



Federal Reserve Bank of Chicago

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Easing and Tightening**

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Unexpected Supply Effects of Quantitative Easing and Tightening

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Abstract

To analyze the evolution of quantitative easing's (QE) and tightening's (QT) effects across consecutive announcements, we focus on their unexpected component. Treasury yield sensitivities to QE and QT supply surprises do not fall monotonically over time, thus later announcements seemed to remain powerful; yield sensitivities to QT surprises are on average larger than sensitivities to QE surprises, implying supply effects did not diminish during periods of market calm amid economic expansion; finally, yield sensitivities are amplified by the amount of interest-rate uncertainty prevailing before the announcement, implying that turning points in the balance sheet policy tended to elicit larger reactions.

Keywords: Balance sheet policy surprises, quantitative easing and tightening, asset supply effects

JEL codes: E43, E44, E52, E58

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1 Introduction

Over the last twelve years, persistently low nominal interest rates have posed a challenge to traditional monetary policy, based on the management of a short-term rate. As demonstrated by the unfolding of monetary policy actions during the onset of the Covid-19 pandemic, the likelihood that the policy rate hits the zero-lower-bound (ZLB) has become significantly higher, making it very valuable for central banks to keep a variety of policy tools at their disposal. One of the available tools is balance sheet policy (BSP) and its most common form has been quantitative easing (QE), large-scale purchases of government-guaranteed securities.¹ QE has been used extensively by all major central banks during the last global financial crisis and, since March 2020, 17 central banks have announced QE interventions to support financial markets amid the pandemic.² Clearly, so far, the use of QE has been limited to periods of crisis, as this tool is not viewed yet as part of normal monetary policy. As argued by Bernanke (2020), the lack of experience with QE created a lot of uncertainty about its effectiveness over time and in normal financial conditions.

In this study, we try to shed some light on the evolution of asset price effects of the Federal Reserve's (Fed) BSP over time and across diverse economic and financial market conditions. We label changes in expected asset supply triggered by the Fed's BSP during a tightening cycle, quantitative tightening (QT), and during an easing cycle, QE.³ During both QT and QE, the asset supply shift induced by the BSP can be either larger or smaller than expected, thus QT and QE are not necessarily synonyms of hawkish and dovish BSP surprises, respectively. The distinguishing characteristics of QT and QE are the economic and financial market conditions that led to the change in BSP and that might induce similar asset supply shocks to possibly have different impacts. In what follows we examine this eventuality.

In particular, we address the following three questions: Does the sensitivity of Treasury yields to asset supply shocks change *during* QE and QT? Does the sensitivity of Treasury yields to asset supply shocks change *across* QE and QT? And if it changes, does it vary in the direction predicted by macro-finance models? The answers to these

¹Other forms of BSP include, for example, credit easing, that is, the purchase of corporate bonds and other privately-issued securities, as well as yield curve control, that is, the targeting of yield levels rather than asset supply.

²See Table 1 in Hartley and Rebucci (2020).

³To divide events into just two categories, we include in a "tightening cycle" also the beginning of reduction in policy accommodation, such as the tapering of asset purchases.

questions are relevant for several reasons. First, it helps us understand whether BSP has diminishing returns across subsequent programs. Second, it helps us understand whether the impact of BSP is diminished during periods of financial market calm, such as those observed during QT. Third, it helps evaluate the impact of the unwinding of QE in the Treasury market, which has been hardly studied before. And last but not least, it speaks to macro-finance theory arguing that central banks' BSP should be effective mainly in the presence of tighter financial constraints or market dysfunctions.

Overall, the joint understanding of all of those BSP aspects can clarify the relative importance of the yield sensitivity versus the size of the asset supply shock for the *total* supply effect of BSP that, to a first approximation, can be thought of as the product of the yield sensitivity and supply shock induced by each BSP announcement. If the yield sensitivity does not materially diminish across the announcements of consecutive programs or across economic and financial market conditions, then one should infer that smaller announcement effects are driven by decreasing asset supply shocks. This is relevant for the BSP design and related communication, as these factors can determine the size and persistence of the supply shocks; while, the yield sensitivity is mostly out of a central bank's control. More importantly, if the marginal impact of BSP on Treasury yields did not decline as the Fed's balance sheet grew and in calmer financial conditions, then perhaps the use of BSP should not be limited to extraordinary circumstances. That is, QE/QT could become part of the standard policy toolkit, especially in an environment in which persistently low interest rates constrain the scope of traditional monetary policy.

Most previous research assessing whether QE has diminishing returns in financial markets has not controlled for expectations about the level and composition of planned asset purchases at the time of QE announcements. That failure might have led to the conclusion that later rounds of QE were less effective than the first QE. Our premise, similarly to Cahill et al (2013), is that later rounds of QE were better anticipated by market participants, and therefore the magnitude of the asset supply surprise—not necessarily the yield sensitivity—has become smaller, inducing smaller changes in asset prices around the formal BSP announcements. This implies that to correctly identify the asset price effects of later rounds of QE and QT, it is necessary to focus on the unexpected component of the BSP announcements, that is, the amount and distribution of asset purchases that was not correctly anticipated by investors. To do so we use the Survey of Primary Dealers (SPD) compiled by the New York Fed

before each FOMC. This is conceptually equivalent to using the unexpected change in the Federal Funds Rate (FFR) to identify the policy rate surprise in the case of conventional monetary policy.

Arguably, the role of investor anticipation is also very relevant during QT as, while both policy-makers and investors had gained experience with BSP during QE, none of them had experience with the unwinding of a central bank's large balance sheet. Turning points in BSP, as demonstrated by the episode of the "Taper Tantrum" in May-June 2013—when the eventuality of the Fed tapering the pace of asset purchases pushed longer-term rates higher by about 120 basis points over two months—imply that substantial uncertainty about the normalization process of the Fed's balance sheet could have amplified asset price effects through both larger BSP surprises and increased interest rate uncertainty. This also suggests that asset supply shocks and interest rate uncertainty might interact, therefore in our study we will account also for this interaction.

Our first innovation in this paper is to develop measures of BSP surprises for both QE and QT in order to assess their relative impact in the Treasury market. Our second contribution consists of using a new identification procedure to quantify supply effects of QE and QT announcements. We build on the methodology of Cahill et al (2013), who rely on *relative* yield changes of *individual* Treasury securities in small time windows around earlier QE announcements. But, differently from that study, our empirical strategy isolates the supply effects of QE and QT by exploiting *sharp kinks* in the yield curve reaction to the supply shocks triggered by various BSP announcements. The kinks and their maturity locations on the yield curve are connected to the release of the operational details of the purchases/reinvestments implementation, which are decided before the formal BSP announcement, and are therefore independent of the price reaction on the day of the announcement. Importantly, the slope change around the kink should retrieve the causal effect of only the supply shock, as it seems reasonable to assume that sharp kinks in the yield reaction cannot be caused by either a change in the expected policy-rate path or in aggregate duration risk, as those factors should affect yields with close maturities (i.e., those around the kinks) similarly and in a smooth fashion. Finally, our third novelty, is to control for the interactions between the asset supply surprise and the uncertainty about longer-term rates prevailing before the BSP announcement.

In each event, the Treasury yield sensitivity is obtained by dividing the slope change

in the yield curve reaction around the kink by the size of the asset supply surprise. This normalization is necessary to be able to compare the relative efficacy of subsequent announcements within QE and QT as well as across QE and QT. Based on a range of estimates, we obtain three main findings. First, within both QE and QT, the Treasury yield sensitivity to asset supply shocks does not seem to fall monotonically across subsequent announcements. This suggests that the supply effects of later announcements remained powerful. Second, the Treasury yield sensitivity to asset supply shocks during QT is at least as large as the yield sensitivity to asset supply shocks during QE, implying the supply effects did not diminish during periods of market calm or across monetary-policy cycles. Third, the impact of both QE and QT announcements seems amplified by the amount of interest-rate uncertainty prevailing before the announcement, implying that turning points in BSP tend to elicit larger reactions. Taken all together these results indicate that tighter financial constraints or market dysfunctions are neither necessary nor sufficient to have sizable QE effects on government bonds.

Our findings show that taking account of investor expectations and uncertainty about BSP ahead of each announcement delivers results and conclusions about the evolution of QE effectiveness quite different from previous studies, as most found that later rounds of QE were less effective than the first QE.⁴ Further, most of our findings pose challenges to existing macro-finance models of QE, in which changes in asset supply have meaningful financial effects only under some form of market dysfunction or tighter financial constraints. Indeed, we find that during the last economic expansion, while the Fed was tightening policy amid very good financial conditions, BSP shocks continued to have significant yield effects. Finally, this also shows that, similarly to the FFR surprises for conventional monetary policy, the magnitude of the BSP surprises is extremely important for the impact of unconventional monetary policy, suggesting that the transmission mechanism of these two policy tools might be more similar than previously thought. Hence, our findings lead to two main policy implications. First, careful forward guidance about the BSP and not just about the policy rate can help control financial market effects by calibrating the size of the supply shock. Second, BSP can still be effective in changing Treasury yields away from the ZLB and during normal market conditions, suggesting that BSP should become part of the normal

⁴See for example, Altavilla and Giannone (2017), Bauer and Neely (2014), Bowman et al (2015), de los Rios and Shamloo (2017), Greenlaw et al (2018), and Krishnamurthy and Vissing-Jorgensen (2011 and 2013).

monetary policy toolkit. This should be the case under the presumption that, once Treasury yields change because of BSP, the economy will respond in the same way that it does to yield changes induced by conventional monetary policy.

The rest of the paper is organized as follows. In the next section, we summarize the literature related to this study. Section 3 describes our measure of the BSP surprise. Section 4 summarizes the events used to estimate the total impact of the supply/scarcity channel and the corresponding Treasury yield sensitivities. Section 5 details our empirical strategy and results. Section 6 analyzes the role of BSP uncertainty in amplifying Treasury yield sensitivities. Section 7 offers concluding remarks.

2 Related Literature

Our work relies on methods and insights from the monetary policy event study literature, from the QE literature focused on the supply/scarcity channel, and from macro-finance studies focused on the role of financial frictions in the transmission of unconventional monetary policy.

A number of papers estimate the impact of central banks' QE programs on interest rates using event studies, but except for Cahill et al. (2013), none focuses on constructing the unexpected component of BSP to better isolate its effects. In most event studies (e.g., Gagnon et al. 2011, Krishnamurthy and Vissing-Jorgensen 2011, 2013), the BSP impact is computed as the sum of yield changes around few specific QE-related events. This approach becomes increasingly problematic after the introduction of the first QE program, as the central bank signaled its intentions well before formal policy announcements and strengthened the conditionality of the QE program to macroeconomic variables. As a consequence, the identification of the relevant events for the event-study becomes extremely hard as, for example, any macroeconomic data releases or any policy makers' speech and interview can alter market participants' expectations. Controlling for pre-announcement market expectations using the SPD helps avoid these limitations. Importantly, relative to Cahill et al. (2013), we extend the computations of the BSP surprises to QT announcements to study the evolution of BSP effects over time and across economic and financial conditions.

Further, our empirical strategy is somewhat related to that of D'Amico and King (2013), as we also rely on the fact that for investors it may have been harder to correctly anticipate the maturity distribution of asset purchases, which in turn generated supply

surprises specific to maturity sectors of the yield curve, triggering the so-called local supply effects. But, while those authors analyze only the first QE program, we are mostly interested in understanding the evolution of supply effects across subsequent programs and across economic and financial conditions. Other examples of studies focused on local supply effects are Joyce and Tong (2012) and McLaren et al. (2014), who analyze QE programs in the UK.

Another strand of the QE literature relevant for our work consists of studies showing that the price impacts of QE announcements do not seem transitory in nature. If they were transitory due to, for instance, asset-specific liquidity effects, they would be less relevant for QE macroeconomic outcomes. Bernanke (2020) argues that if announcement effects were predictably temporary then, first, smart investors could profit by betting on reversal and, second, we should not observe cross-asset impacts around the announcements of Treasury-only QE, as those cross-asset impacts would be inconsistent with Treasury-specific liquidity effects. Indeed, Bernanke (2020) reports evidence showing that predicting reversals of QE announcement effects is not a money-making strategy,⁵ and that QE's cross-asset impacts are similar to those observed following conventional monetary policy announcements. For example, Gilchrist and Zakrajšek (2013) and Gilchrist, Lopez-Salido, and Zakrajšek (2015) find large and significant effects of QE on corporate bond yields and credit risk in the US, D'Amico and Kaminska (2019) find significant and persistent effects of various rounds of QE on corporate bond yields for the UK, Rosa (2012) and Mamaysky (2018) find significant effects of QE on equities and equity-implied volatility for a few countries, and Di Maggio et al. (forthcoming) show that the Fed's QE programs that did not include MBS purchases reduced mortgage rates. Overall, the cited evidence indicates that it is reasonable to assume that the Treasury yield effects identified by event studies are viewed by investors as largely persistent.

Relatedly, Mamaysky (2018) estimates the maximal time horizon of asset price responses following QE events and finds that, in the case of the US, UK, and Europe, high-frequency event-study analysis is appropriate to capture the full QE response of government bonds, as increasing the response horizon to several weeks does not change the conclusions about QE effects on government bond yields. In contrast, in the case of riskier and less liquid assets, analysis over a short time frame leads to incorrect

⁵For example, Neely (2016) shows that time series models that estimate a quick reversal of the effects of QE announcements do not predict well asset prices.

conclusions about the possible effects of QE, as the maximal response horizon seems to occur over several weeks after QE announcements. This suggests that our analysis of Treasury yield changes in short time windows around BSP announcements should largely capture the full effect of QE/QT on Treasury yields, while eliminating the influence of other confounding factors on those yields.

