), it appears that size of the balance sheet may reach the target around the end of 2021. At that point, the Fed will need to begin adding to the SOMA to offset both the normal growth in liabilities as well as the ongoing MBS principal repayments (see Exhibit 6.13).

The impact of balance sheet normalization may depend in part on the Fed's decision regarding the size and composition of their normalized SOMA portfolio. It would seem prudent to begin implementing a policy aimed at achieving the desired compositional characteristics – Treasuries vs MBS, maturity structure, etc. -- well ahead of the time that the portfolio reaches the target size.

7. Lessons learned

Our review suggests that large scale asset purchases have a more modest effect on the bond market than many financial analysts and policy makers seem to believe. Here we discuss what that means for the Fed's balance sheet and policies going forward.

7.a. Objectives for the Fed's balance sheet

7.a.1. Size of the Fed's balance sheet

We conclude that the most important and reliable instrument of monetary policy is the short-term interest rate rather than the size of the Fed's balance sheet. The primary consideration in deciding how fast and how far to reduce the size of the Fed's balance sheet should be

maintaining the volume of excess reserves that is necessary in order to ensure the viability of the operating procedures that the Fed relies on to control the short-term interest rate. The current operating procedures have resulted in tremendous volatility in the daily levels of reverse repurchase agreements, coping with which likely requires a large average level of excess reserves. Unless the Fed changes the way in which it uses reverse repos to set a floor for the level of short-term interest rates, it will be difficult for the Fed to keep excess reserves permanently much below a value around $500 B – especially since the Treasury cash balance (a liability item on the Fed's balance sheet) is far larger and more volatile than pre-crisis. Some of the scenarios considered by Fed staff in which excess reserves are maintained below $100 B seem unrealistic given the current operating system. Other long run scenarios offered by Fed officials have shown reserve balances settling in at $1 trillion (see Powell, 2017). The FOMC should make a determination of the appropriate size of the Fed's balance sheet over the long term and provide market guidance as soon as is practical.

7.a.2. Fed holdings of mortgage backed securities

In addition to the size of the Fed's balance sheet, we raise the question of its composition, in particular Fed holdings of MBS. Goodfriend (2014) noted the important distinction between monetary policy (control of the risk-free short-term interest rate) and credit policy (acquisition of risky assets by the Federal Reserve). Risks on the Fed's balance sheet are ultimately a risk to taxpayers, at a minimum changing the state-contingent path of Treasury receipts from the Fed, and possibly requiring a capital injection from the Treasury to the Fed in extreme circumstances. One could argue that such decisions should be made by the fiscal authority rather than an independent Federal Reserve. Delegating these decisions to the Federal Reserve brings the Fed's daily decisions more directly into public debate, making it harder to preserve the central bank's

independence. And if the Fed takes upon itself to pick winners and losers in the allocation of risky credit, on what basis should it do so? Should housing be a higher priority than business fixed investment?

However, given likely low policy ammunition around the next crisis, we think the Fed should maintain optionality when it comes to buying MBS. In particular, we suggest a "Treasury first" approach to asset buying rather than a "Treasury only" approach. Hence it makes sense for the Fed to hold at least a small amount of MBS on its portfolio to signal that that channel is not completely out of the question. On the other hand, maintaining a level of MBS above $1 trillion several years down the road and even after balance sheet growth resumes, as our baseline calculations imply, goes well beyond what seems appropriate in the current environment.

7.a.3. Fed holdings of long-term Treasury securities

Similar issues apply to the Fed's holding of long-term Treasury bonds. We noted in Section 3.a that one mechanism whereby such purchases could have an effect is by taking term-structure risk out of private-sector portfolios and onto the Fed's balance sheet. This again is fundamentally a fiscal decision and should remain so in normal times. Indeed, the Treasury's own objectives for its maturity risk led it to increase the average maturity of outstanding Treasury debt over the 2009-2017 period, offsetting and even reversing the efforts by the Fed to lower the average maturity of publicly held debt. In the current environment, the Fed should leave this decision to the Treasury and return to a balance sheet that consists mostly of short-term Treasury securities.

7.a.4. Implications for the great unwind

The Fed has been extremely cautious in allowing its balance sheet to contract, and indeed achieved almost no reduction in the fourth quarter of 2017. In part this is because of the

very conservative caps on the amount of redemptions in any given month. In practice these are difficult to achieve given the substantial uncertainties and lumpiness associated with MBS redemption. Always staying under a cap in the presence of substantial operating uncertainty necessarily means that the average drawdown will be considerably below the cap. The Fed's current plans call for substantial gross purchases of MBS and long-term Treasuries in any month when principal payments exceed the cap. In an environment of rising interest rates, these purchases will expose the Fed to new risks of capital loss even as it is trying to take such risks off its balance sheet.[23] It makes sense to consider larger and looser caps, possibly specified in terms of quarterly rather than monthly changes, with caps perhaps removed completely by 2019.

7.b. Conclusions

We find that the Fed's balance sheet is a less reliable and effective tool than as perceived by many, and that the central question going forward should be the path for short-term interest rates rather than the path of the balance sheet. That leaves lowering the short rate as the primary tool available to fight the next recession. Exhibit 7.1 summarizes the magnitude by which the Fed lowered the fed funds rate during the nine most recent recessions. On average the stimulus exceeded 4%, and was never less than 2%.

Some recent research has concluded, however, that the short-term safe real interest rate (sometimes denoted r^*) is currently near zero and has high probability of remaining low over the medium term.[24] If so, and if inflation remains below 2%, short term nominal rates will also likely remain low. The Fed would then have significantly less ability to fight a recession by lowering nominal rates than it generally ended up needing in recent historical downturns.

[23] See Cavallo et al. (2018) for a quantification of the risks associated with different target levels for the Fed's balance sheet.
[24] See among others Hamilton, Harris, Hatzius and West. (2016), Holston, Laubach and Williams (2017), and Bauer and Rudebusch (2017).

Solutions that have been proposed to either handle the zero lower bound or make less likely that the economy again hits the zero lower bound include: price level targeting, perhaps temporary (e.g., Bernanke (2017)); a higher inflation target (e.g., Blanchard, Dell'Ariccia and Mauro (2010)); nominal GDP targeting (e.g., Frankel (2012)); and, somewhat more narrowly, a commitment by the Fed to overshoot a 2% inflation target during expansions so as to make the inflation target more clearly symmetric (e.g., Evans (2016)). Sorting out these and other options is an important task for future research.

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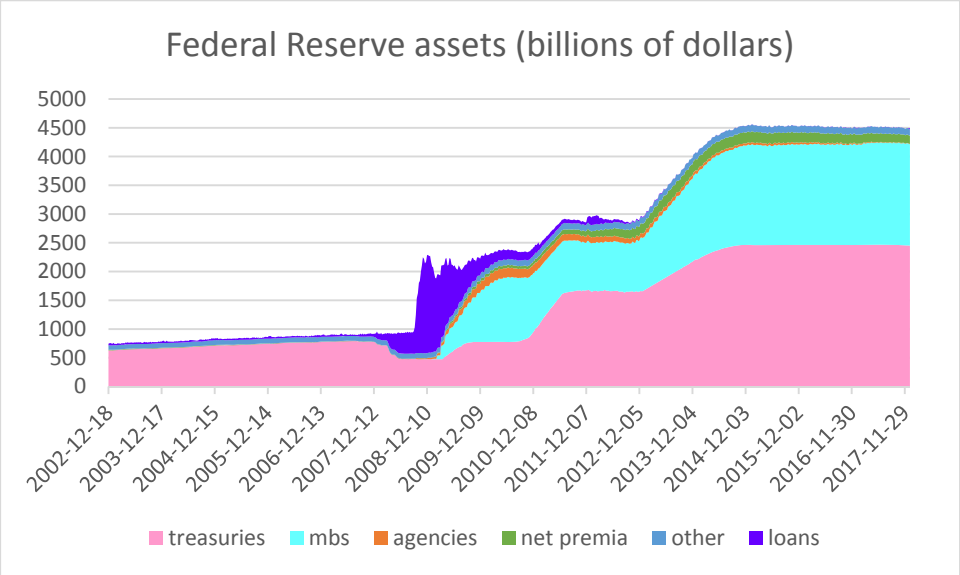
Exhibit 2.1 Overview of Monetary Policy Programs and Actions, 2007-2017

	Event or program	Date	Comments
(1)	Cut in Federal funds target from 5.25% to 4.75%	9/2007	The first of a series of cuts that led to the zero lower bound.
(2)	Programs to provide liquidity and credit and stabilize the financial system	2007-2009	TAF*, TARP* and other programs are initiated to provide loans, capital and credit, primarily to financial institutions; the Fed participates in stabilization of "too big to fail" institutions such as AIG.
(3)	Interest on bank reserves introduced	10/2008	
(4)	QE1	11/2008-8/2009	Federal Reserve purchase of $200bn of agency debt, $1,250 of agency MBS and $300bn of Treasuries.
(5)	Zero lower bound encountered	12/2008	Target range for the Federal funds rate now 0 to 0.25%.
(6)	QE2	11/2010-6/2011	Federal Reserve purchase of $600bn of Treasuries.
(7)	Maturity extension program	9/2011-12/2012	Federal Reserve purchase of $667bn of 6-30 year Treasuries using shorter term Treasuries.
(8)	QE3	9/2012-10/2014	Federal Reserve purchase of MBS and Treasuries; $40bn - $85bn/month.
(9)	Reverse repos introduced	9/2013	In conjunction with interest on reserves, to be used to support the target range for Federal funds rate, upon exit from the zero lower bound.
(10)	Exit from zero lower bound	12/2015	Target range for the Federal funds rate now 0.25%-0.50%
(11)	The Great Unwind begins	10/2017	Federal Reserve begins to reduce its holdings of long maturity assets.

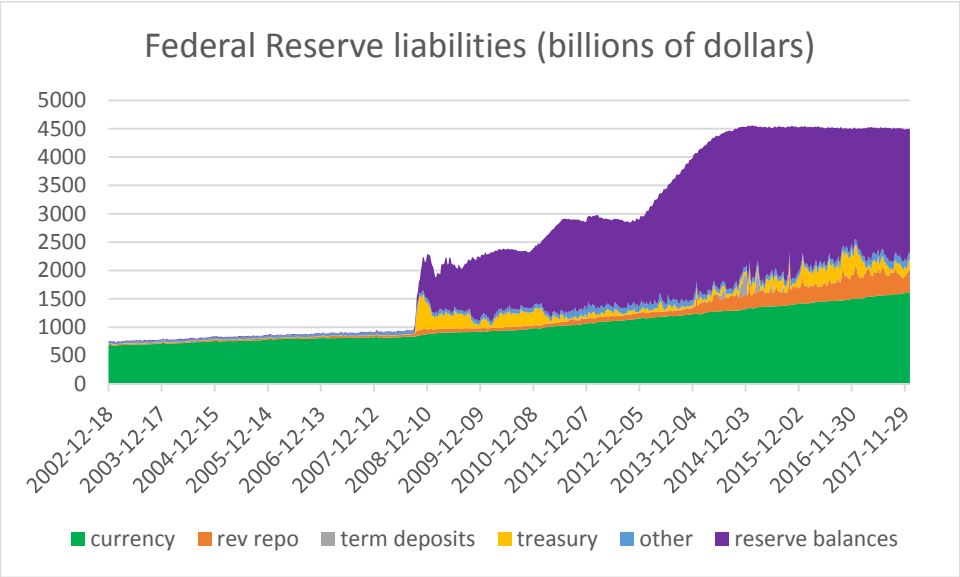
Notes to Exhibit 2.1. *TAF = Term Auction Facility, TARP = Troubled Asset Relief Program. Source: For 2007-2011, https://www.stlouisfed.org/financial-crisis/full-timeline. For 2012-present: various.

Exhibit 2.2. Federal Reserve assets, Dec 18, 2002 to Jan 3, 2018



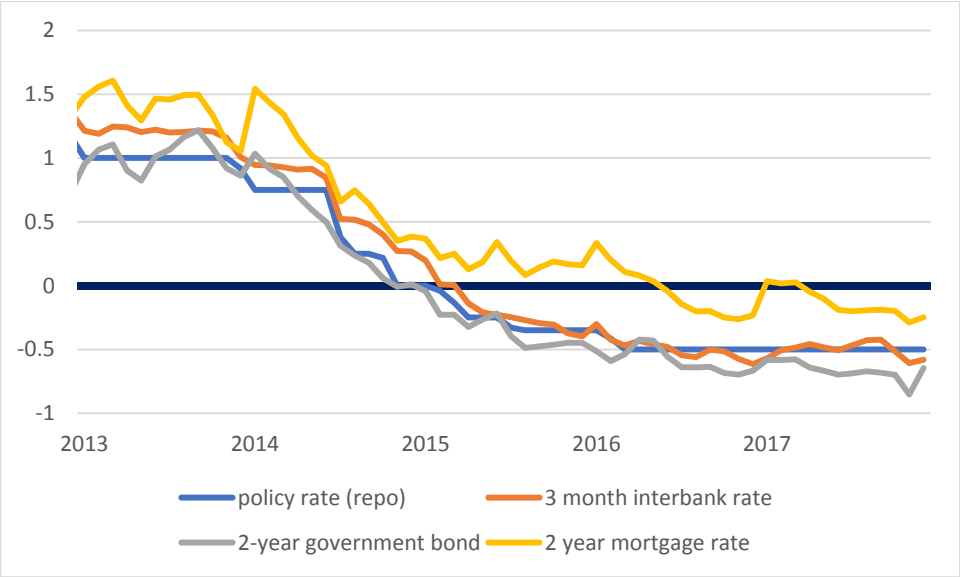
Notes to Exhibit 2.2. Wednesday values in billions of dollars. Treasuries: U.S. Treasury securities held outright. MBS: Mortgage-backed securities held outright. Agencies: Federal agency debt securities held outright. Net premia: unamortized premia minus unamortized discounts. Other: sum of float, other Federal Reserve assets, foreign currency denominated assets, gold, Treasury currency, and special drawing rights. Loans: sum of loans, net portfolio holdings of Commercial Paper Funding Facility LLC, Maiden Lane I, II, and III, net portfolio holdings of TALF LLC, repurchase agreements, preferred interests in AIA Aurora LLC and ALICO Holdings LLC, central bank liquidity swaps, and term auction credit. Data source: Federal Reserve H41 archive.

Exhibit 2.3. Federal Reserve liabilities, Dec 18, 2002 to Jan 3, 2018



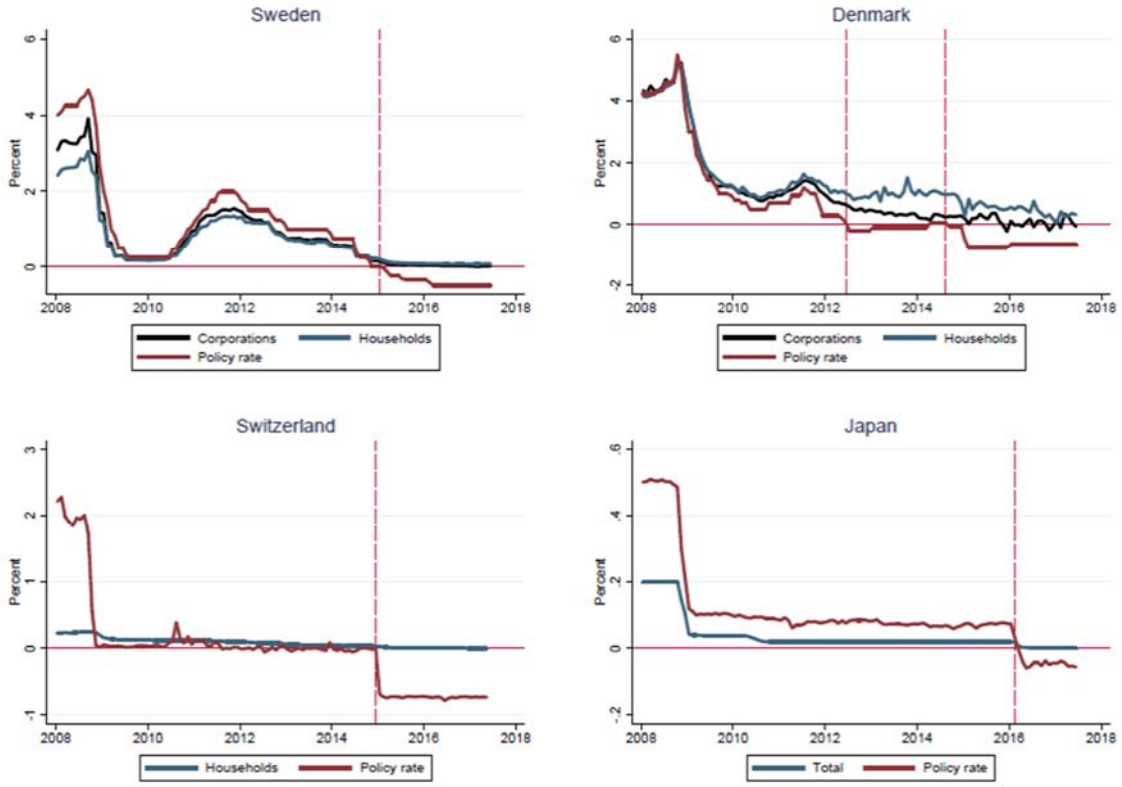
Notes to Exhibit 2.3. Wednesday values in billions of dollars. Currency: currency in circulation. Rev repo: Reverse repurchase agreements (foreign official and international accounts plus others). Term deposits: term deposits held by depository institutions. Treasury: U.S. Treasury general account plus supplementary financing account. Other: Treasury cash holdings plus foreign official, service-related and other deposits plus other liabilities and capital. Reserve balances: reserve balances with Federal Reserve banks. Data source: Federal Reserve H41 archive.

Exhibit 3.1. Interest rates in Sweden (monthly averages, Jan 2013 to Dec 2017)



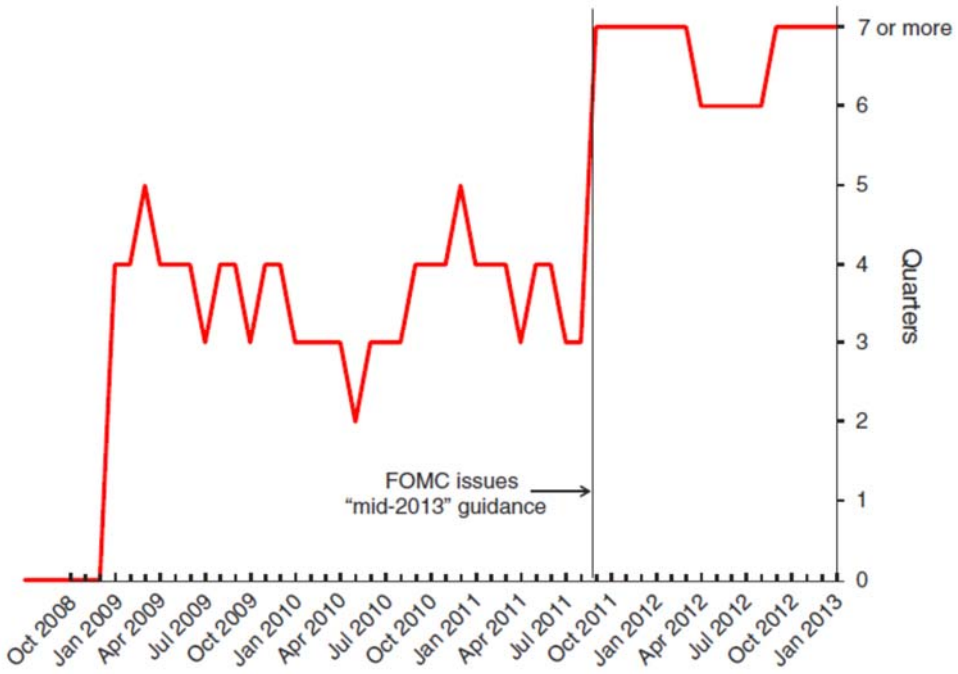
Notes to Exhibit 3.1. Data source: Riksbank.

Exhibit 3.2. Policy rates (in red) and household and corporate bank deposit rates (blue or black) for Sweden, Denmark, Switzerland, and Japan



Notes to Exhibit 3.2. The policy rates are defined as the Repo Rate (Sweden), the Certificates of Deposit Rate (Denmark), SARON (Switzerland), and the Uncollaterized Overnight Call Rate (Japan). The red vertical lines mark the month in which policy rates became negative. Source: Eggertsson, Juelsrud, and Wold (2017).

Exhibit 3.3. Blue Chip consensus expected number of quarters until first federal funds rate increase (top-coded at 7 quarters)



Notes to Exhibit 3.3. Source: Swanson and Williams (2014).