Finally, our findings have implications for the growing literature on the interplay between market imperfections and unconventional monetary policy. In most macro-finance models, changes in asset supply matter for asset prices and the macroeconomy only in the presence of market imperfections that restrict arbitrage opportunities, such as: capital constraints on financial intermediaries, limited-risk bearing capacity, elevated transactions costs, and limited market participation. Vayanos and Vila (2009), for example, highlight the interaction between preferred-habitat investors and risk-averse arbitrageurs: when their risk-aversion is high, the supply effects due to the preferred-habitat investors become relatively more important in determining bond prices and term premiums. Curdia and Woodford (2011), He and Krishnamurthy (2013), Gertler and Karadi (2011, 2013), and Schabert (2015), among others, emphasize alternative imperfections in financial markets that allow central bank purchases and sales to affect asset prices and, in turn, economic activity and inflation. Overall, all these studies lead to similar conclusions about the financial and, as a consequence, macro impact of QE: if frictions and distortions are smaller outside of a crisis, then the benefits of central bank asset purchases are diminished. In our work, estimates of a large yield sensitivity to QT supply shocks, which occurred in normal market conditions and during an economic expansion, cast doubts on the empirical validity of some of these theoretical mechanisms.

3 Balance Sheet Policy Surprises and Data

Financial markets are inherently forward looking and react only to the new information contained in policy announcements. Therefore, to correctly identify the asset price effects of BSP announcements it is necessary to focus on the unexpected component of those announcements. In the event-study analysis of *conventional* monetary policy, it has been the standard for almost two decades to focus on the unexpected component of the change in the FFR around FOMC announcements. In contrast, in the event-study analysis of *unconventional* monetary policy, distinguishing the expected and

unexpected component of BSP is far from being the standard approach. For any monetary policy tool, whether the FFR or forward guidance or balance sheet, what matters following FOMC announcements is the unexpected change in the tool, also known as monetary policy surprise. Similar to the seminal works of Kuttner (2001) for the FFR and Gurkaynak et al (2005) for forward guidance, we will try to show that isolating the policy surprise is very important for evaluating BSP such as QE and QT.

In particular, we control for the pre-announcement market expectations in order to estimate the *total* asset supply surprise, that is, the unexpected component of the total size of the announced program; and then, we exploit the programs' operational details to compute the *local* asset supply surprises, that is, the unexpected component local to the maturity sectors in which the purchases were conducted. The quality of these surprises' measurement depends on the availability of market participants' expectations about: (i) the likelihood of each asset purchase program being announced, (ii) the size and maturity distribution of purchases, (iii) the monthly pace of purchases/reinvestments for open-ended programs, and (iv) redemption caps for QT implementation. Most of this information is contained in the SPD results compiled by the New York Fed's Open Market Trading Desk (the Desk) *before* each FOMC announcement. Occasionally, in a "flash" survey, the Desk also asks respondents to update their responses immediately *after* an FOMC meeting to gauge how expectations have changed due to new information. We use both regular and flash SPD data to measure shifts in market expectations about the Fed's BSP. Clearly, the availability of a flash survey makes the measurement of the surprise much more precise. The results of the SPD have been public since 2011 but we have access to them since 2009. For each QE/QT event used in this study, the Appendix describes the details of the SPD data and surprise computation, which consistently shows that the asset supply surprise is just a *fraction* of the actual size of the program (as also shown in columns 2 and 3 of Table 2). This indicates that using the actual size of QE programs in event studies to analyze and compare their asset price efficacy can be very misleading.

In using the SPD median expectations as a measure of market expectations (which at times is the only available survey measure), it is worth bearing in mind that the SPD might not reflect the marginal investor's expectations very closely. Most of the survey's respondents are sophisticated investors and attentive "Fed watchers," likely less liable to surprise than the broad investor community. In some instances,

comparison across different surveys has confirmed that primary dealers’ thinking tends to be more homogeneous and more in tune with policymakers’ thinking, potentially biasing downward our measure of the asset supply surprise.⁶ Nevertheless, since we are more interested in comparing the magnitude of Treasury yield sensitivities across different events rather than just measuring their absolute size, we still favor the use of the SPD as it provides the views of the same type of investors consistently across FOMC-related events. More importantly, since the primary dealers are among the largest investors that have the ability to trade and affect prices within the small time windows considered in our event-study, they tend to be the “representative investors” in those time windows around BSP announcements.

Finally, to measure and illustrate the Treasury market reaction, we use a new dataset consisting of intraday price quotes on all outstanding U.S. nominal Treasury securities for the 2009-2019 period from Thompson Reuters Tick History. On average, we have high-frequency information for about 200 securities at each point in time over a sample period of more than 10 years. These data allow us to capture individual yield changes in small time windows around BSP announcements, which are crucial to our new identification procedure described in Section 5. Usually the event window starts 15 minutes before the announcement and ends 15 minutes after the announcement, but it can extend up to two hours after the announcement, either to capture the reaction to the Fed Chair’s press conference if during the Q&A session investors received additional information, or to give market participants more time to process relatively more complex BSP statements, for instance, addendums provided with the FOMC decision.⁷

4 Events providing an ideal testing ground

Across both QE and QT episodes, we use the following criteria to select events that can help identify the sensitivity of Treasury yields to a supply shock: (i) The presence of a sharp kink in the yield curve reaction to the announcement, (ii) availability of enough

⁶For example, we have compared some of the SPD questions to similar questions in the Bloomberg survey and Blue Chip Survey, when similar questions were available, which however happened rarely as SPD questions tend to be more granular.

⁷We look for all available traded quotes that are the closest to the beginning and end of the event window, and we drop a given CUSIP from our sample if no quote exists in the 30 minutes before the start time or after the end time. This should ensure both enough reaction time and a precise identification of the reaction to a specific event.

information to measure the supply surprise from the SPD, and (iii) the absence of significant policy-rate surprises. This last condition has been harder to meet because of the implicit or explicit forward guidance in every FOMC statement, but in Section 5, we discuss in detail why this should not be an issue for our identification.

A potential concern might be that focusing on events characterized by kinks could bias our estimates upward if those kinks were a manifestation of extreme market segmentation and lack of liquidity. But we do not think this is the case as, for example, all major QT announcements are characterized by kinks in the yield curve reaction and took place during periods of market calm and in the absence of market dysfunctions. As we describe below, it seems that the formation of kinks depends on the *granularity* of the information received during the announcements, rather than on market segmentation or other factors that could amplify the supply effects. In other words, kinks seem to be the result of very targeted trading executed by well informed investors. For instance, detailed information as that in the “Addendum to the Policy Normalization Principles and Plans” of the June 2017 FOMC meeting generated kinks in the yield curve reaction, while broad guidelines as those received in the “Statement Regarding Monetary Policy Implementation and Balance Sheet Normalization” of the January 2019 FOMC meeting did not generate kinks. And both of these announcements, being part of QT, occurred during good financial market conditions. Further, as we will show in Section 5, in the case of earlier QE programs, our estimates of the supply effect are not larger than those reported in other studies (e.g., D’Amico and King, 2013; Cahill et al., 2013) that do not exploit kinks in their approach.

4.1 During QE

The announcement of LSAP1 (March 18, 2009):

At 2:15 p.m. the FOMC announced its decision to increase purchases of agency MBS by \$750 billion, agency debt by \$100 billion, and to purchase up to \$300 billion of longer-term Treasury securities over the subsequent six months. Without prior notice, the Desk announced at 2:44 p.m. that the Treasury purchases would be concentrated in the 2- to 10-year maturity sector. According to market commentaries and the SPD, those large-scale asset purchase (LSAP) programs were more aggressive than anticipated, resulting in lower-than-expected future supply of assets, that is, a dovish supply surprise. In particular, according to the SPD the Treasury purchases had the lowest likelihood of being announced (52% chance), leading to a dovish Trea-

sure supply surprise of \$142.5 billion; while, the MBS purchases were largely expected, leading to a dovish MBS supply surprise of \$217.5 billion (see Appendix for the surprise computation). In the 30-minute window around the FOMC announcement, as shown by the red dots in the top-left panel of Figure 1, longer-term yields declined by more and plateaued at around -45 basis points at the 15-year maturity and beyond. Following the Desk announcement, shifts in market expectations about the maturity distribution of Treasury purchases created a sharp kink in the yield curve reaction, shown by the blue dots in the top-left panel of Figure 1. That is, based on the 2:15 p.m. announcement, all longer-term Treasury securities were perceived as equally eligible for purchases, but following the 2:44 p.m. statement, investors assigned much smaller probability to the purchase of securities with maturities above 10 years. This caused a price reversal among those securities, which created a kink around the 10-year maturity—the upper bound of the maturity range to be targeted by LSAP1 purchases.

The Reinvestment policy announcement (August 10, 2010):

At 2:15 p.m., the FOMC announced that it would keep the face value of its System Open Market Account (SOMA) holdings constant by reinvesting principal payments from agency debt and agency MBS in longer-term Treasury securities. At 2:45 p.m., the Desk indicated that it would again concentrate Treasury purchases in the 2- to 10-year maturity sector, and it would refrain from purchasing securities for which the SOMA already held large concentrations. According to market commentaries and the SPD, the reinvestment program was largely unanticipated, creating a dovish supply surprise of about \$185.6 billion (see Appendix for the surprise computation). And, the program’s intended implementation had a novel aspect, as the Desk statement implied that securities already held by the Fed in high concentration had a lower probability of being bought. At that time, the largest and smallest fractions of SOMA holdings were in the 10-to-17-year and 4-to-5.5-year maturity sectors, respectively.⁸ Following the FOMC announcement, as shown by the red dots in the top-right panel of Figure 1, the initial yield curve reaction was quite similar in shape to the one prevailing after the LSAP1 announcement. Following the Desk statement, as shown by the blue dots, securities with maturity longer than 10 years reversed part or all of their initial yield declines as they had a lower probability of being purchased. In contrast, yields of

⁸The Federal Reserve’s SOMA portfolio held at the time of the announcement the following shares of privately-held Treasury amount outstanding: about 13% in the 1.5-4-year maturity sector, 7% in the 4-5.5-year maturity sector, 14% in the 5.5-7-year maturity sector, 13% in the 7-10-year maturity sector, 27% in the 10-17-year, and 14% in the 17-30-year.

securities in the 4-to-6-year sector, which had a relatively higher probability of being bought, decreased further. This pattern created two kinks, around the 5- and 6.5-year maturities, respectively.

The announcement of MEP1 (September 21, 2011):

At 2:23 p.m. the FOMC announced its intention to extend the average maturity of its security holdings by purchasing \$400 billion of Treasury securities with remaining maturity between 6 and 30 years and selling an equal amount with remaining maturity of 3 years or less. That is, the maturity extension program (MEP) would have reduced the supply of Treasuries in the 6- to 30-year maturity sector by increasing the supply of Treasuries in the 0- to 3-year maturity sector. According to the SPD, these relative supply changes were larger than expected, creating a dovish \$146.5 billion supply surprise in longer-term Treasuries (see Appendix for the surprise computation). Following the announcement, as shown in the bottom-left panel of Figure 1, yields increased at the front-end of the curve and decreased at the long-end of the curve. This pattern created a kink around the 3-year maturity, roughly the threshold between the maturity sectors targeted for sales and those targeted for purchases.

The announcement of MEP2 (June 20, 2012):

At 12:30 p.m. the FOMC announced its decision to extend the MEP through the end of 2012, resulting in the purchase and sale of \$267 billion of additional Treasury securities. The Desk contemporaneously released the operational details, which stated the suspension of the practice of rolling over maturing Treasury securities into new issues at auction. Although the MEP extension was in part expected by the SPD respondents, the decision to redeem securities, which allowed the Fed to further increase its longer-term purchases, was unexpected. Overall, this created a dovish \$174.75 billion surprise in longer-term Treasuries (see Appendix). Just like during the MEP1 announcement, Treasury yields increased at the short end of the yield curve and decreased at the long end, generating again a kink around the 3-year maturity, shown in the bottom-right panel of Figure 1.

4.2 During QT

It should be stressed that, in the case of QT announcements, the location of the kink is not simply connected to a new operational detail released during the announcement, but it is also related to the Desk's purchase rules in place since December 2013 and the reinvestment rules in place since December 2015. Those rules, by determining the

maturity distribution of asset purchases/reinvestments, affect also the distribution of the asset supply surprise across maturity sectors of the yield curve; and, since the kink is the peak of the yield curve reaction, it tends to be in the maturity sector characterized by the largest asset supply surprise. In other words, the shape of the yield curve reaction is connected to the relative size of the asset supply surprises local to the various maturity sectors. The computation of the local asset supply surprises is detailed in the Appendix for the interested reader.