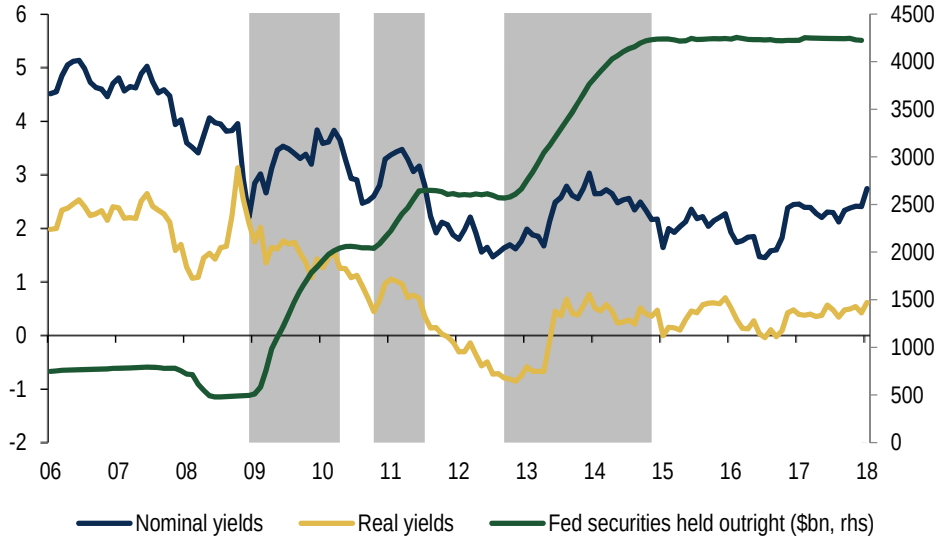
Exhibit 3.4. Interest rate on constant-maturity 10-year Treasury bond

Notes to Exhibit 3.4. Rate implied by Chicago Board of Trade TNX contract, minute-by-minute observations (in Central Time) during March 18, 2009. Data source: Datastream.

Exhibit 3.5. QE1 and QE2 announcements used by Krishnamurthy and Vissing-Jorgensen (2011) and change (in basis points) in yield on 10-year Treasuries in 2 days following announcement, on the day of the announcement, and within 30 minutes of the announcement

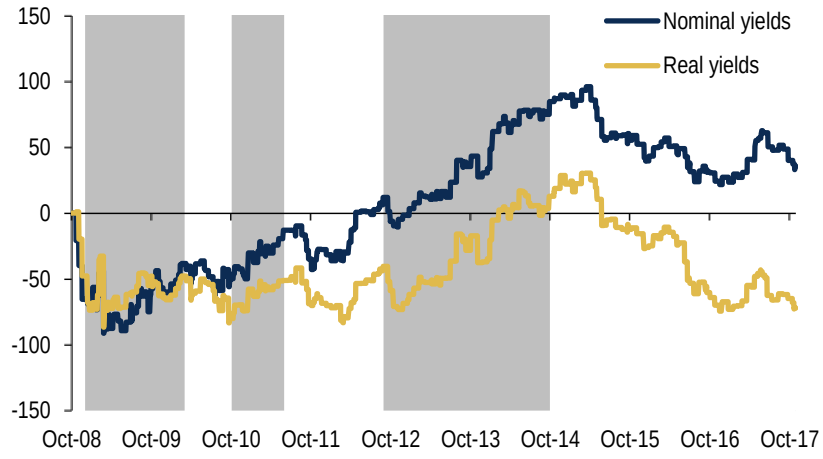
date	time	event	48 hour	24 hour	30 minute	description
QE1						
25-Nov-08	8:15	Fed press release	-36	-24	-3	The initial announcement that the Federal Reserve would purchase up to $100 billion of agency debt and up to $500 billion of agency MBS.
1-Dec-08	13:45	speech	-25	-21	1	Chairman Bernanke's speech on the Federal Reserve Policies in the Financial Crisis, which suggested that the Federal Reserve could purchase longer-term Treasury securities in substantial quantities in order to stimulate the economy.
16-Dec-08	14:15	FOMC statement	-33	-16	-14	The Federal Reserve will continue to consider ways of using its balance sheet to further support credit markets and economic activity.
28-Jan-09	14:15	FOMC statement	28	12	1	The FOMC statement that was interpreted by some market participants as disappointing because of its lack of concrete language regarding the possibility and timing of purchases of longer-term Treasuries in the secondary market.
18-Mar-09	14:15	FOMC statement	-41	-51	-44	The FOMC statement, which announced purchases of Treasury securities of up to $300 billion and increased the size of purchases of agency MBS and agency debt to up to $1.2 trillion and $200 billion, respectively.
Sum			**-107**	**-100**	**-59**	
						0
QE2						
10-Aug-10	14:15	FOMC statement	-14	-7	-7	To help support economic recovery in the context of price stability, the Committee will keep the Federal Reserve's holdings of securities at their current level by reinvesting principal payments from agency debt and agency mortgage-backed securities in longer-term Treasury securities. The Committee will continue to roll over the Federal Reserve's holdings of Treasury securities as they mature.
21-Sep-10	14:15	FOMC statement	-16	-10	-1	The FOMC is prepared to provide additional accommodation if needed.
Sum			-30	-17	-8	

Exhibit 4.1. Bond yields tended to rise during the implementation of QE1, 2 and 3



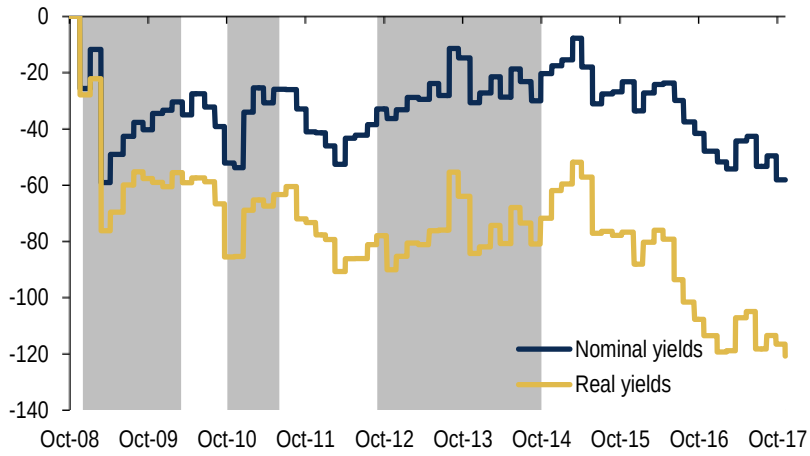
Notes to Exhibit 4.1. The shaded area in this an all subsequent chart shows the period of balance sheet expansion: Jan 2009 to Mar 2010 for QE1, Nov 2010 to June 2011 for QE2 and Oct 2012 to Oct 2014 for QE3. Many of the announcement effects should come before or at the start of the shaded areas.

Exhibit 4.2. Cumulative change in yields on all "Fed Days" (meeting, minutes, chair speech)



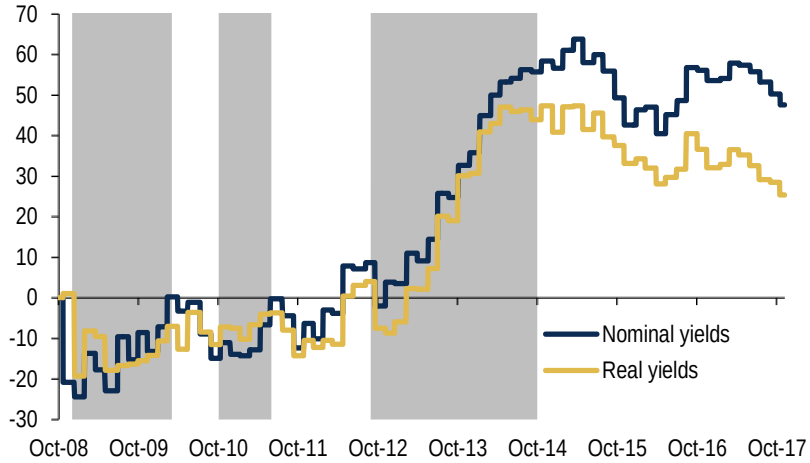
Notes to Exhibit 4.12. The cumulative move is the sum of the actual change in yields on days of FOMC meetings, minute and Chair speeches and with zero for non-Fed Days. The cumulative change in this and all subsequent charts is in basis points.

Exhibit 4.3. Cumulative change on Fed meeting days



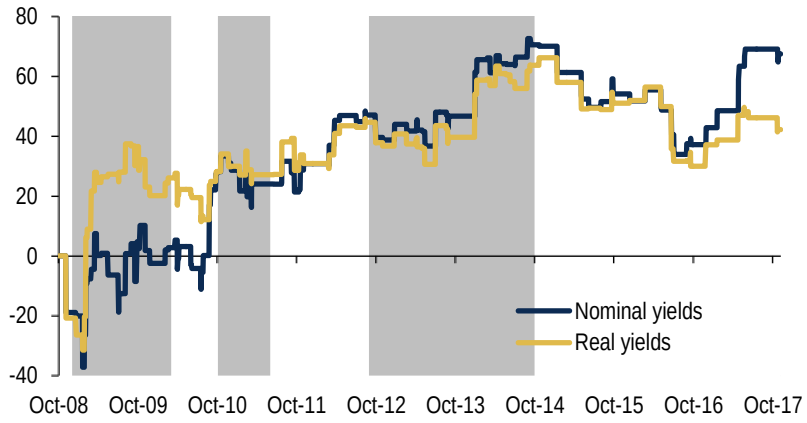
Notes to Exhibit 4.3. Cumulative sum using actual yield changes on FOMC meeting days and zero for all other days.

Exhibit 4.4. Cumulative change on Fed minutes days



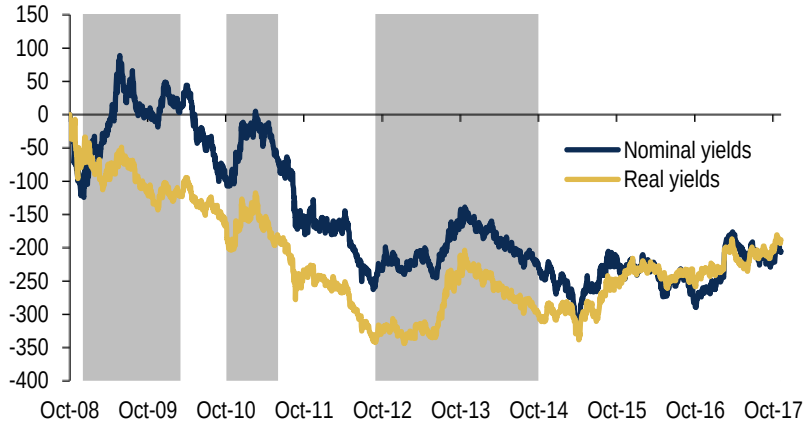
Notes to Exhibit 4.4. Cumulative sum using actual yield changes on days when the minutes were released and zero for all other days.