The Post-Taper-Tantrum FOMC Meeting (June 19, 2013):

In the case of the June 2013 FOMC meeting, according to Bloomberg Newsfeed, QE-related remarks during the Fed Chair's press conference gathered more attention than the FOMC statement, as they were viewed as more hawkish than expected. Hence, our event study is centered around the time of those remarks. Specifically, market participants were very focused on the Chair's 2:38 p.m. remarks indicating that, if the economy evolved as expected by the Committee, the Committee anticipated "moderating the monthly pace of purchases" in the latter part of 2013 and ending purchases in mid-2014. Further, the Chair also indicated that the majority of the Committee did not expect to sell agency MBS during the policy normalization process. As detailed in the Appendix, the change from the pre-FOMC SPD to the post-FOMC flash SPD shows a reduction in the expected amount of asset purchases. Primary dealers anticipated the tapering of purchases to start in September 2013 rather than December 2013 for both Treasuries and MBS, the size of the Fed's Treasury holdings to decrease by \$27.5 billion, and the size of the Fed's MBS portfolio to decrease by \$38 billion. Overall, this constituted a hawkish asset supply surprise, and Treasury yields increased in the 30-minute window around the Chair's key remarks, as illustrated in the top-left panel of Figure 2, which exhibits a kink around the 5-year maturity.

The FOMC announcement delaying the start of tapering (September 18, 2013):

Despite market-wide expectations that the Fed was going to start tapering LSAP3 in September 2013, at its September 2013 meeting, the FOMC "decided to await more evidence that progress will be sustained before adjusting the pace of its purchases." This decision had the exact opposite effect of the June 2013 FOMC announcement, as most primary dealers shifted again the expected start of tapering from September 2013 to December 2013, as shown in the responses to the pre- and post-FOMC (flash) SPD, reported in the Appendix. Such a shift implied a larger-than-expected pace of

purchases for three additional months, creating a dovish \$95 billion Treasury supply surprise and a dovish \$119.5 billion MBS supply surprise. The yield curve reaction to the dovish surprises is shown in the top-right panel of Figure 2, which exhibits a kink around the 6-year maturity.

The FOMC announcement including the Normalization Addendum (June 14, 2017):

The Minutes of the May 2017 FOMC meeting stated that the Fed’s balance sheet run-off would be accomplished through gradually increasing monthly redemption caps whose exact size was going to be announced soon.⁹ Consistent with this information, the June 2017 FOMC statement was accompanied by a Normalization Addendum providing investors with precise details about the cap sizes and schedule. As shown in the top panel of Figure 3, relative to the expected (blue) Treasury cap sizes and schedule reported in the June SPD, the announced (red) Treasury cap schedule and terminal size turned out to be a bit higher than expected, implying overall less reinvestments and therefore less Treasury purchases than anticipated. This provided a hawkish supply surprise of \$78.2 billion (see Appendix) that pushed yields higher, creating a kink around the 3-year maturity, shown in the bottom-left panel of Figure 2. In contrast, for MBS, the terminal cap size turned out to be lower than expected, as seen in the bottom panel of Figure 3, implying more reinvestment and therefore larger MBS purchases than expected. This created an \$18 billion dovish MBS surprise (see Appendix).

The FOMC announcement including the Balance Sheet Normalization Principles and Plans (March 20, 2019):

The FOMC announced the phasing out of the balance sheet reduction, which market participants viewed as occurring faster than they had anticipated, implying a larger terminal size of the Fed’s balance sheet. In other words, the gradual portfolio reductions that started in October 2017 were coming to an end sooner than anticipated and, therefore, the size of the SOMA portfolio was going to plateau at a larger level. This faster-than-expected tapering of QT, which would be implemented by decreasing rather than increasing redemption caps, provided a dovish supply surprise of \$51.8 billion (see Appendix); that is, the opposite effect of the faster-than-expected tapering

⁹Specifically, the Committee instructed the Desk to reinvest principal payments it receives from securities held in SOMA only to the extent that they exceeded gradually rising redemption caps. Therefore, as the caps increased, a smaller amount of payments would be reinvested, resulting in a smaller roll-over at Treasury auctions and in a larger supply left in the hands of private investors.

of QE described in the June 2013 FOMC. As shown in Figure 4, while primary dealers expected the redemption cap reduction to begin in September 2019 and the balance sheet normalization to end sometime in 2019:Q4 (blue line), the FOMC announced at 2:00 p.m. that the redemption cap reduction would start in May 2019 and stop in September 2019 (red line), implying larger reinvestments and thus larger Treasury purchases. As shown in the bottom-right panel of Figure 2, following the announcement, Treasury yields decreased and formed a kink around the 5-year maturity.

5 Empirical Strategy and Results

For each of the eight events described in the previous section, to identify and quantify the Treasury yield effect of the asset supply surprise, we use the yield curve reaction depicted in each panel of Figures 1 and 2. In particular, we exploit the relative yield changes of individual Treasury securities around the kink, which implies estimating the following specification:

$$\Delta Y_{i,t} = \alpha + \beta_1 * (\tau_{i,t} - K_t) + \beta_2 * D_i * (\tau_{i,t} - K_t) + \dots + u_{i,t} \quad (1)$$

where $\Delta Y_{i,t}$ is the yield change of security i within a narrow time-interval t around the announcement, $\tau_{i,t}$ is the maturity of security i , K_t is the kink location in the maturity range, and D_i is a dummy variable that takes the value of one to the right of the kink (i.e., for maturities larger than the kink’s maturity) and thus allows the change in slope after the kink, and “...” indicates higher order polynomials that could be added to the baseline.¹⁰ Since we are going to focus on the linear specification, the coefficient of interest is β_2 , which retrieves the change in slope of the yield reaction around a specific maturity identified by the kink point. This should isolate the “supply/scarcity effect” of the BSP surprise, as we estimate equation (1) using only securities whose maturity is within a few years of the kink.¹¹ Specifically, in our baseline, the estimation is restricted

¹⁰The explanatory power could be increased by adding higher-order polynomials. However, the quadratic term increases the R-squared only marginally, except for June 2017 (from 0.62 to 0.75), so we stick to the linear specification.

¹¹The literature (e.g., D’Amico et al., 2012) has identified three main channels of QE’s transmission mechanism. The supply/scarcity (a.k.a., portfolio balance) channel works by changing the available supply of the targeted assets and tends to affect more the yields of those assets and their close substitutes. The signaling channel works through changes in the expected future path of the policy rate. The duration-risk channel affects term premiums by changing the amount of aggregate duration risk held by private investors.

to securities with maturity within three years of the kink, and for robustness, we also re-estimate equation (1) restricting the maturity distance to two years from the kink.

The rationale behind our identification of the “supply/scarcity effect” is the following. Since we include only Treasury securities with similar maturity, it seems reasonable to assume that duration risk cannot be the main driver of the yield change around the kink. However, since we set the maximum maturity distance from the kink to three years to increase the number of observations, our supply/scarcity effect can be affected by small differences in the duration risk of the various securities. This potential bias should be negligible and, being present across both the QE and QT samples, should not significantly hamper our comparison of BSP effects for QE and QT. Further, when in the robustness analysis we reduce the maturity distance from the kink to two years, differences in duration risk should become even less relevant.

Another potential driver of yield variations around BSP announcements could be the signaling effect, that is, a change in the expected future path of the policy rate induced by the BSP’s release. However, it is very unlikely that the signaling effect plays an important role in the slope change around the kink for several reasons. First, most of the kinks are at or beyond the 4-year maturity, where the impact of the signaling channel tends to be quite small. Usually, changes in the policy-rate path affect the most shorter-term securities.¹² Second, during MEP1 and MEP2, when the kink is closer to the 3-year maturity, shorter-term yields went up and not down in response to a dovish monetary policy surprise. Third, changes in the expected policy-rate path can hardly create such abrupt kinks at a specific maturity. Calendar-based forward guidance could create such kinks, but such explicit forward guidance is absent from the FOMC statements used in our analysis.

Finally, for each event, the kink’s precise location is determined using a gradient-based algorithm that refines the search of the kink starting from an initial guess. Such guess consists of the maturity where we expect the kink to appear based on the operational details of the Fed’s BSP implementation; for instance, the 10-year maturity in the case of LSAP1, as explained in Section 4.1.¹³ Then, the gradient of the yield curve reaction is analyzed along the maturity spectrum that extends a few years to the left and right of the initial guess, that is, we repeatedly estimate the local gradient

¹²See Swanson (2015), Greenwood, Hanson, and Vayanos (2015), and King (forthcoming).

¹³The kink’s location is usually close to the end of the maturity range receiving more or less purchases than expected because of purchase/reinvestment practices. The mapping between the maturity bound and the kink location should be less precise the less segmented the market is.

within rolling windows and the point where the gradient changes sign is selected as the kink. We favor this procedure for the following reason. In theory, the location of the kink could be strictly dictated by the operational details, which being determined before the announcement are independent of the asset price reaction following the announcement. In practice, it would be unreasonable to expect a perfect mapping between kink’s locations and operational details, because such mapping would require an extreme form of market segmentation across adjacent maturity sectors. This could probably be a realistic assumption for the first QE, which was announced at the height of the global financial crisis. Indeed, in the case of LSAP1, we do have a nearly perfect mapping between the operational detail and the kink’s location. But, for subsequent events, and especially QT announcements, this does not have to be the case. Therefore, we search for the change in gradient in the proximity of a reasonable guess. The implicit assumption is that investors reveal their preferences about securities’ degree of substitutability through their trading and we take it as given.

5.1 Results

The results from our baseline specification are summarized in Tables 1 and 2, with the first column reporting the estimates of the supply effect, β_2 , for each FOMC announcement. While in this section, we focus on the cross-sectional regressions that deliver for each event a separate β_2 , as our main goal is to analyze its evolution over time and across QE and QT events; in the next section, we shift our focus to panel regressions that pool all QE and QT events together, allowing us to obtain a more robust estimate of the average β_2 across multiple BSP announcements.

In inspecting Table 1, it is worth bearing in mind two aspects of the estimates. First, the size of the β_2 coefficients is not normalized yet by the magnitude of the asset supply surprise, hence a comparison of their relative sizes is not warranted. Second, the sign of the coefficient depends on the relative size of the supply surprises in the maturity sectors adjacent to the kink. Specifically, if the maturity sectors after the kink are perceived as being affected by a less (more) dovish surprise than the maturity sectors before the kink, then the coefficient will be positive (negative). This implies that the sign of β_2 does not reflect the overall easing or tightening provided by the BSP decisions. The main takeaways of Table 1 are purely statistical. The t-statistics reveal that the slope changes around the kink are highly significant for all

events.¹⁴ The adjusted R-squared are quite large, varying between 45 and 95 percent, indicating that the supply effect is an important driver of the yield reaction around BSP announcements. To visualize this first set of results, Figures 5 and 6 show the fit of the yield reaction in the 3-year maturity windows around the kink for QE and QT, respectively. For each event, the maturity at the kink is rescaled to equal zero, and the left and right panels illustrate the estimated slopes to the left and right of the kink. The difference between the right and left slope estimates is equivalent to β_2 in equation (1).¹⁵

Next, the Treasury yield *sensitivities* to a \$100 billion supply surprise are obtained dividing β_2 by the size of the asset supply surprise and multiplying by 100, and they are reported in the last two columns of Table 2. For each announcement, we provide a range of values for the estimated sensitivity, which depends on whether we use either the total or the local asset supply surprises to normalize β_2 , shown in the second and third column of Table 2. Since these surprise measures rely on different assumptions about the degree of market segmentation, we believe that providing a lower (LB) and upper bound (UB) for the estimates is a more robust approach. Specifically, the LB is obtained dividing β_2 by the total supply surprise, which does not require taking a stance on the degree of market segmentation, as it implicitly assumes that the unexpected change in supply affects all Treasury securities, independently of their maturity. In contrast, the UB is obtained dividing β_2 by the local supply surprise, which being equal to the relative supply changes in the maturity sectors adjacent to the kink, implies a higher degree of market segmentation, that is, the securities around the kink react only to supply changes close to the kink. Further, while in Table 2, the BSP surprises include only unexpected changes in Treasury holdings; in Table 3, the total asset supply surprises include also unexpected changes in MBS holdings, which provides an additional set of Treasury yield sensitivities, based on the alternative assumption of perfect substitutability between Treasuries and MBS.

By observing the last two columns of Table 2, it is easy to note that both the lower and upper bound of the Treasury yield sensitivities do not fall monotonically over

¹⁴ Recall from Section 4.1 that in the case of the Reinvestment announcement there are two kinks. Our baseline estimates are obtained using the second kink, at the 6.75-year maturity, but for robustness we also use the first kink at the 5.1-year maturity and obtain very similar results. That is, β_2 equals 1.974, t-stat equals 11.4, and adjusted R² equals 0.839.

¹⁵ Since for illustrative purposes those fitted lines have been obtained estimating two separate OLS regressions, while our main results are based on the single regression described in equation (1), β_2 is not exactly equal to the difference in slopes.

time, indicating that there is no evidence of diminishing returns of the supply/scarcity channel across subsequent BSP announcements. Further, on average, the yield sensitivity during QT events is larger than the yield sensitivity during QE events, implying that the impact of asset supply shocks did not diminish in normal market conditions and away from the ZLB. We reach the same conclusions about the evolution of the Treasury yield sensitivity even when we account for the MBS supply surprise in the total asset supply surprise, as shown in the last column of Table 3. We consider the LB of the estimated Treasury yield sensitivities in Table 2 as our reference estimates, since they are normalized by the total supply surprise that relies on minimal assumptions. It is reassuring, however, that the main message stays the same when we use alternative measures of the BSP surprises.

Overall, our results suggest that, in evaluating the relative efficacy of BSP announcements, it is very important to account for the size of the shift in expectations about asset supply, because doing so leads to conclusions and policy implications quite different from those reached in previous QE studies.¹⁶ We also think that our novel findings are made more striking by the fact that are specific to the supply/scarcity channel, that is, the only QE channel that in macro-finance models requires some form of market dysfunction to work and is predicted to have larger effects during financial crises.¹⁷ In contrast, not only we find that the supply/scarcity channel remained powerful across vastly different financial market conditions, but its effects were apparently larger during the economic expansion.

However, the evidence reported in Table 2 and 3 also shows that the magnitude of the asset supply surprise is not the only factor driving the Treasury yield effects of BSP, as the yield sensitivities still display notable variation over time (despite being normalized by the BSP surprise). First, they seem to become particularly large at turning points of the BSP. For example, toward the end of QE (June 2013), as the Fed announced its intention to reduce the amount of policy accommodation provided through the balance sheet, and again toward the end of QT (March 2019), as the Fed announced its intention to stop tightening monetary policy and stabilize the size of

¹⁶For example, Altavilla and Giannone (2017), Bauer and Neely (2014), Bowman, Londono, and Saprizza (2015), de los Rios and Shamloo (2017), Greenlaw et al. (2018), and Krishnamurthy and Vissing-Jorgensen (2011 and 2013), all document decreasing impacts of QE announcements across subsequent programs and conclude that later rounds of QE were less effective than the first QE.

¹⁷Differently from the supply/scarcity channel, the signaling and duration-risk channels do not rely on any form of limits to arbitrage. See for more detail Greenwood and Vayanos (2014), King (forthcoming), and Bauer and Rudebusch (forthcoming).

its long-run portfolio. Due to the lack of experience with the balance sheet normalization process, those turning points could have been characterized by elevated BSP uncertainty that amplified the yield reaction. In Section 6, we explore this eventuality. Second, some variation in the yield sensitivity could be due to variation in the kink’s location, which determines the average maturity of the yields affected by the surprise. In other words, in LSAP1 we estimate supply effects around the 10-year maturity, but in QT we mostly estimate supply effects around the 5-year maturity. This would matter if preferred habitat or limits to arbitrage vary across segments of the yield curve, which cannot be excluded. But, we observe the largest yield sensitivities for events where the kink is located around the 3- and 5-year maturities, which are among the most liquid segments and usually not the preferred habitat of institutional investors. Third, convexity hedging could also be an amplifying factor. That is, following a positive interest rate shock due to the BSP announcement, as in June 2013 and 2017, agency MBS prepayments are expected to decline, and hence MBS average duration in investors’ portfolios extends. Consequently, investors tend to sell longer-term Treasuries to shed duration fast from their portfolio, and such Treasuries’ selloff pushes prices down and interest rates further up, amplifying the initial shock. We believe that this could have been a relevant amplifying factor of the yield reaction to the June 2013 and June 2017 QT announcements.

Finally, Tables 4, 5, and 6 report the results of our robustness checks, which consist of re-estimating the β_2 coefficients and yield sensitivities using securities with maturity distance within two years from the kink rather than three years. As can be noted, the results are qualitatively very similar to those of our baseline specification. We have also re-done the estimation using securities whose duration rather than maturity is within two years from the kink, not shown for brevity, and the results are again qualitatively similar, confirming our main conclusions.

6 Interest rate uncertainty as magnifying force

In this section, we investigate whether investor uncertainty about BSP amplified its impact on Treasury yields. Our proxy of BSP uncertainty is the investor uncertainty about longer-term interest rates before each BSP announcement, which we measure

from volatilities implied by swaption contracts¹⁸ written on the 10-year swap rate and with expiration ranging from 1 month to 10 years.¹⁹ Differently from other interest rate derivatives, swaptions are very liquid for long-term rates and at long horizons. This is very important as those are the interest rates and time horizons most affected by BSP actions; while, other monetary policy interventions, such as changes in forward guidance, mostly affect short-term rates over short to medium horizons. In particular, QE-related shocks are estimated to have their largest impact at the 7-year maturity and beyond, while forward-guidance shocks have their largest impact between the two- and five-year maturity. See for example, Swanson (2015), Greenwood, Hanson, and Vayanos (2015), and King (forthcoming).

Figure 7 shows, for each BSP announcement used in our study, how the swaption-implied volatility of the 10-year interest rate measured at different horizons changed over the period *before* the announcement. That is, each panel summarizes how the entire term structure of investor uncertainty about the 10-year rate evolved over the six weeks prior to the FOMC meeting. In the top left panel, it can be noted that before the first LSAP announcement, the uncertainty about the 10-year rate increased substantially across all horizons up to 4 years ahead. This is perhaps not surprising as there was a lot of uncertainty about the possibility of a Treasury purchase program that, as already discussed in Section 4.1, was not correctly anticipated by many market participants. Ahead of the subsequent QE announcements, as shown in the remaining left panels, the term structure of the 10-year rate uncertainty moved lower, most likely indicating that the Fed communication about later asset purchase programs had improved somewhat. In contrast, ahead of the first QT announcement, shown in the top right panel, investor uncertainty about the 10-year rate increased considerably, especially at shorter horizons. This is by far the largest increase in BSP uncertainty across the eight events, and it occurred during the "Taper Tantrum," when investors seemed very uncertain about the potential tapering of QE. Similarly, also prior to the September 2013 announcement that delayed the start of tapering, the 10-year rate uncertainty increased somewhat, but much less than in the "Taper Tantrum" period.

¹⁸A swaption is an option on an interest rate swap that gives the owner the right to enter an interest rate swap at a predetermined fixed rate when the option expires. That is, the owner of a payer swaption pays the fixed rate and receives a sequence of Libor rates at semiannual intervals over the life of the swap.

¹⁹Swaptions have been used in other studies to analyze how interest rate uncertainty varies around macroeconomic and monetary policy announcements. See for example Fornari (2004) and Hattori, Schrimpf, and Sushko (2016).

Finally, ahead of the last two QT events, shown in the bottom right panels, the term structure of investor uncertainty about the 10-year rate declined, most likely because the normalization process of the Fed balance sheet was well under way.

Figure 8 illustrates instead how the term structure of the 10-year rate uncertainty changed *on the day of* each BSP announcement. Previous research on the impact of scheduled announcements on swaption-implied volatility has found that such volatility normally declines post-release as uncertainty is resolved (e.g., Ederington and Lee, 1996). However, this does not seem to be always the case following BSP announcements. As shown in the top right panel, following the June 2013 announcement that the FOMC anticipated to moderate the pace of purchases in the latter part of the year, investor uncertainty about the 10-year rate spiked at very short horizons. This sharp increase in implied volatility is a bit surprising as the FOMC communication was in line with what the Fed Chair Bernanke had testified in front of Congress the month before. However, since market-based measures of uncertainty are contaminated by risk premiums, it is possible that part of the increase in implied volatility is due to an increase in investor risk aversion. This, in turn, would suggest that investors did not view favorably the upcoming slow down of QE purchases and possibly considered it premature. Further, also following the June 2017 FOMC meeting, the 10-year rate uncertainty increased a bit over the near term.

Overall, both figures show that the Fed’s pre- and post-release communication about BSP decisions could have been important for fluctuations in longer-term interest rate uncertainty that, in turn, might have played a role in the investors’ reaction to BSP announcements. To investigate this possibility, we modify our empirical specification to account for investor uncertainty about upcoming BSP actions, proxied by the swaption-implied volatility of the 10-year rate. In particular, to capture whether market uncertainty about the 10-year rate was *unusually elevated ahead of* a specific FOMC meeting, we proceed in three steps. First, for each forecasting horizon (i.e., for each swaption expiration), we compute the average 10-year rate uncertainty prevailing over the 10 days prior to the meeting.²⁰ Second, to collapse these average implied volatilities specific to each horizon into one number for each FOMC meeting, we compute their weighted sum using weights that are inversely related to the length of the forecasting horizon, so that near-term volatilities get a higher weight and we still pre-

²⁰For robustness, we have also computed the average over 5 or 20 days prior to each meeting and results are very similar, therefore are not shown for brevity.

serve the information contained in the entire term structure of uncertainty. (We use two versions of this uncertainty variable, one with a maximum horizon of 5 year for the term structure and one with a maximum horizon of 10 years and we will show that results are quite similar). Finally, this proxy of BSP uncertainty is normalized dividing by the average implied volatility prevailing in the year before the FOMC meeting and subtracting one. In this way, a value equal to 0 indicates that BSP uncertainty in the 10 days prior to the FOMC was not elevated relative to the previous year, while a large and positive (negative) value indicates that BSP uncertainty was particularly higher (lower) relative to the previous year. This normalization is necessary to account for the average level of interest-rate uncertainty that characterized a certain state of the economy, and in particular to control for the unusual uncertainty of the global financial crisis. Our measures of BSP uncertainty ahead of each FOMC announcement are summarized in Table 7. It is interesting to note that, following the normalization, the event characterized by the highest BSP uncertainty is the September 2013 announcement and not the June 2013 announcement, which, however, together with the LSAP1 and MEP1 announcements, remains one of the four events with somewhat unusually elevated uncertainty.

Then, we pool together all eight BSP events in one panel and estimate three different specifications for our panel regression. First, a specification identical to equation (1) but with event fixed effects, as the estimated β_2 of this regression provides us with the average “supply/scarcity effect” across all eight BSP announcements and is, therefore, a useful term of comparison before including our measure of BSP uncertainty. Second, we augment the first specification by interacting the two main regressors with our proxy of the BSP uncertainty, BPS_unc :

$$\Delta Y_{i,t} = \alpha + \beta_1 * (\tau_{i,t} - K_t) + \beta_2 * D_i * (\tau_{i,t} - K_t) + \beta_3 * (\tau_{i,t} - K_t) * BPS_unc + \beta_4 * D_i * (\tau_{i,t} - K_t) * BPS_unc + u_{i,t}, \quad (2)$$

where β_4 measures the amplifying effect of the excess 10-year interest-rate uncertainty ahead of the BSP announcement, with BPS_unc being calculated using the swaption-implied volatilities up to the 5-year horizon. Finally, the last specification is the same as in equation (2) but BPS_unc is calculated using the swaption-implied volatilities up to the 10-year horizon, that is, a longer term structure of 10-year interest-rate

uncertainty.

As shown in Table 8, on average, the supply/scarcity effect of a BSP announcement is of about -2.34 basis points per \$110bn, which is the average size of the BSP surprise across our events, and all coefficients are statistically significant; but, if ahead of the FOMC meeting investor uncertainty about the 10-year interest rate is unusually elevated, then the average effect is of about -7.8 basis points, as β_4 equals almost -5.5 basis points and it is statistically significant. This implies that elevated interest rate uncertainty makes the supply effect of a given BSP announcement about three times as large, explaining a significant amount of variation in the estimates of the β_2 coefficients and related yield sensitivities in Table 1 and 2.

Further, as shown in the last two rows of Table 8, those estimates are unchanged if we use our second proxy of uncertainty that considers changes in implied volatilities up to 10 years ahead. Finally, as shown in Table 9, the coefficient estimates are also very little changed when we restrict the maturities to 2 years around the kink, which should be expected if the duration risk played no role in the estimates resulting from the baseline specifications. This also indicates that a supply/scarcity effect varying in magnitude between 2.3 and 7.8 basis points per \$110bn BSP surprise is quite meaningful in terms of absolute size of the BSP impact, because it does not include the additional effects that can derive from the signaling and duration-risk channels, which the QE literature found to be significant as well.²¹

7 Conclusions

Exploiting sharp kinks in the yield curve reaction within narrow time-intervals around BSP announcements, we estimate the Treasury yield sensitivity to asset supply surprises induced by unexpected changes in QE and QT programs, with the latter being hardly studied before. By including in our 10-year sample (2009-2019) BSP events that span very diverse macroeconomic and financial market conditions, we can examine the state-dependence of the supply effect of BSP and whether such policy has diminishing returns.

Our analysis indicates that BSP's supply effects do not fall monotonically across subsequent QE and QT announcements and do not get smaller in normal financial

²¹See for example Bauer and Rudebusch (forthcomig), Cahill et al (2013), and Greenwood and Vayanos (2014).

market conditions and away from the ZLB. This is quite the opposite of what predicted by most macro-finance models of central bank asset purchases. Importantly, our findings have relevant implications for the conduct of monetary policy, as they seem to suggest that the usefulness of BSP might not be limited to exceptional circumstances such as the global financial crisis and the covid-19 pandemic.

Further, since we also show that not only investor expectations but also investor uncertainty about BSP is very important for the Treasury yield effects of QE and QT, it could be very valuable to provide forward guidance about the BSP, and not just about the policy rate. This is because such forward guidance, by allowing the Fed to better shape expectations and uncertainty about future asset supply, could make BSP more efficient, that is, could deliver larger and more persistent asset price effects with potentially smaller changes to the central bank's balance sheet.

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Appendix

In this Appendix, we describe the surprise computation for each event. In particular, we provide an upper and lower bound for the size of the BSP surprise and, since the surprise is the denominator of the yield sensitivity estimate, an upper/lower bound for the surprise corresponds to a lower/upper bound for the yield sensitivity estimate. In the case of the Treasury-only surprises, our bounds rely on two alternative assumptions about the degree of market segmentation in the Treasury market. Each has its own limitations, but together they provide a reasonable range for the true value of the surprise.