Exhibit 4.5. Cumulative change on Fed chair speech days



Notes to Exhibit 4.5. Cumulative sum using actual yield changes on days when the Chair gave and economic or policy related speech and zero for all other days.

Exhibit 4.6. Cumulative change in all non-Fed Days



Notes to Exhibit 4.6. Cumulative sum using actual yield changes on non-Fed Days and zero for all Fed Days.

Exhibit 4.7. Decomposing the net change into positive and negative moves

		# days positive change	Cumulative positive change	# days negative change	Cumulative negative change	Total
Full sample	Nominal	131	694.2	127	-676.3	17.9
until 12/06/17	Real	132	582.0	119	-658.2	-76.2
Expansion	Nominal	73	427.9	68	-415.8	12.1
until 5/21/2013	Real	79	330.0	62	-379.3	-49.3
Exit	Nominal	58	266.3	59	-260.5	5.8
from 5/22/2013	Real	53	252.0	57	-278.9	-26.9

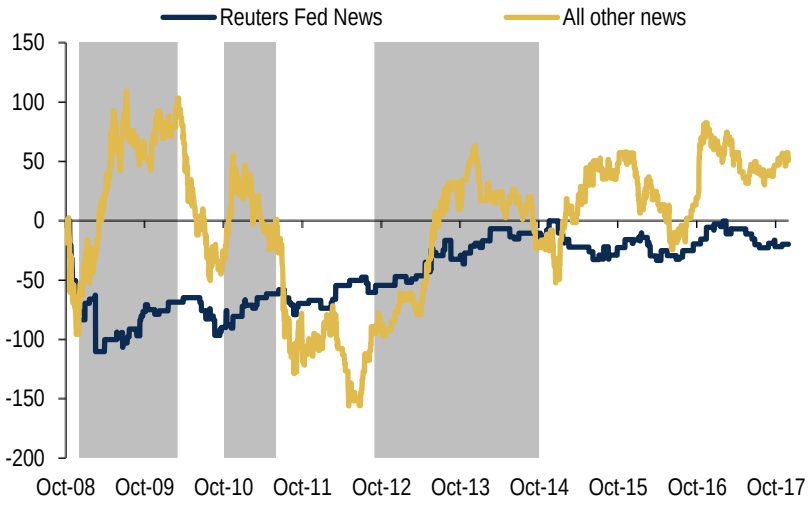
Notes to Exhibit 4.7. Cumulative move in yields on Fed Days, divided into days when yields went up and days when yields went down. The first two rows show the cumulative move for our entire sample (starting in November 2008) and the later rows divide the sample with the day before Bernanke's first taper tamper warning.

Exhibit 4.8. Events that moved the bond market significantly according to Reuters

Category	Frequency	Details
Fed	161	Balance Sheet (83), Interest Rate (80), Fed Purchase (16), Other (3)
Macro data	348	US economic data (348)
Europe	191	Economic/political news (135, ECB (37), European bonds (19)
Other international news	88	China (32), NK (6), Central banks(non-Fed/ECB) (14), Other countries (36)
Technicals/Supply	76	Technicals (28), Supply side news(48)
Stocks/Oil	65	Stock market movement (45), Oil price (20)
Continuation/Correction	75	Continuation (33), Correction (42)
US politics	50	US political news (50)
Other	71	
Total	1125	

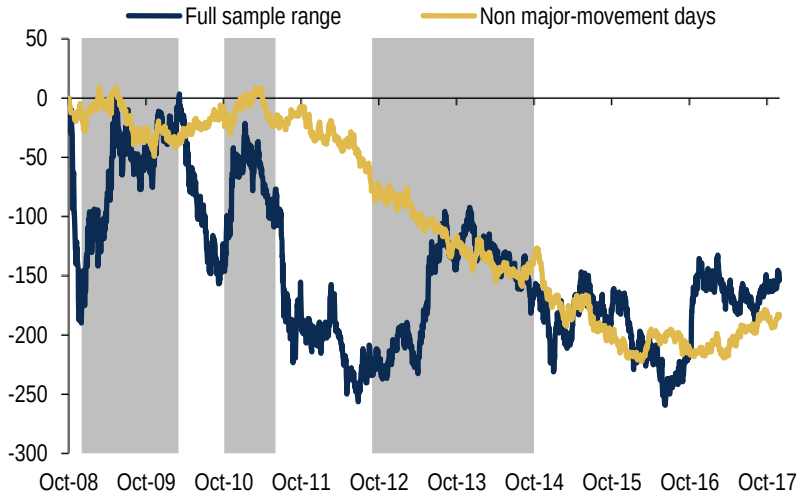
Notes to Exhibit 4.8. The numbers in the details differ from the reported total frequency because some days contain more than one story.

Exhibit 4.9. Nominal change on Reuters Fed News days and all other Reuters News days



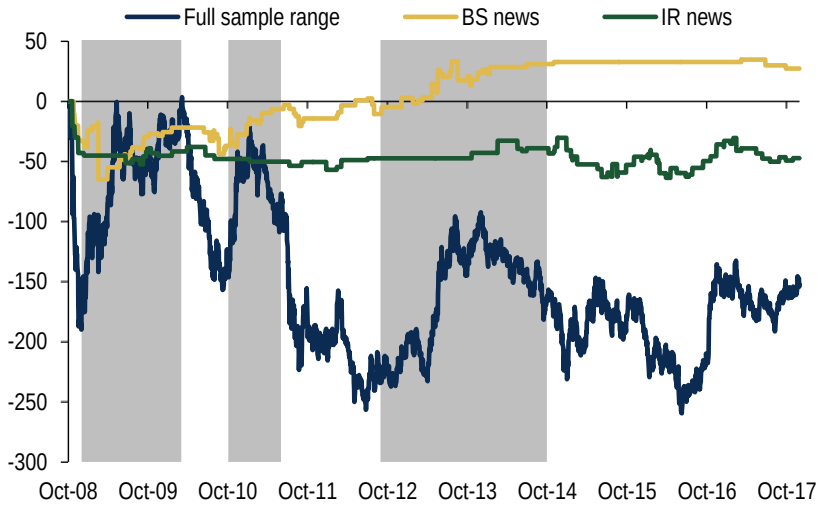
Notes to Exhibit 4.9. The blue line is the cumulative change in yields when Reuters identified Fed news as a driver of markets, with zero for all other days. The yellow line shows the cumulative market move on all other Reuters days, with zero for all other days.

Exhibit 4.10. Cumulative change in yields for all days and for all non-Reuters Days



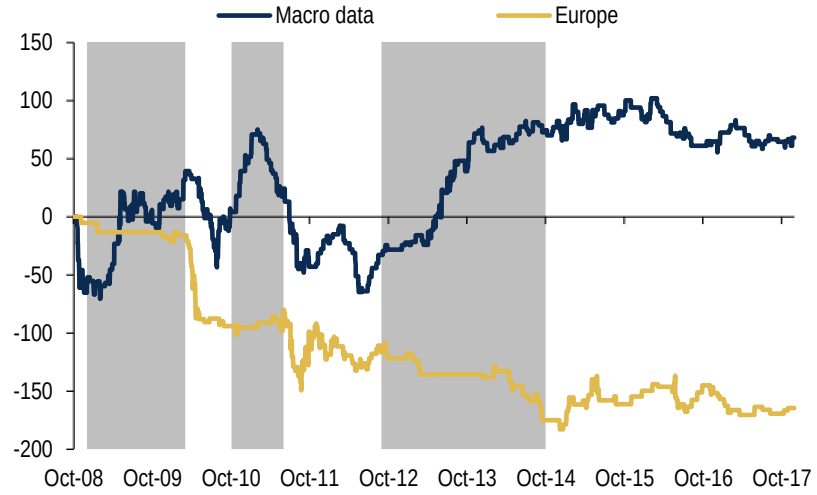
Notes to Exhibit 4.10. Recall that days with small moves (less than one standard deviation) are not included in out Reuters News day data set. This chart compares the cumulative move on these small movement days to the overall cumulative move in yields on all days.

Exhibit 4.11. Decomposing the Reuters Fed News into balance sheet and interest rate news



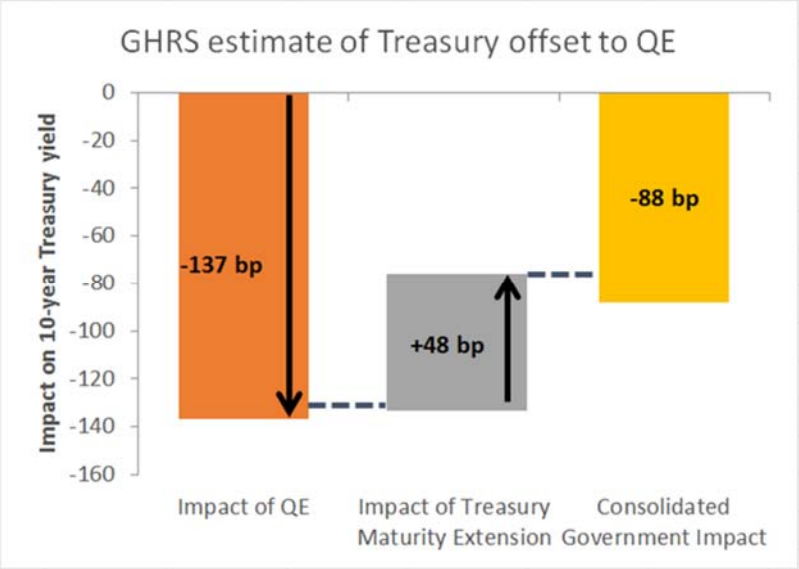
Notes to Exhibit 4.11. This chart separates out the two kinds of Reuters Fed News days, showing cummulative moves for each. For reference it also shows the cummulaitve move in yields for all days in the sample.