The upper bound is given by the total size of the Treasury surprise at announcement. This method takes no stance on the degree of market segmentation. The lower bound is given by the size of the surprise local to the kink, obtained from the relative supply changes only in the maturity buckets adjacent to the kink. This implies a high degree of market segmentation, as it assumes that only the supply surprises local to the kink trigger the yield reaction around the kink (i.e., a tight relation between the maturities of the bonds' quantities and prices). Table 2 and Table 5 in the main text contain the surprise estimates used to compute the yield sensitivities.

The bounds in Table 2 and Table 5 only take into account the supply surprise in the Treasury market. Since at times agency securities (i.e., agency MBS and agency debt) were included in the Fed's BSP, we also perform a robustness check using a version of the total surprise that includes unexpected changes in the supply of both Treasury and agency securities. This implies that large investors view Treasuries and agency securities as perfect substitutes. Table 3 and Table 6 in the main text contain these alternative surprise estimates.

LSAP1

The March 2009 SPD asked about the likelihood that the Fed would announce a purchase program related to Treasuries, agency debt, and agency MBS. However, it did not ask about the expected size of those programs, so we make the conservative assumption that the dealers perfectly forecasted the announced size of the program. Hence, for each asset class, the surprise is obtained by simply multiplying the announced size by the median probability of the Fed *not* announcing purchases of that asset class. Table A1 reports those median probabilities, actual sizes, and surprises (in billions), which measure the upper bound of LSAP1 surprises.

Table A1: LSAP1 Surprises

Asset Class	<i>Prob</i> (NO announcement)	Size (\$bn)	Surprise (\$bn)
Treasuries	0.475	300	142.5
Agency Debt	0.30	100	30
Agency MBS	0.25	750	187.5

To compute the surprise local to the kink we need some additional assumptions. First, we assume that before the FOMC announcement, investors expected Treasury purchases to be distributed over the entire maturity range and to be proportional to the amount outstanding in each maturity sector. This seems quite reasonable considering the absence of any guidance prior to the FOMC meeting. Second, since the Desk indicated that it would concentrate Treasury purchases in the 2- to 10-year sector, we assume that market participants interpreted the Desk's guideline as about 80% of purchases being allocated to that sector. Reportedly, this interpretation was quite common among market participants at that time. Third, we use the Fed's auction maturity sectors (reported in the first row of Table A2) released by the Desk before the start of the actual purchases but after the FOMC meeting. These three assumptions imply that, after the Desk announcement on the day of the FOMC, investors recalibrated their expectations as follows: 80% of purchases would occur in the 2- to 10-year maturity range, distributed within that range proportionally to the amount outstanding in each auction maturity sector. Similarly, the remaining 20% of purchases would be allocated to the 10- to 30-year range proportionally to the amount outstanding in the two auction maturity sectors included in that range. Table A2 contains the pre- and post-announcement expected maturity distribution of purchases. The LSAP1 local supply surprise is computed as $2 * [(22.1 * 300 - 17.8 * 157.5) - (4.5 * 300 - 8 * 157.5)] / 100 = \$74.73bn$, using only the supply changes in the two maturity sectors adjacent to the kink located at the 10-year maturity.

Table A2: Maturity Distribution of LSAP1 Purchases

Fed Auction Sectors	1.5-2.5Y	2.5-4Y	4-5.5Y	5.5-7Y	7-10Y	10-17Y	17-30Y
Expected	17.4%	20%	18%	8.5%	17.8%	8%	10.3%
Announced	9.7%	25%	22.3%	10.6%	22.1%	4.5%	5.8%

Reinvestment

The August 2010 SPD asked about the probability of the Fed announcing the reinvestment of proceeds from agency MBS either 1) into Treasuries and Agency MBS, and 2) into only Treasuries. The median probability reported for option 1 was 32.5%, while for option 2 it was 10%. Publicly available information indicated that about \$206.25bn of agency MBS proceeds were set to roll off the Fed’s balance sheet over the next six months (the same horizon as LSAP1). Similar to LSAP1, we obtain the surprise for each asset class by multiplying the size (\$206.25bn) by the median probability of the Fed *not* announcing a program related to that asset class. Therefore, the total surprise is \$185.6bn for Treasuries only and \$139.2bn for Treasury and agency securities together, as seen in Table A3.

Asset Class	<i>Prob</i> (NO announcement)	Actual Size (\$bn)	Surprise (\$bn)
Treasuries	0.90	206.25	185.6
Treasuries or Agencies	0.675	206.25	139.2

For the computation of the local surprise, we assume the expected maturity distribution of the reinvestment purchases to be the same as the actual maturity distribution of LSAP1 purchases (second row of Table A4), as before the August 2010 FOMC meeting investors did not receive any new information that could lead them to expect a different maturity distribution. Similar to LSAP1, on the day of the FOMC, the Desk indicated that it would “concentrate purchases in the 2- to 10-year sector,” but also announced that it would “refrain from purchasing securities for which there is heightened demand or of which the SOMA already holds large concentrations.” To account for the change in market expectations caused by this statement, we use security-level data to identify any Treasury securities for which the Fed already held 25% or more of the total amount outstanding. Since these securities had a lower likelihood of being purchased, we adjust each sector’s expected share of purchases in inverse proportion to the amount already owned by the Fed. This implies that, for example, since the Fed already held a relatively higher concentration of securities in the 10- to 17-year maturity range, the expected share of purchases allocated to that sector is reduced by a larger factor, as seen in Table A4. The reinvestment local supply around the kink is computed as $2 * [(26.12 * 206.25 - 24.48 * 20.6) - (7.3 * 206.25 - 24.13 * 20.6)]/100 = \$77.49bn$.

Table A4 Maturity Distribution of Reinvestment Purchases

Fed Auction Sectors	1.5-2.5Y	2.5-4Y	4-5.5Y	5.5-7Y	7-10Y	10-17Y	17-30Y
Expected	6.29%	25.87%	24.48%	24.13%	4.55%	10.49%	4.20%
Announced	2.42%	58.48%	26.12%	7.30%	2.61%	1.23%	1.83%

MEP1

The September 2011 SPD (question 7b) reports a 78% median probability of the Fed increasing the duration of its portfolio through an “Operation Twist” at some point over the next two years. Further, conditional on the MEP being announced, dealers expected the size of the program to be \$325bn. As a result, the expected total purchases were $0.78 * \$325\text{bn} = \253.5bn . In contrast, the Fed announced a \$400bn MEP, creating a total Treasury surprise of \$146.5bn. There was no MBS component in MEP1.

Question 8c in the same SPD shows that dealers correctly anticipated that the MEP would be implemented over a six-month period, and by selling Treasuries with remaining maturity less than 3 years to buy Treasuries with remaining maturity between 7 and 30 years. This information is very useful for the computation of the local surprise. We obtain the expected maturity distribution of purchases for MEP1 by proportionally reallocating to the 6- to 30-year sector the share of purchases previously allocated to the 1.5- to 6-year sector. Then we use the actual maturity distribution of purchases released by the Desk contemporaneously to the FOMC announcement, listed in Table A5.²² As a result, the MEP1 local surprise is $[(100 - 32.99) * 400 - (100 - 42.23) * 253.5]/100 = \126.67bn .

Table A5 Maturity Distribution of MEP1 Purchases

Fed Auction Sectors	0-3Y	3-6Y	6-8Y	8-10Y	10-20Y	20-30Y
Expected	-100%	0%	44.23%	44.23%	3.85%	7.69%
Announced	-100%	0%	32.99%	32.99%	4.12%	29.90%

MEP2

²²The announced weights do not sum to 100 because 3% of purchases were allocated to TIPS, which we do not include here. Thus, to compute the local surprise, we rescale the announced weights to sum to 100, the results of which are displayed in the third row of Table A.5.

In the June 2012 SPD, dealers reported a 45% median probability of extending the MEP at some point over the next 2 years (question 7b). At the time, the Fed held \$205bn in short-term Treasuries whose maturity was expected to fall below 3 years over the next six months. It is conceivable that this publicly available information was used by market participants to form their expectations ahead of the MEP2 announcement. Thus, the expected amount of purchases under the MEP2 is $0.45 * \$205bn = \$92.25bn$. However, the Desk's statement indicated that it would stop rolling over maturing Treasuries at auction, allowing the Fed to further increase its long-term purchases from \$205bn to \$267bn. Thus, the \$267bn program created a \$174.75bn total Treasury surprise (\$267bn minus \$92.25bn). There was no MBS component in MEP2. To compute the local surprise, we simply apportion the total surprise according to the Desk's purchase/sale weights, which did not change from the MEP1 weights listed in Table A5. We compute the local surprise as $[(100 - 32.99) * 174.75]/100 = \$117.1bn$.

June 2013 FOMC: Post-taper tantrum

In the case of this event, the Desk conducted both a pre- and post-FOMC survey on June 10 and June 24, respectively. Question 6a from these two surveys shows the expected start of tapering moving forward from December 2013 to September 2013 (the first reduction in the pace of purchases is highlighted in Table A6). Further, as shown in the last row of each panel in Table A6, the change in the expected monthly pace of purchases from the June 10 to the June 24 SPD implies a \$27.5bn hawkish Treasury surprise and a \$38bn hawkish MBS surprise, respectively—a smaller-than-expected amount of purchases in each asset class. To compute the local surprise, we allocate the Treasury total surprise across the Fed auction maturity sectors according to the Desk's purchase weights already in place during LSAP3, shown in Table A.7.²³ Then, we take the difference between the surprise in the 7-10-year sector and each of the surprises in the adjacent maturity sectors, and sum those two differences: $(8.22 - 0.57) + (8.22 - 4.54) = \$11.34bn$.

In computing those surprises, we do not use information from question 6b, which asks about expected changes in the SOMA portfolio beyond the one-year horizon, as we posit that elevated uncertainty about QE tapering and the policy normalization process led market participants to heavily discount longer-term changes to the balance sheet policy.

²³https://www.newyorkfed.org/markets/longertermtreas_faq_12122012.html

Table A6 Expectations about the monthly pace of purchases (\$bn) in SPD from June 10 to June 24, 2013

Treasuries	Jun13	Jul13	Aug13	Sep13	Oct13	Nob13	Dec13	Jan14	Feb14	Mar14	Apr14	May14	Jun14
June 10	45	45	45	45	45	45	30	25	20	15	10	5	0
June 24	45	45	45	40	35	32.5	30	25	20	15	10	5	0
Change				-5	-10	-12.5							

MBS	Jun13	Jul13	Aug13	Sep13	Oct13	Nob13	Dec13	Jan14	Feb14	Mar14	Apr14	May14	Jun14
June 10	40	40	40	40	40	40	30	25	20	15	0	0	0
June 24	40	40	40	35	33	29	25	20	15	10	5	0	0
Change				-5	-7	-11	-5	-5	-5	-5	+5		

Table A7 June 2013 Local Supply Surprises

Fed Auction Sectors	4-4.75Y	4.75-5.75Y	5.75-7Y	7-10Y	10-20Y	20-30Y
Desk's Weights	11%	12%	16%	29%	2%	27%
Surprise (\$bn)	3.12	3.40	4.54	8.22	0.57	7.65

September 2013 FOMC: Tapering feint

Also for this event, the Desk conducted both a pre- and post-FOMC survey on September 9 and September 23, respectively. Question 1a from the September 9 SPD indicated that dealers expected the FOMC to announce QE3 tapering at the upcoming meeting. In contrast, the FOMC announced it was not yet ready to reduce its monthly pace of purchases. This announcement had the exact opposite effect of the June 2013 FOMC announcement: question 8 from both the September 9 and September 23 SPD shows the expected start of tapering moving backward from September 2013 to December 2013 (the first reduction in the pace of purchases is highlighted in Table A8). Further, as shown in the last row of each panel in Table A8, the change in the expected monthly pace of purchases from the September-9 to the September-23 SPD implies a \$95bn dovish Treasury surprise and a \$119.5bn dovish MBS surprise, respectively—a larger-than-expected amount of purchases in each asset class. To compute the local surprise, again we allocate the Treasury total surprise across the Fed auction maturity sectors according to the Desk's LSAP3 weights, shown in Table A9. Then, just as for June 2013, we take the difference between the surprise in the 7-10-year sector and each of the surprises in the adjacent maturity ranges, and sum those two differences: $(28.40 - 1.96) + (28.40 - 15.67) = \39.18bn .

Consistent with the previous event, in computing those surprises, we do not include data from question 8c about changes in SOMA from 2015 through 2018, as we

posit again that elevated uncertainty about QE tapering and the policy normalization process led market participants to heavily discount longer-term balance sheet policy decisions.

Table A8 Expectations about the monthly pace of purchases (\$bn) in SPD from Sep 09 to Sep 23, 2013

Treasuries	Sep13	Oct13	Nob13	Dec13	Jan14	Feb14	Mar14	Apr14	May14	Jun14	Jul-Dec14
Sep 9	40	35	32.5	30	25	20	15	15	7.5	0	0
Sep 23	45	45	45	40	35	30	25	20	15	10	5
Change	+5	+10	+12.5	+10	+10	+10	+10	+5	+7.5	+10	+5
MBS	Sep13	Oct13	Nob13	Dec13	Jan14	Feb14	Mar14	Apr14	May14	Jun14	Jul-Dec14
Sep 9	35	35	30	25	25	20	15	10	5	0	-5
Sep 23	40	40	40	35	35	30	25	20	16.5	13	20
Change	+5	+5	+10	+10	+10	+10	+10	+10	+11.5	+13	+25

Table A9 September 2013 Local Supply Surprises

Fed Auction Sectors	4-4.75Y	4.75-5.75Y	5.75-7Y	7-10Y	10-20Y	20-30Y
Desk's Weights	11%	12%	16%	29%	2%	27%
Surprise (\$bn)	10.77	11.75	15.67	28.40	1.96	26.44

June 2017 FOMC: Redemption caps announced

At the June 2017 meeting, the FOMC released the policy normalization addendum detailing the intended redemption cap schedule to gradually reduce the size of its portfolio. We compare the FOMC's announced caps to the expected caps in questions 4c and 4e of the SPD and obtain a month-by-month surprise from the start of the cap implementation through December 2019 (see Figure 3 in main text). We believe it is sufficient to stop in December 2019 because dealers' expectation of SOMA's size at year-end 2019 (question 5 in the SPD) closely matches their expectation of SOMA's size at year-end 2025 (question 7), suggesting dealers anticipated the Fed's portfolio run-off would be completed by 2019. Comparing the expected and announced caps gives a \$125bn hawkish Treasury surprise and a \$18bn dovish MBS surprise because the MBS/Treasury caps were lower/higher than expected, respectively.

However, putting together publically available information from the Fed's System Open Market Account (SOMA), the Treasury's Monthly Statement of the Public Debt

(MSPD), and the Securities Industry and Financial Markets Association (SIFMA) (as described in the Addendum at the end of this Appendix) reveals that, in certain months, the amount of Treasuries set to expire would be below the expected redemption caps. This implies that there is no surprise in those months, making the actual Treasury hawkish surprise estimate (\$78.2bn) smaller than the one obtained by only comparing the actual and expected caps (\$125bn). Figure 3 illustrates how the expected redemptions in those months were not affected by the FOMC’s higher-than-expected redemption caps. Since we assume that primary dealers use all the available information, we estimate a \$78.2bn hawkish Treasury surprise, and a \$18bn dovish surprise for MBS. The maturity distribution of the \$78.2bn hawkish Treasury surprise is displayed in Table A10.

Since the Fed rolled over maturing securities at auction, for this event the maturity ranges are determined by the maturities of Treasury issuance; thus, to compute the local surprise consistently across events, we need to combine the 2- and 3-year maturities into one range, the 5- and 7-year maturities into one range, and the 10- and 30-year maturities into one range. As a result, the local surprise is computed as follows: $[(16.47+13.59)-(12.48+14.54)]+[(16.47+13.59)-(12.99+8.14)] = \11.97bn .

Table A10 June 2017 Local Supply Surprises

Maturity	2Y	3Y	5Y	7Y	10Y	30Y
Surprise (\$bn)	12.48	14.54	16.47	13.59	12.99	8.14

March 2019 FOMC: QT tapering

At the March 2019 meeting, the FOMC announced a reduction in its redemption caps, implying larger asset purchases than before. Before the meeting, primary dealers were already expecting an accommodative adjustment to QT (question 5a), but they underestimated the dovishness of the Fed’s policy move. In particular, they expected the initial reduction in caps to occur in September 2019 and the end of QT to occur sometime in 2019:Q4. In contrast, the FOMC announced that the cap reduction would start in May 2019 and that QT would end in September 2019, implying a \$75bn dovish Treasury surprise (see Table A11). Adding SOMA, MSPD, and SIFMA data, however, produces a slightly lower \$50.8bn dovish surprise because Treasury redemptions were sometimes below the caps (see Figure 4 in the main text).

Table A11 Expectations about the monthly caps (\$bn) before and after March 2019 FOMC

	Mar19	Apr19	May19	Jun19	Jul19	Aug19	Sep19	Oct19	Nov19	Dec19
Pre	30	30	30	30	30	30	20	10	0	0
Pre	30	30	15	15	15	15	15	0	0	0
Change			-15	-15	-15	-15	-5	-10		

Since, similar to the June 2017 event, this event’s maturity ranges are determined by the maturities of Treasury issuance, to compute the local surprise consistently across events we need to combine the 2- and 3-year maturities into one range, the 5- and 7-year maturities into one range, and the 10- and 30-year maturities into one range. As a result, the local surprise is computed as follows: $[(10.41 + 8.405) - (9.948 + 10.27)] + [(10.41 + 8.405) - (7.071 + 4.706)] = \5.63bn , as seen in Table A12.

Table A12 March 2019 Local Supply Surprises

Maturity	2Y	3Y	5Y	7Y	10Y	30Y
Surprise (\$bn)	-9.948	-10.27	-10.41	-8.405	-7.071	-4.706

Additional Addendum on SOMA Surprise Methodology for June 2017 and March 2019

The Treasury sells its notes and bonds in six different maturities: 2, 3, 5, 7, 10, and 30 years. It sorts these six maturities into two different monthly auctions: a mid-month auction selling 3, 10, and 30-year Treasuries, and an end-month auction selling 2, 5, and 7-year Treasuries. After ending QE3 in October 2014, the Fed held the size of its balance sheet constant by reinvesting principal payments from its maturing Treasuries into new Treasury notes and bonds at Treasury auctions. Then, in late 2017, the Fed began to reduce the balance sheet by redeeming some principal payments from its maturing Treasury securities each month—but only up to a monthly cap. To quantify the policy surprise, we use unexpected changes in this monthly cap schedule released at the FOMC announcements in June 2017 and March 2019.

The Fed reinvests principal payments from its maturing Treasuries according to an entirely deterministic mechanism which has been in place since December 2015.²⁴

²⁴<https://www.newyorkfed.org/markets/treasury-rollover-faq-12-16-2015.html>

To obtain the total dollar amount to be reinvested at Treasury auctions in a given month, the Fed adds up the dollar amount of Treasuries set to mature during that month and then subtracts the FOMC-directed cap on Treasury redemptions. Changes in the FOMC redemption cap therefore directly affect the total reinvestment amount. Two key numbers then determine the allocation of these reinvestments across the six Treasury maturities. The first is the proportion of Treasuries maturing at the mid-month auction (3, 10, and 30-year) versus those maturing at the end-month auction (2, 5, and 7-year) within each month. The Fed splits its total pool of reinvestment dollars between these two auctions according to this first proportion. Then, at each auction, the Fed allocates reinvestment purchases across an auction's three maturities according to the maturity-level proportion of Treasury issuance within each auction.

Take a hypothetical example from the Federal Reserve Bank of New York where \$21bn of SOMA's Treasury portfolio matures and the FOMC cap is \$6bn for that month. The Fed will therefore reinvest \$15bn during the month. Assume mid-month Treasuries (3, 10, and 30-year) constitute \$7bn of the maturing \$21bn, and end-month Treasuries (2, 5, and 7-year) comprise the remaining \$14bn. The Fed thus allocates 33% of the \$15bn (so \$5bn) to reinvesting at the mid-month auction and 67% of the \$15bn (\$10bn) to reinvesting at the end-month auction. Next, at each auction, the Fed's allocation across an auction's three maturities depends on the maturity-level proportions of Treasury issuance within each auction. Assume that for the end-month auction, the Treasury announces offerings of \$25bn for 2Y Treasuries, \$15bn for 5Y, and \$10bn for 7Y. Thus, the Fed reinvests 50% of the \$10bn (\$5bn) in 2Y Treasuries, 30% of the \$5bn (\$3bn) in 5Y Treasuries, and 20% of the \$5bn (\$2bn) in 7Y Treasuries.

The pre-determined nature of the Fed's reinvestment mechanism allows market actors to anticipate SOMA monthly purchases ahead of time and also enables us to measure market expectations of reinvestment purchases. The Fed releases weekly CUSIP-level snapshots of its SOMA portfolio holdings, while the Treasury Department releases a Monthly Statement of the Public Debt (MSPD) containing CUSIP-level data on issuance date and amount outstanding. Combining the SOMA and MSPD data reveals the monthly reinvestment amount in dollars, in addition to the auction-level proportions of Treasuries maturing each month. The Securities Industry and Financial Markets Association (SIFMA) releases monthly data on Treasury issuance volumes broken out by maturity. Adding in the SIFMA data produces an approximation of market expectations for issuance volumes and therefore the maturity-level proportions

of Treasuries within each auction. For each of the six maturities, we recreate the amounts investors expected the Fed to purchase each month as part of its reinvestment policy. Then, when the FOMC announces changes in redemption caps, we look at the maturity-specific expectations before and after the announcement, quantifying the six maturity-specific surprises in dollars by taking the difference at each maturity. As a result, we quantify how much the market expectations of Fed purchases/sales changed because of a given balance sheet policy adjustment.

Table 1: Treasury Yield Impact at the Kink

	β_2 in bps	T-Stat	Adj R-Sq	N. of obs.
LSAP1	2.278	5.12	0.783	27.0
Reinvestment	1.131	9.32	0.712	70.0
MEP1	-4.701	-22.9	0.869	97.0
MEP2	-1.572	-11.9	0.748	94.0
Jun13 FOMC	-2.977	-34.1	0.946	138
Sep13 FOMC	3.353	7.67	0.450	106
Jun17 FOMC	-2.277	-20.7	0.720	170
Mar19 FOMC	1.387	16.6	0.801	159

Table 2: Treasury Yield Sensitivity to a \$100 billion BSP Surprise

	β_2 in bps	Total Surp.	Local Surp.	Sensit. LB	Sensit. UB
LSAP1	2.278	143	74.7	1.59	3.048
Reinvestment	1.131	186	77.5	0.61	1.46
MEP1	-4.701	147	127	3.209	3.711
MEP2	-1.572	175	117	0.900	1.343
Jun13 FOMC	-2.977	27.5	11.3	10.8	26.2
Sep13 FOMC	3.353	95.0	39.2	3.530	8.56
Jun17 FOMC	-2.277	78.2	12.0	2.912	19.0
Mar19 FOMC	1.387	50.8	5.63	2.730	24.6

Table 3: Treasury Yield Sensitivity to a \$100 billion BSP Surprise including MBS

	β_2 in bps	Treasury + MBS Surprise	Sensitivity with MBS
LSAP1	2.278	360	0.633
Reinvestment	1.131	139	0.813
MEP1	-4.701	147	3.209
MEP2	-1.572	175	0.900
Jun13 FOMC	-2.977	65.5	4.545
Sep13 FOMC	3.353	215	1.563
Jun17 FOMC	-2.277	60.2	3.782
Mar19 FOMC	1.387	50.8	2.730

Table 4: Treasury Yield Impact at the Kink, 2-year bandwidth

	β_2 in bps	T-Stat	Adj R-Sq	N
LSAP1	2.719	3.477	0.626	18.0
Reinvestment	1.839	9.745	0.728	47.0
MEP1	-5.115	-15.7	0.773	74.0
MEP2	-1.247	-6.333	0.499	75.0
Jun13 FOMC	-2.655	-23.8	0.894	95.0
Sep13 FOMC	2.364	2.677	0.072	70.0
Jun17 FOMC	-2.412	-16.2	0.710	142
Mar19 FOMC	0.748	8.857	0.522	103

Table 5: Treasury Yield Sensitivity to a \$100 billion BSP Surprise,
2-year bandwidth

	β_2 in bps	Total Surp.	Local Surp.	Sensit. LB	Sensit. UB
LSAP1	2.719	143	74.7	1.908	3.639
Reinvestment	1.839	186	77.5	0.991	2.374
MEP1	-5.115	147	127	3.492	4.038
MEP2	-1.247	175	117	0.714	1.065
Jun13 FOMC	-2.655	27.5	11.3	9.655	23.4
Sep13 FOMC	2.364	95.0	39.2	2.488	6.033
Jun17 FOMC	-2.412	78.2	12.0	3.084	20.1
Mar19 FOMC	0.748	50.8	5.63	1.473	13.3

Table 6: Treasury Yield Sensitivity to a \$100 billion BSP Surprise including MBS,
2-year bandwidth

	β_2 in bps	Treasury + MBS Surprise	Sensitivity with MBS
LSAP1	2.719	360	0.755
Reinvestment	1.839	139	1.321
MEP1	-5.115	147	3.492
MEP2	-1.247	175	0.714
Jun13 FOMC	-2.655	65.5	4.054
Sep13 FOMC	2.364	215	1.102
Jun17 FOMC	-2.412	60.2	4.006
Mar19 FOMC	0.748	50.8	1.473

Table 7: Measure of Uncertainty about BSP. Average uncertainty about the 10-year rate prevailing over the 10 days prior to the meeting, computed using the entire term-structure of swaption-implied volatility over a maximum horizon (MaxH) of either 5 or 10 years (5Y or 10Y)

MaxH	LSAP1	Reinv	MEP1	MEP2	Jun2013	Sept2013	Jun2017	Mar2019
5 Y	0.096	-0.203	0.018	-0.092	0.149	0.306	-0.136	-0.129
10 Y	0.095	-0.199	0.019	-0.093	0.146	0.299	-0.133	-0.128

Table 8: Impact of Investor Uncertainty about BSP on Treasury Yield Sensitivity (3-year bandwidth)

	Intercept	β_1	β_2	β_3	β_4	Adj. R-Sq	N. of obs.
Point Est	9.718	1.311	-2.344				818
T-Stat	(67.9)	(26.6)	(-26.9)			0.980	
Point Est	8.893	1.281	-2.373	2.998	-5.489		818
T-Stat	(59.3)	(27.7)	(-28.7)	(11.7)	(-10.8)	0.983	
Point Est	8.891	1.283	-2.377	3.061	-5.617		818
T-Stat	(59.3)	(27.8)	(-28.8)	(11.7)	(-10.9)	0.983	