Exhibit 4.12. Other Reuters News days that caused large cummulative moves



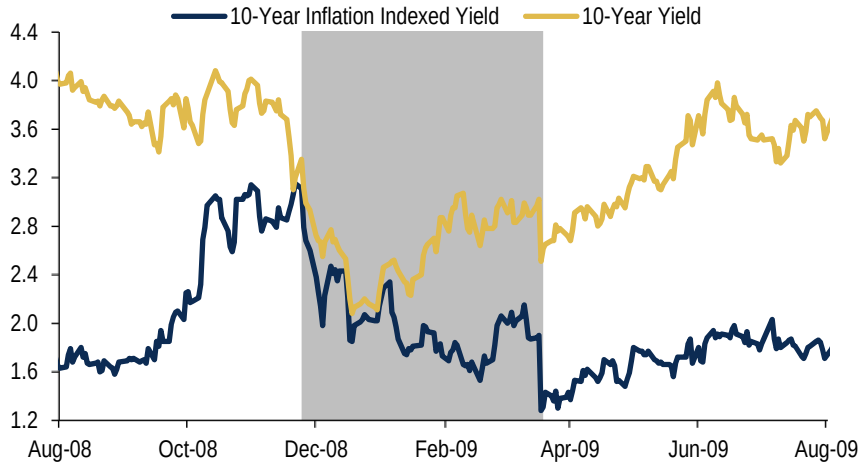
Notes to Exhibit 4.12. Our Reuters News data base captures all the days where the market moved at least one standard deviation. The chart shows the cumulative impact of US macro data announcements and developments in Europe.

Exhibit 4.13. Treasury debt management policy acted as an offset to Fed QE.



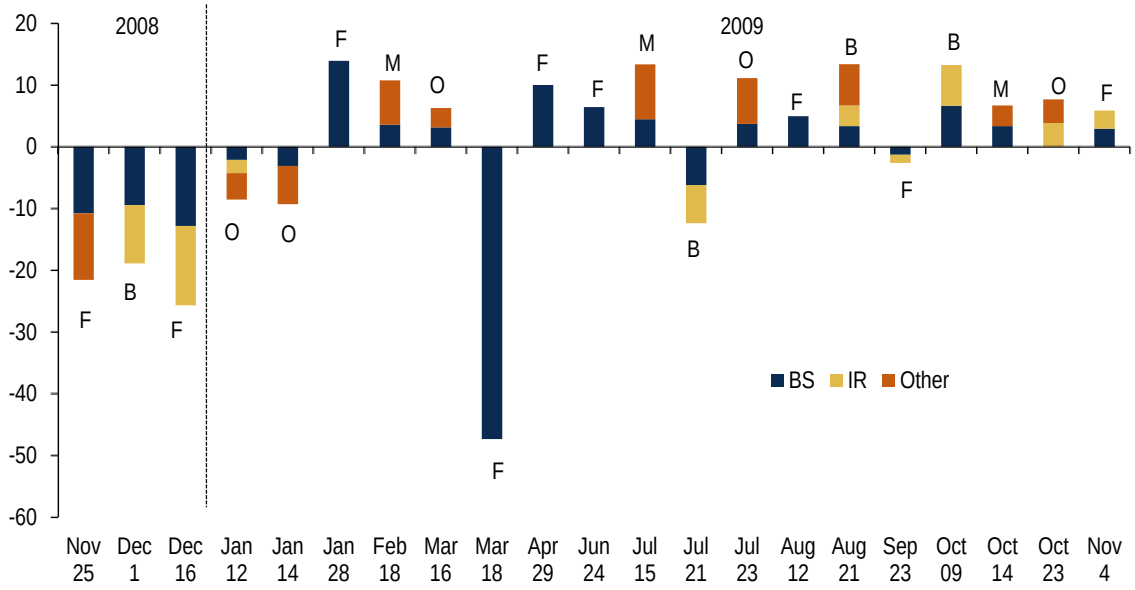
Notes to Exhibit 4.13. Source: Greenwood et al. (2014).

Exhibit 4.14. Real and nominal bond yields around QE1 announcements



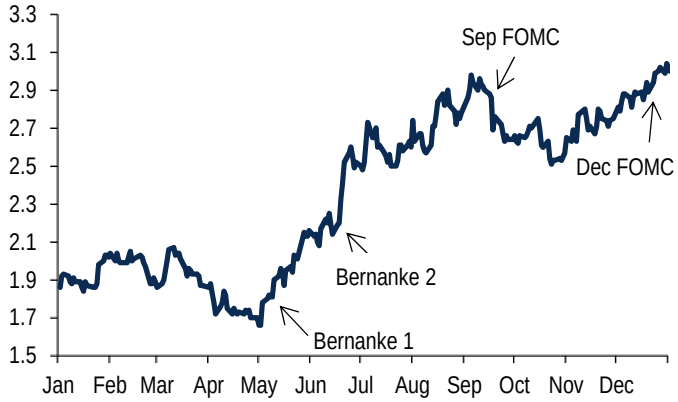
Notes to Exhibit 4.14. Level of yields in percent. Shaded area covers the period from the first (November 25, 2008) to the second (March 18, 2009) QE1 announcement.

Exhibit 4.15. Change in 10 year yields on Reuters Fed Days under QE



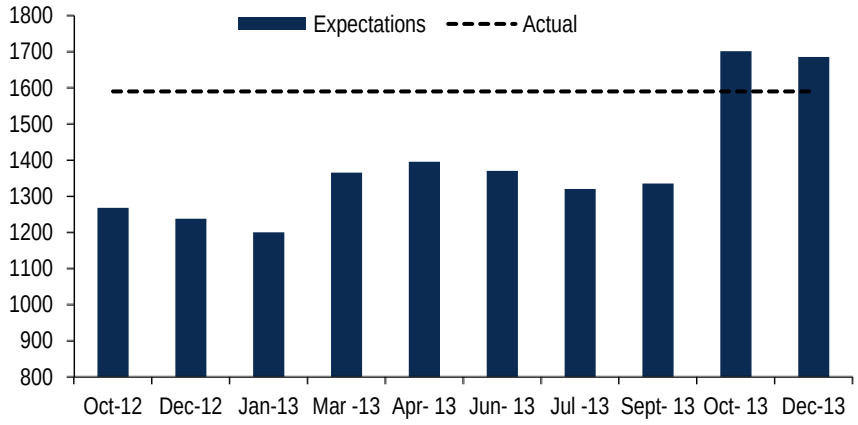
Notes to Exhibit 4.15. Total bar heights denote change in 10 year yield on QE1 days for which Reuters report indicated at least some balance sheet component. Where interest rate guidance or other developments were also mentioned by Reuters, beige and orange shading was used in addition to the blue for balance sheet. F: FOMC meetings; B: Bernanke speeches; O: speeches by other FOMC members (O); M: minutes.

Exhibit 5.1. Nominal bond yields during the tantrum



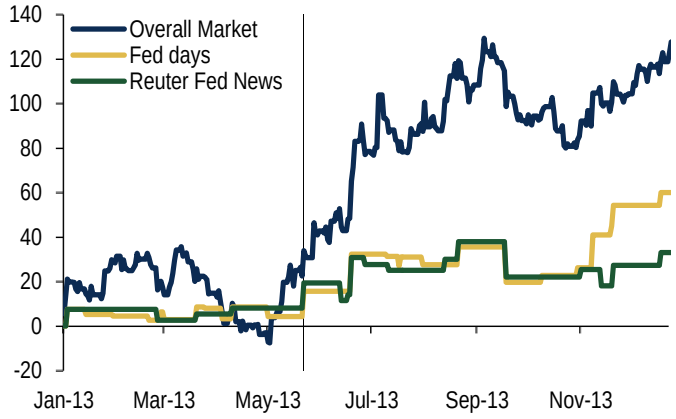
Notes to Exhibit 5.1 10 year treasury yields around four major Fed signals: Bernanke's two taper warnings, the failure to announce tapering at the September FOMC meeting and the actual announcement at the December meeting.

Exhibit 5.2. Implied balance sheet peak based on primary dealer survey



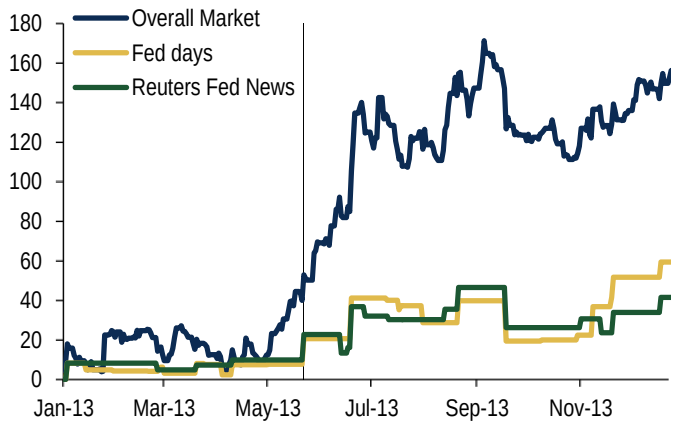
Notes to Exhibit 5.2. Respondents give the amount of Treasury and MBS purchases that would be in effect after various future FOMC meetings. We use the median responses to construct expectations about the total size of the QE3 program. For meetings that were omitted in the surveys, we fill out the missing data based on two principles: i) cuts to asset purchases would be initiated at a meeting with a press conference, and ii) unless the forecasts implied some tapering, asset purchases would be ended abruptly. We make the second assumption because it appears that respondents were not expecting asset purchases to be tapered until after Bernanke's May 22, 2013 comments. The assumption implies slightly larger estimates of the total size of QE3, all else being equal.

Exhibit 5.3. Cumulative change in nominal bond yields during Taper Tantrum



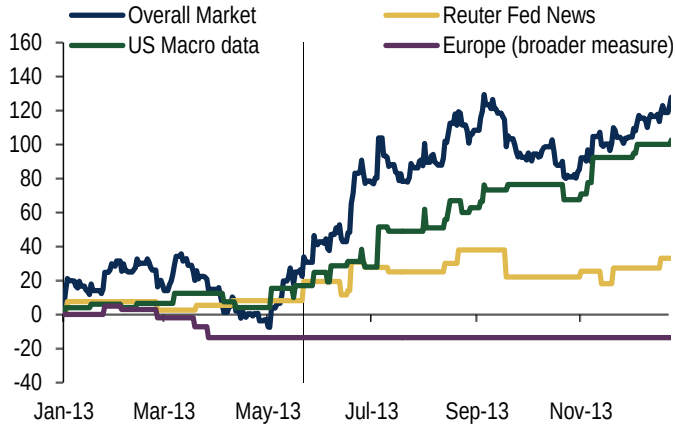
Notes to Exhibit 5.3. Cumulative change in basis points from December 31, 2012 to December 31, 2013. Vertical line is drawn on May 21, the day before Bernanke's first warning. Overall market is cumulative change on all days that year. Fed Days is the cumulative change on FOMC meeting days, the release of minutes and relevant Fed Chair speeches (with zero for all other days). Reuter Fed News is the same calculation allowing Reuters to pick the relevant Fed days.

Exhibit 5.4. Cumulative change in real bond yields during Taper Tantrum



Notes to Exhibit 5.4. Same as previous exhibit, but with real rather than nominal yields.