Table 9: Impact of Investor Uncertainty about BSP on Treasury Yield Sensitivity (2-year bandwidth)

	Intercept	β_1	β_2	β_3	β_4	Adj. R-Sq	N. of obs.
Point Est	9.058	1.131	-2.105				818
T-Stat	(59.9)	(15.2)	(-15.9)			0.984	
Point Est	8.852	1.154	-2.189	1.061	-3.004		818
T-Stat	(53.8)	(15.6)	(-16.5)	(2.46)	(-3.62)	0.985	
Point Est	8.850	1.155	-2.192	1.093	-3.093		818
T-Stat	(53.8)	(15.6)	(-16.5)	(2.48)	(-3.66)	0.985	

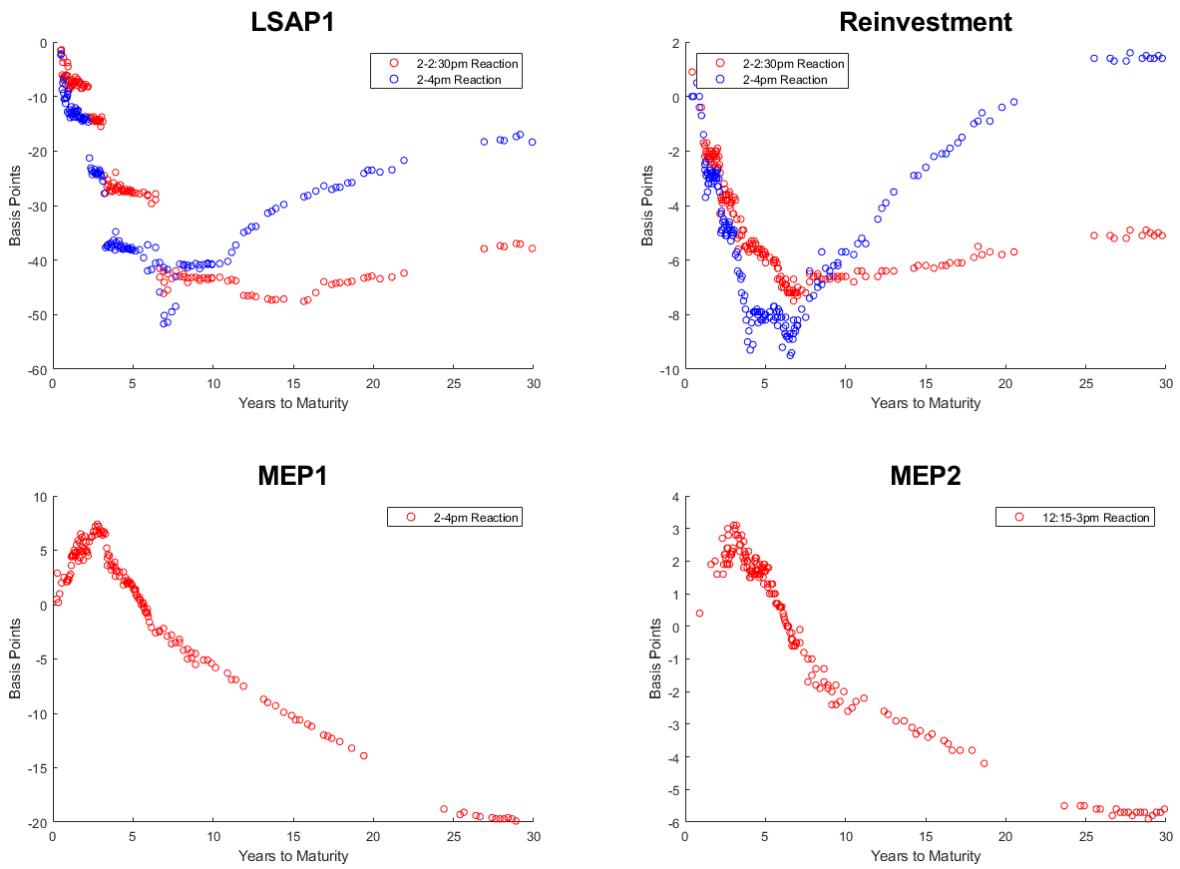


Figure 1: Yield curve reactions to four QE announcements: LSAP1, Reinvestment, MEP1 and MEP2. Each dot represents the change in a Treasury security's yield in the small time window around the FOMC announcement.

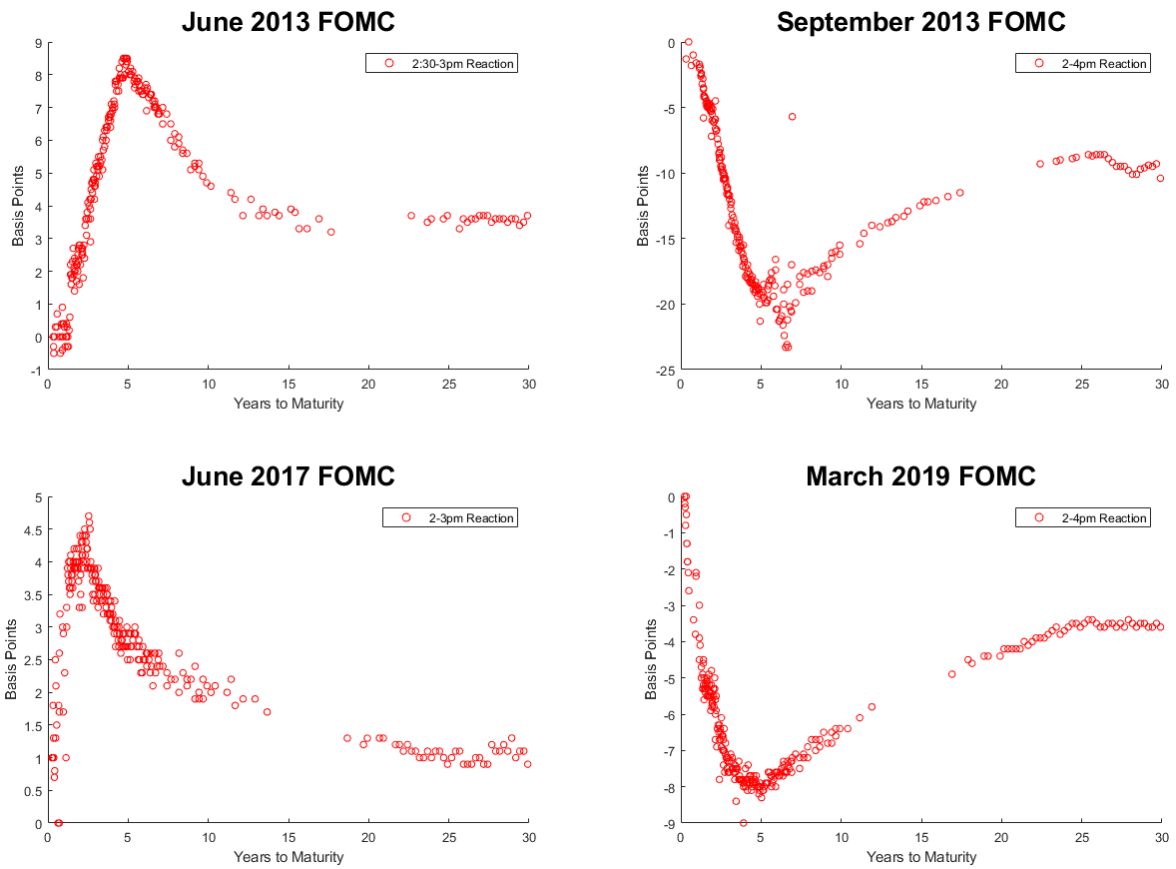


Figure 2: Yield curve reactions to four QT announcements. Each dot represents the change in a Treasury security's yield in the small time window around the FOMC announcement.

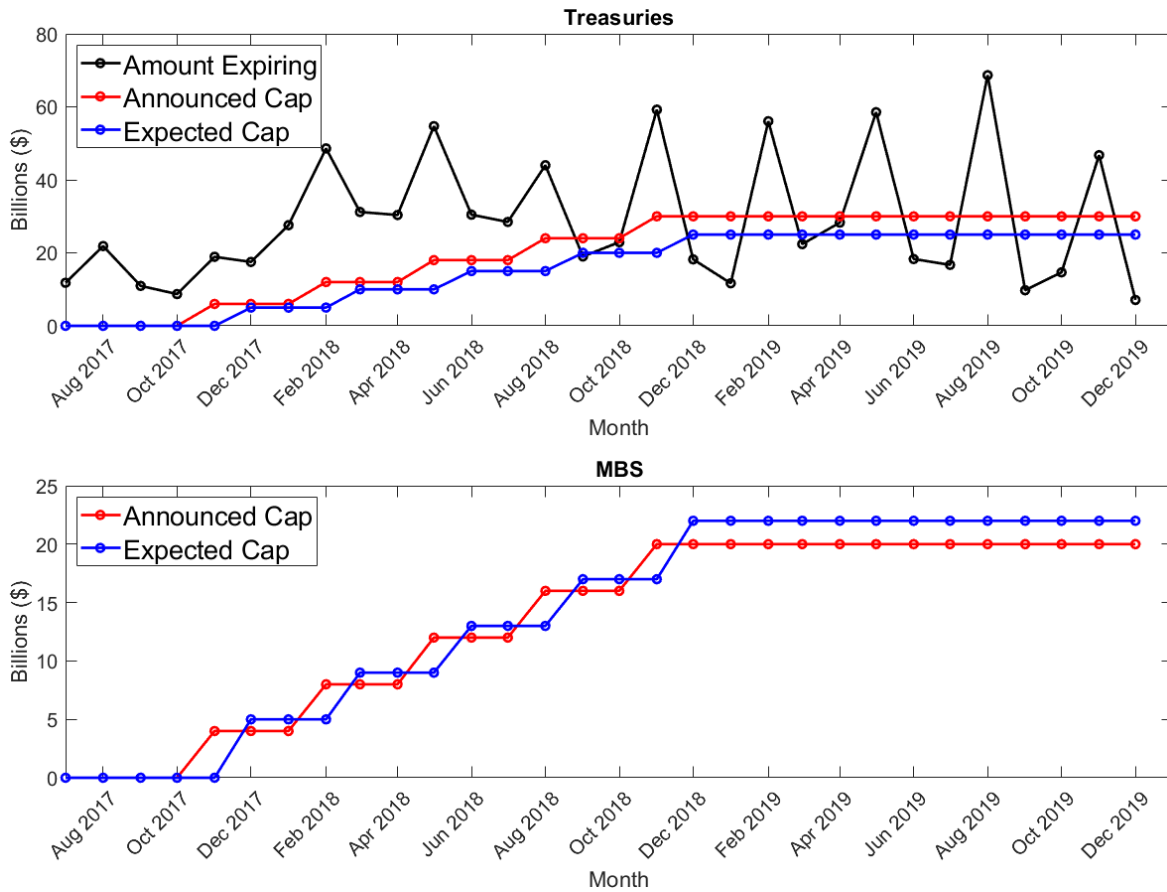


Figure 3: June 2017 Treasury and MBS expirations and Caps. The top panel shows the expected and announced cap schedules for Treasury securities, together with the amount of Treasury securities expiring each month. The bottom panel shows the expected and announced cap schedule for agency MBS.

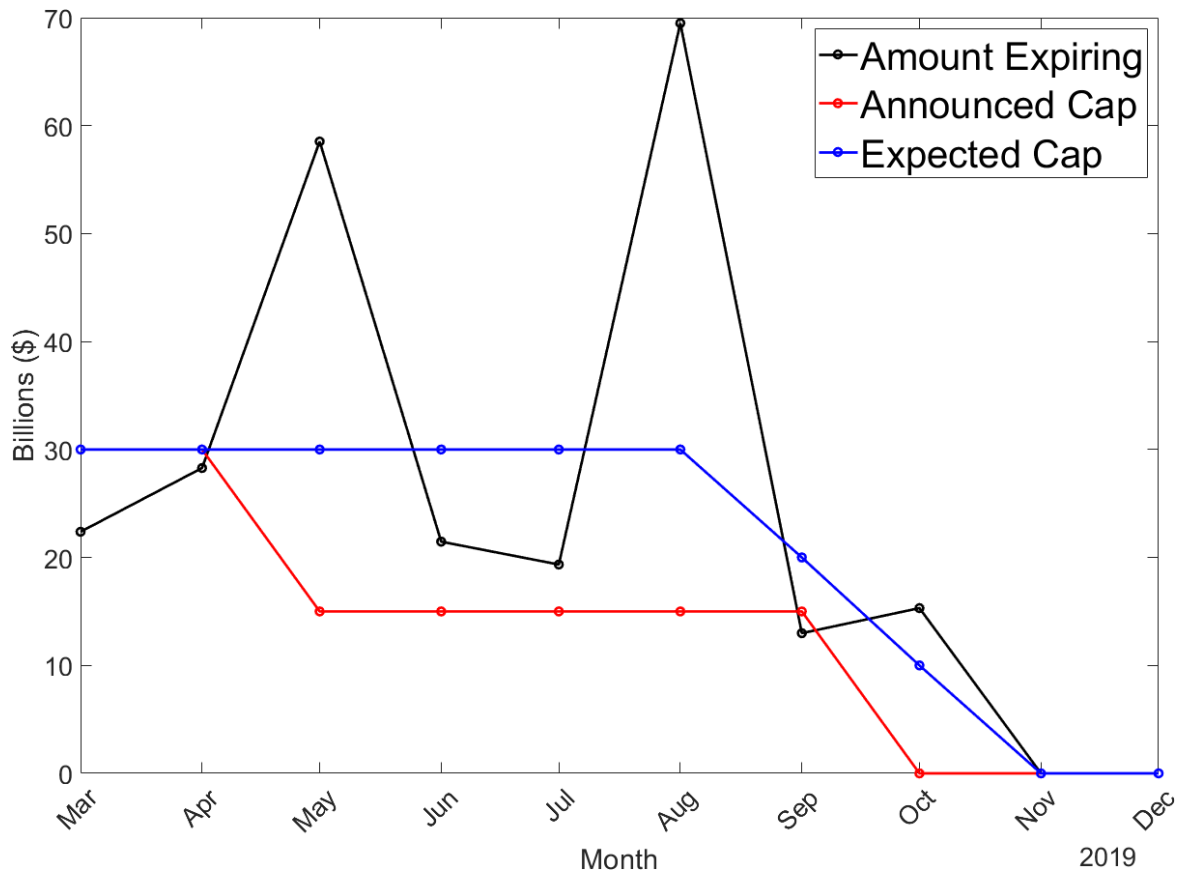


Figure 4: March 2019 Treasury expirations and Caps. The panel shows the expected and announced cap schedules for Treasury securities together with the amount of Treasury securities expiring each month.