Exhibit 5.5. Causes of cumulative nominal bond yield changes during taper tantrum



Notes to Exhibit 5.5. Compares cumulative movement in nominal yields on three kinds of Reuters News days to the cumulative market movement on all days. Attribution to causes is based on Reuters news stories, as described in the text.

Exhibit 5.6. Median expectations for balance sheet shrinkage

Primary dealer survey

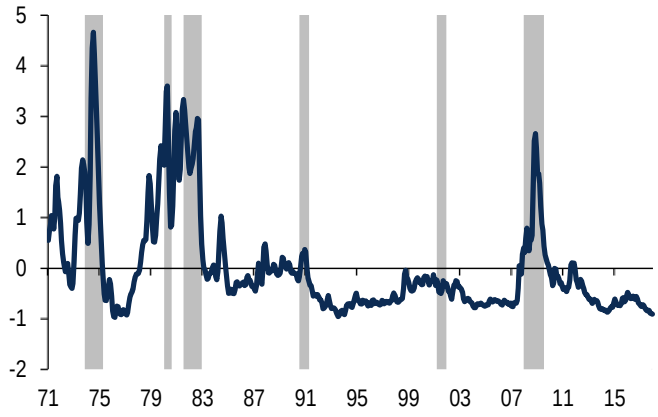
	Expectations (Jan 2017)	Actual outcome	Hawkish?
Start shrinkage	Jun-18	Oct-17	✓
Balance sheet (yearend '19, $Bn)	3,770	3,598	✓
Pause hiking	Two meetings	One meeting	✓
State contingent or preprogramed	Uncertain	Pre programed	✓

Blue Chip survey

	Expectations (Jan 2017)	Actual outcome	Hawkish?
Start shrinkage	2H 2018	Oct-17	✓
Balance sheet (yearend '19, $Bn)	3,991	3,598	✓
Pause hiking	1.5 meetings	One meeting	✓
State contingent or preprogramed	Uncertain	Pre programed	✓

Note to Exhibit 5.6 Data are from Blue Chip and Federal Reserve Bank of New York. Neither survey asked investors whether they expected the Fed to announce its whole exit plan out of the gate.

Exhibit 5.7. Financial conditions index

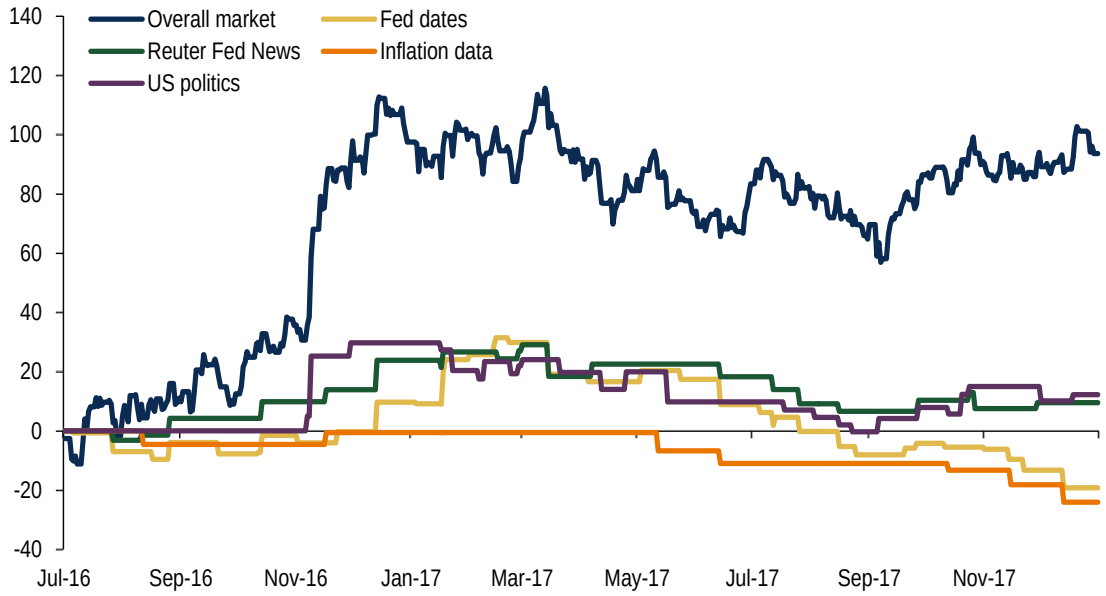


Note to Exhibit 5.7. Source is the Federal Reserve Bank of Chicago

Exhibit 5.8. Fitted one-year forward treasury rate

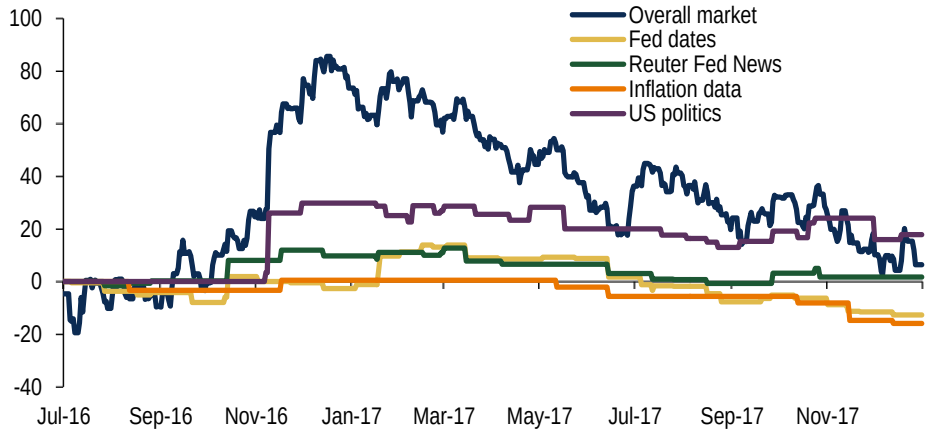
Notes to Exhibit 5.8. Source Federal Reserve Board.

Exhibit 5.9. Causes of cumulative nominal yield change during shrinkage shrug



Note to Exhibit 5.9. The sample starts July 1, 2016. Attribution to causes is based on Reuters news stories, as described in the text.

Exhibit 5.10. Causes of term premium changes during shrinkage shrug



Note to Exhibit 5.10. Term premium estimates are from Adrian, Crump and Moench (ACM), Federal Reserve Bank of New York. Attribution to causes is based on Reuters news stories, as described in the text.

Exhibit 6.1. Maximal monthly amounts by which the Fed will allow principal payments to reduce its holdings of Treasury securities and MBS

	Treasuries	MBS
2017:Q4	6	4
2018:Q1	12	8
2018:Q2	18	12
2018:Q3	24	16
2018:Q4	30	20

Exhibit 6.2. Maximal monthly amount by which the Fed will allow principal payments to reduce its holdings of Treasury securities and MBS and average monthly reductions expected to be realized by Bonis, Ihrig and Wei (2017)

	cap	drawdown
2018 Q1	20	17.7
Q2	30	28.5
Q3	40	33.0
Q4	50	37.2
2019-2021	50	30.0

Exhibit 6.3. Historical and projected Fed assets, Dec 18, 2002 to Dec 31, 2025

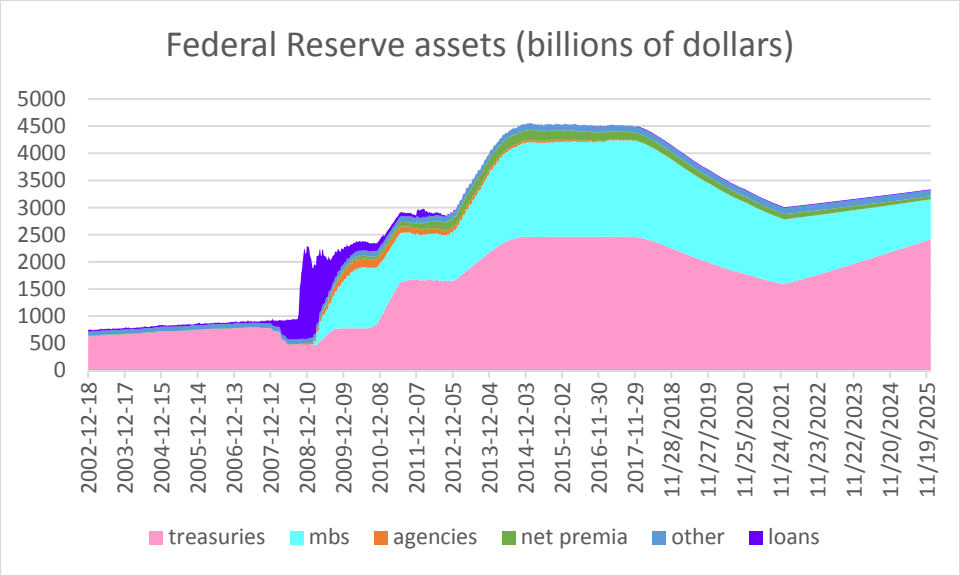


Exhibit 6.4. Historical and projected Fed liabilities, Dec 18, 2002 to Dec 31, 2025

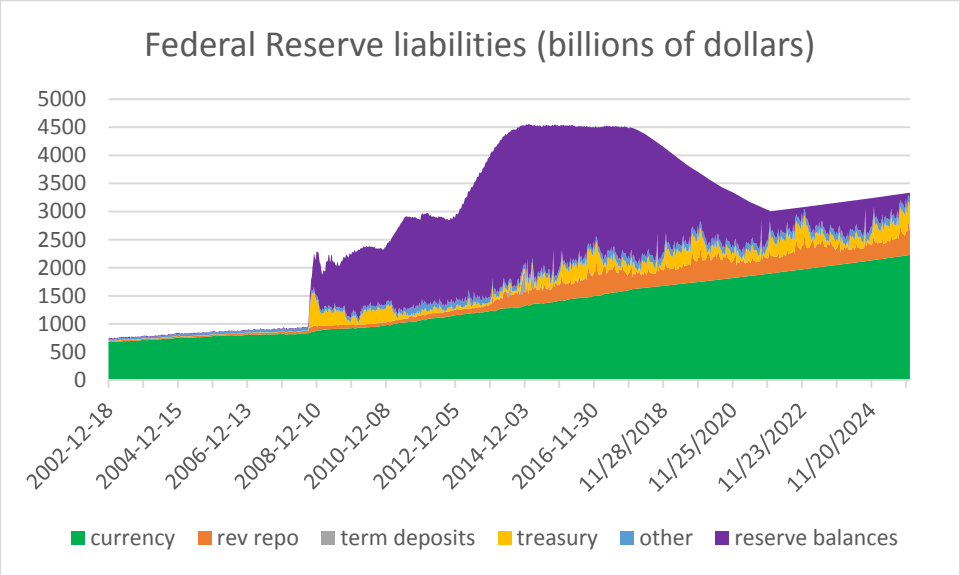


Exhibit 6.5. Treasury cash balance, daily, Jan 1, 2006 to Jan 26, 2018

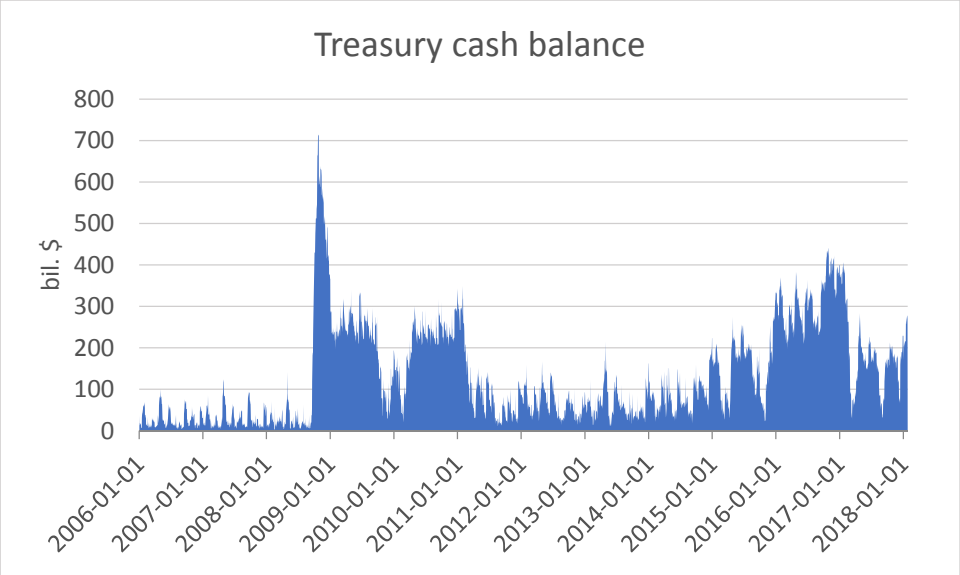


Exhibit 6.6. Federal Reserve reverse repos, Wed values, Jan 6, 2010 to Jan 3, 2018

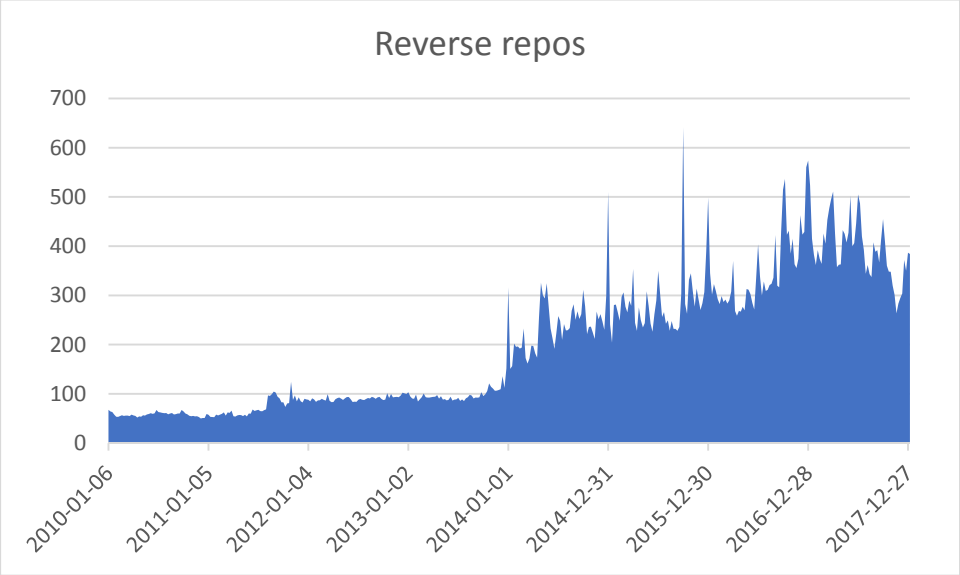
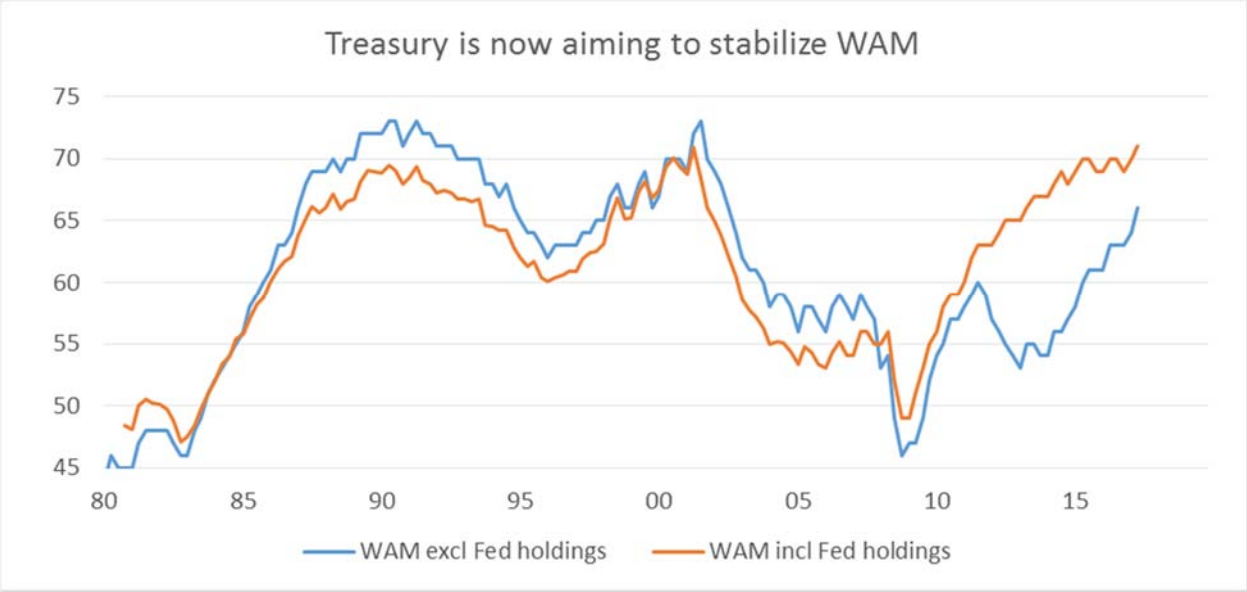


Exhibit 6.7. Treasury financing gap, 2018 to 2027

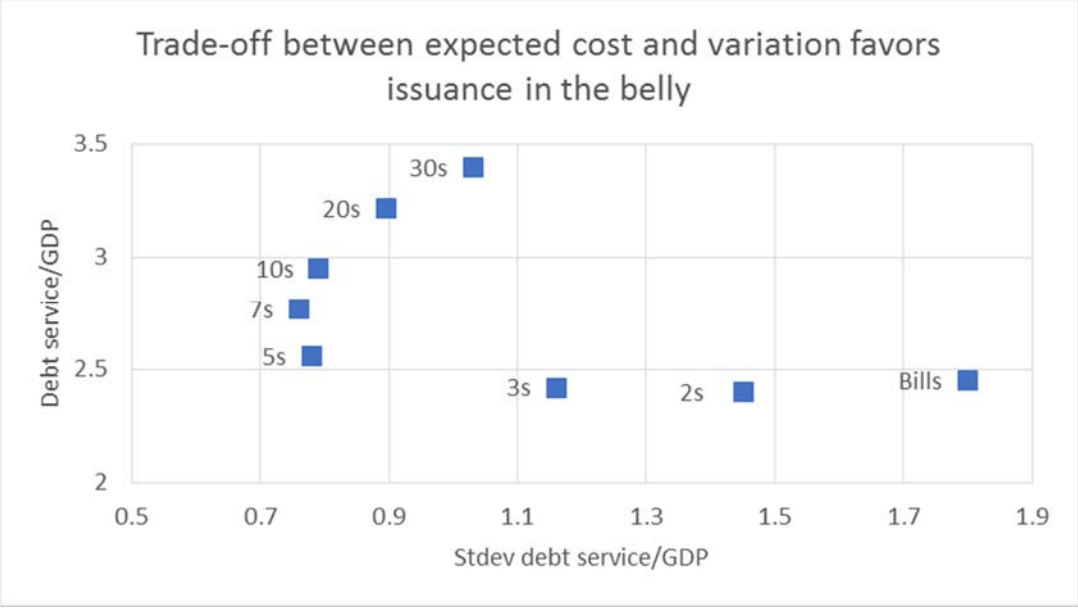
Notes to Exhibit 6.7. Financing gap represents the amount that Treasury issuance must be increased based on an assumed budget deficit path. The budget path that is assumed here reflects the "Other Policies Extended" version of the estimates produced by the Committee for a Responsible Federal Budget on February 9, 2018 (following passage of the bipartisan spending package).Source: Author's calculations based on CBO, CRFB, FRBNY and US Treasury data.

Exhibit 6.8. Weighted average maturity of outstanding marketable Treasury debt (in months)



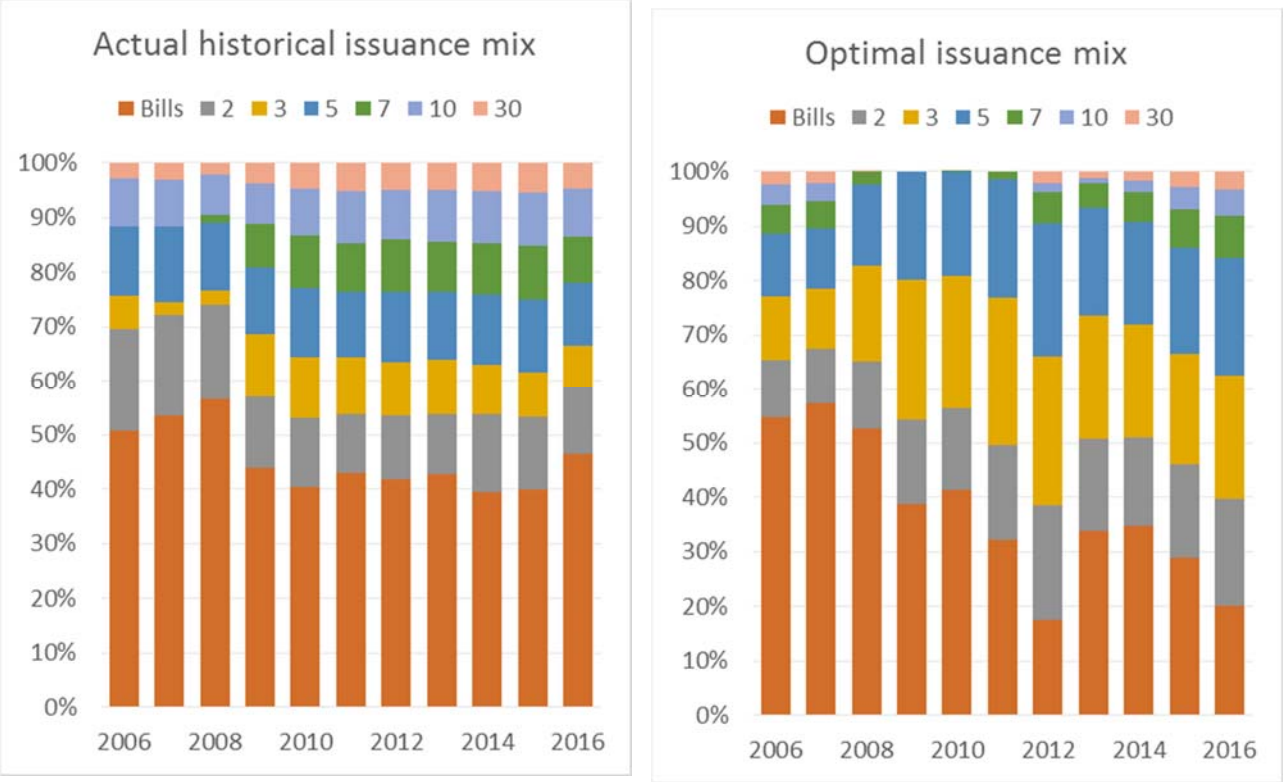
Notes to Exhibit 6.8. Source: U.S. Treasury.

Exhibit 6.9. Cost of Treasury issuance at certain maturity points versus the variability of that cost



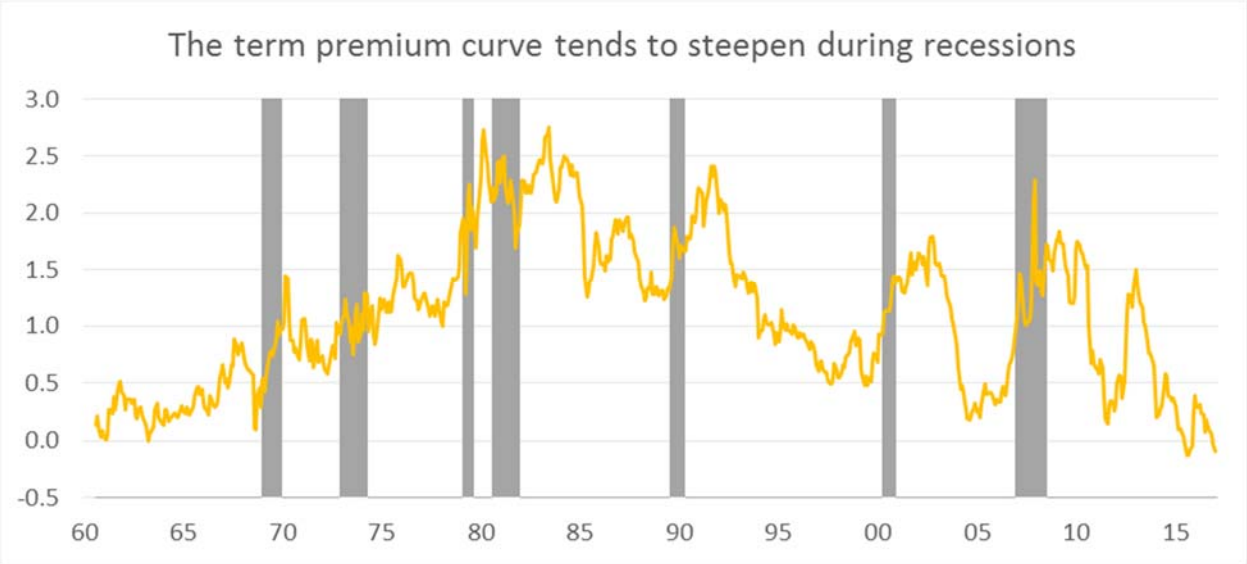
Notes to Exhibit 6.9. Source: TBAC

Exhibit 6.10. Actual Treasury issuance mix versus an optimal strategy derived from the TBAC model



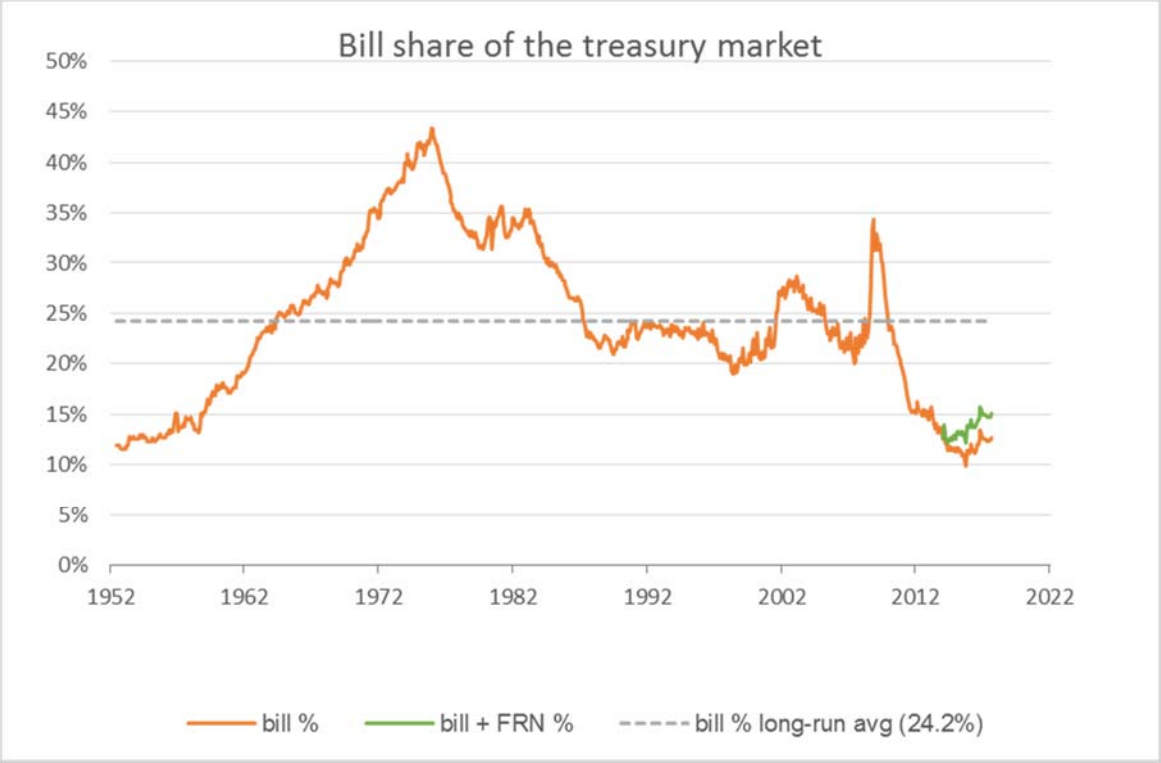
Notes to Exhibit 6.10. Source: Treasury Department and TBAC.

Exhibit 6.11. Difference between 10 year and 2 year Treasury term premium



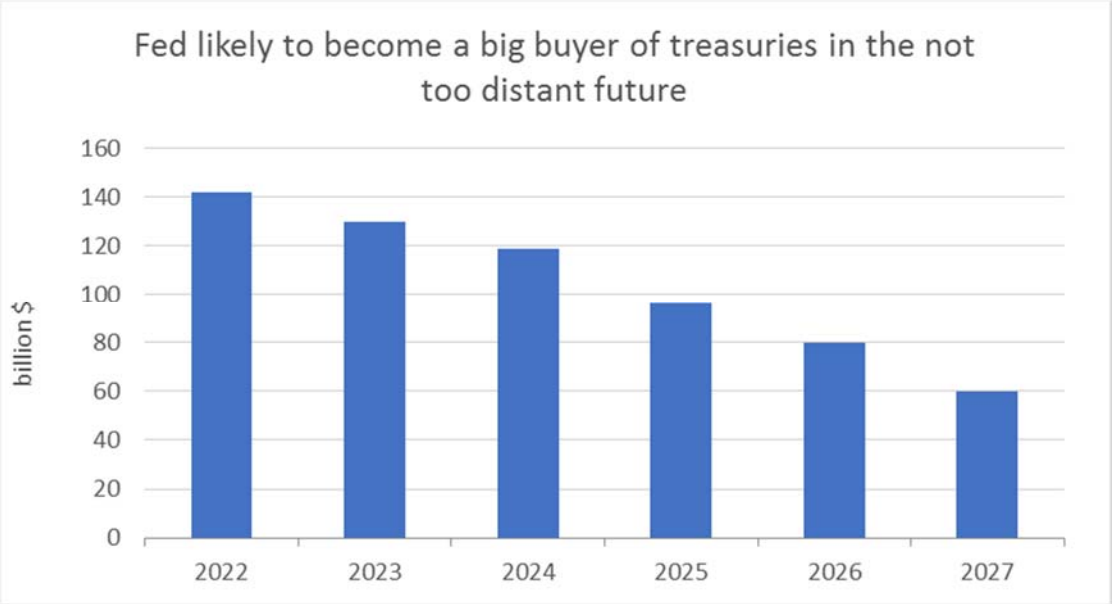
Notes to Exhibit 6.11. Shaded areas indicate NBER designated recession. Source: ACM term premia estimates, Federal Reserve Bank of New York.

Exhibit 6.12. Bills as a % of Treasury marketable debt outstanding



Notes to Exhibit 6.12. Source: MSPD, Bureau of Economic Analysis.

Exhibit 6.13. MBS redemptions after 2021 based on median scenario, 2022 to 2027



Notes to Exhibit 6.13. Source: FRBNY.

Exhibit 7.1. Fall in fed funds rate in recent U.S. recessions

Period	Fall
1957:8-1958:6	2.3
1960:4-1961:4	2.4
1969:12-1971:1	4.8
1973:11-1975:5	4.8
1980:1-1980:9	3
1981:7-1983:1	10.4
1990:7-1991:5	2.4
2001:3-2002:1	3.6
2007:12-2009:8	4.1
average	4.2

Notes to Exhibit 7.1. Fall in monthly average effective fed funds rate between month recession began and two months after it ended.