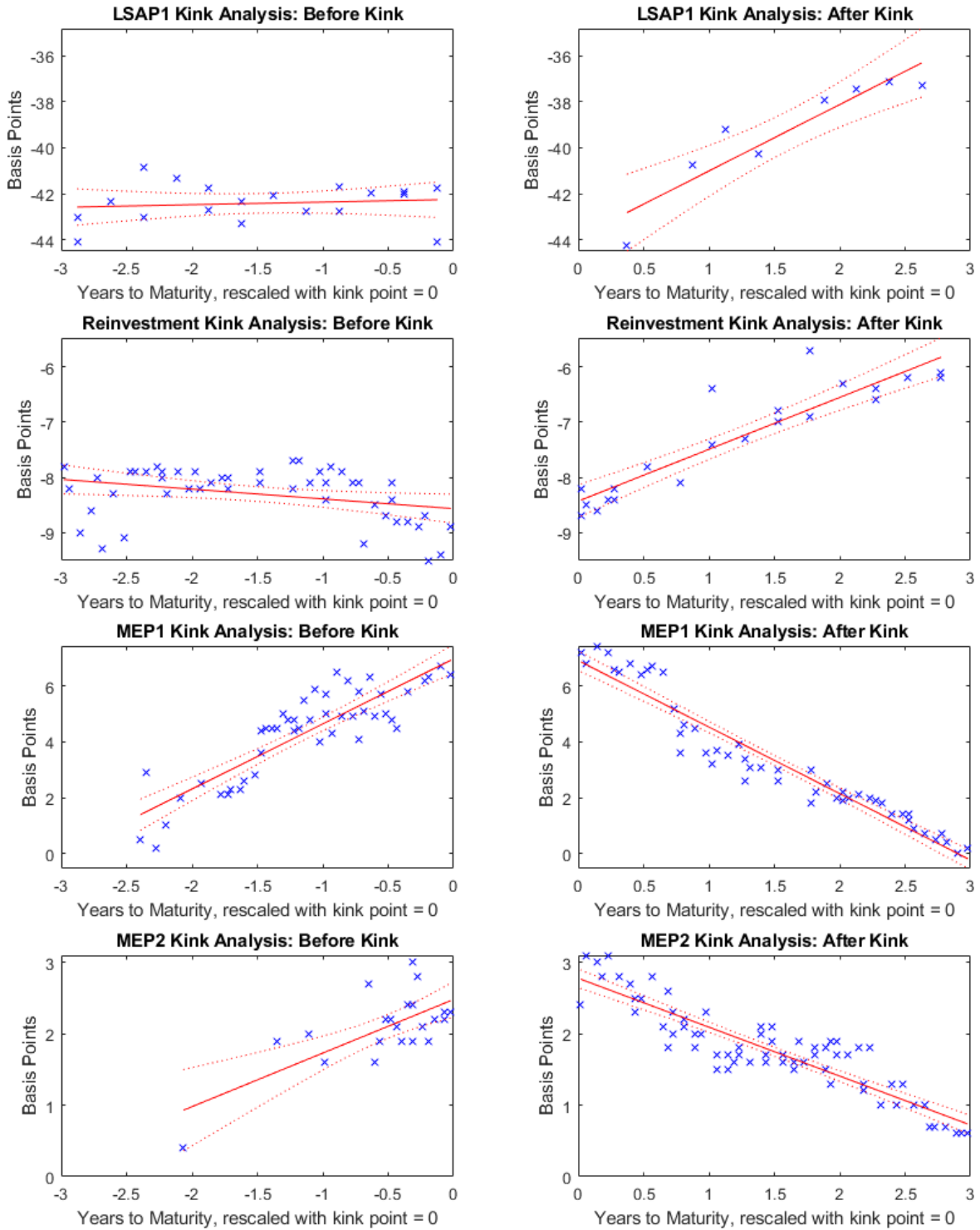


Figure 5: QE Kink Analysis. Each row shows the yield reactions and the fitted line to the left and right of the kink for each event.

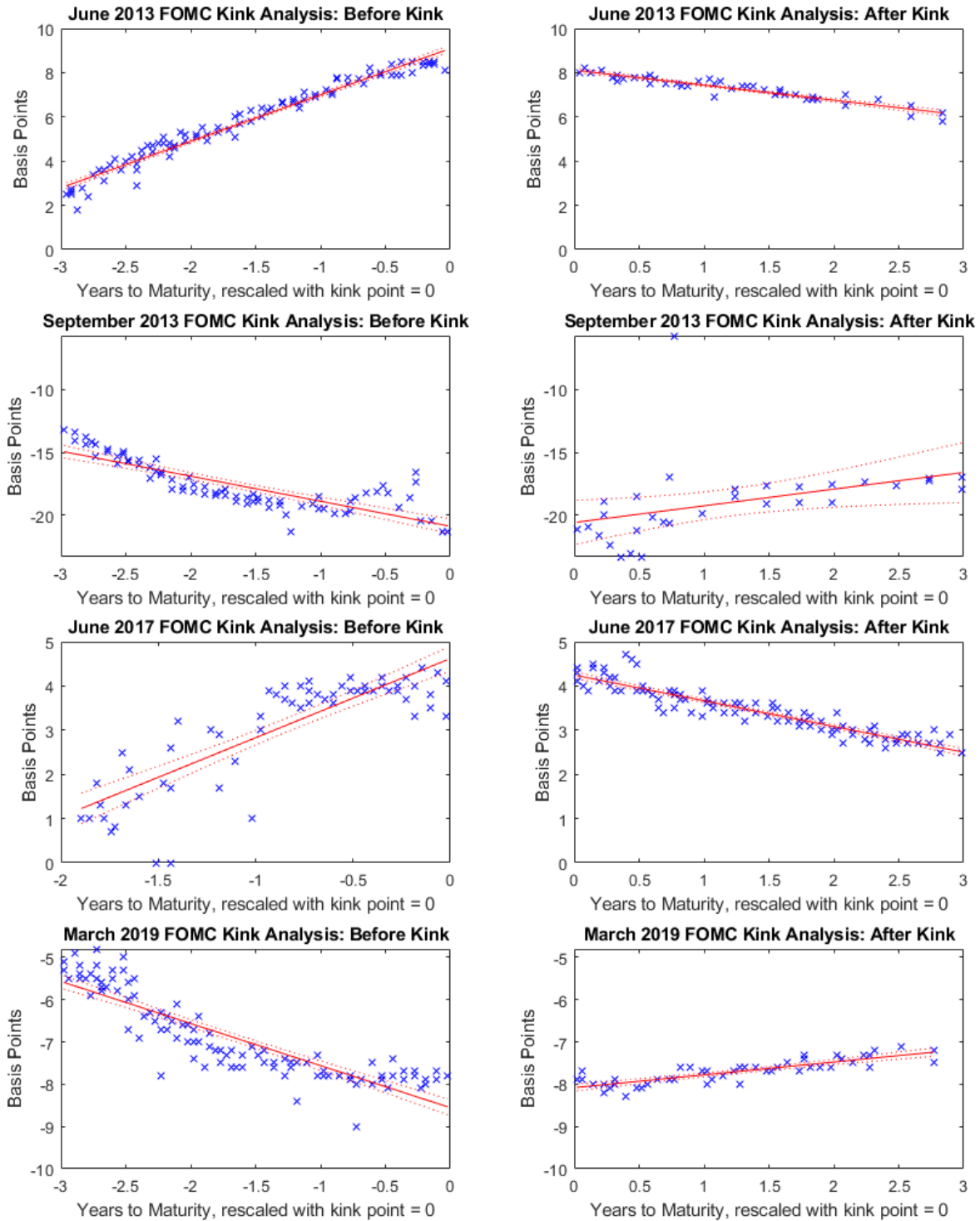


Figure 6: QT Kink Analysis. Each row shows the yield reactions and the fitted line to the left and right of the kink for each event.

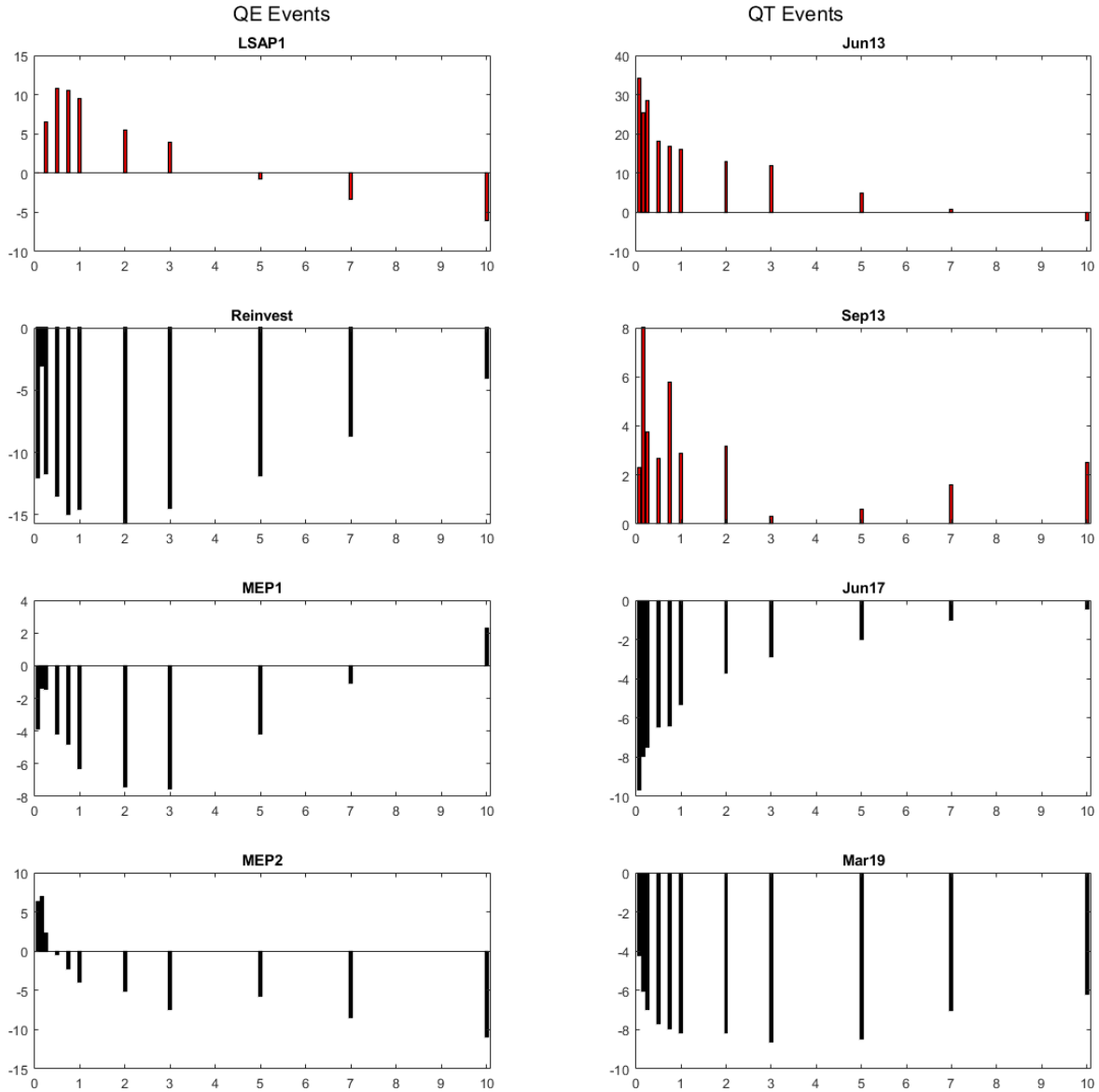


Figure 7: Evolution of the Term structure of the 10-Year Rate Uncertainty ahead of each BSP announcement: each panel shows the change in the swaption-implied volatility of the 10-year rate across different forecasting horizons in the six weeks preceding the day of the announcement.

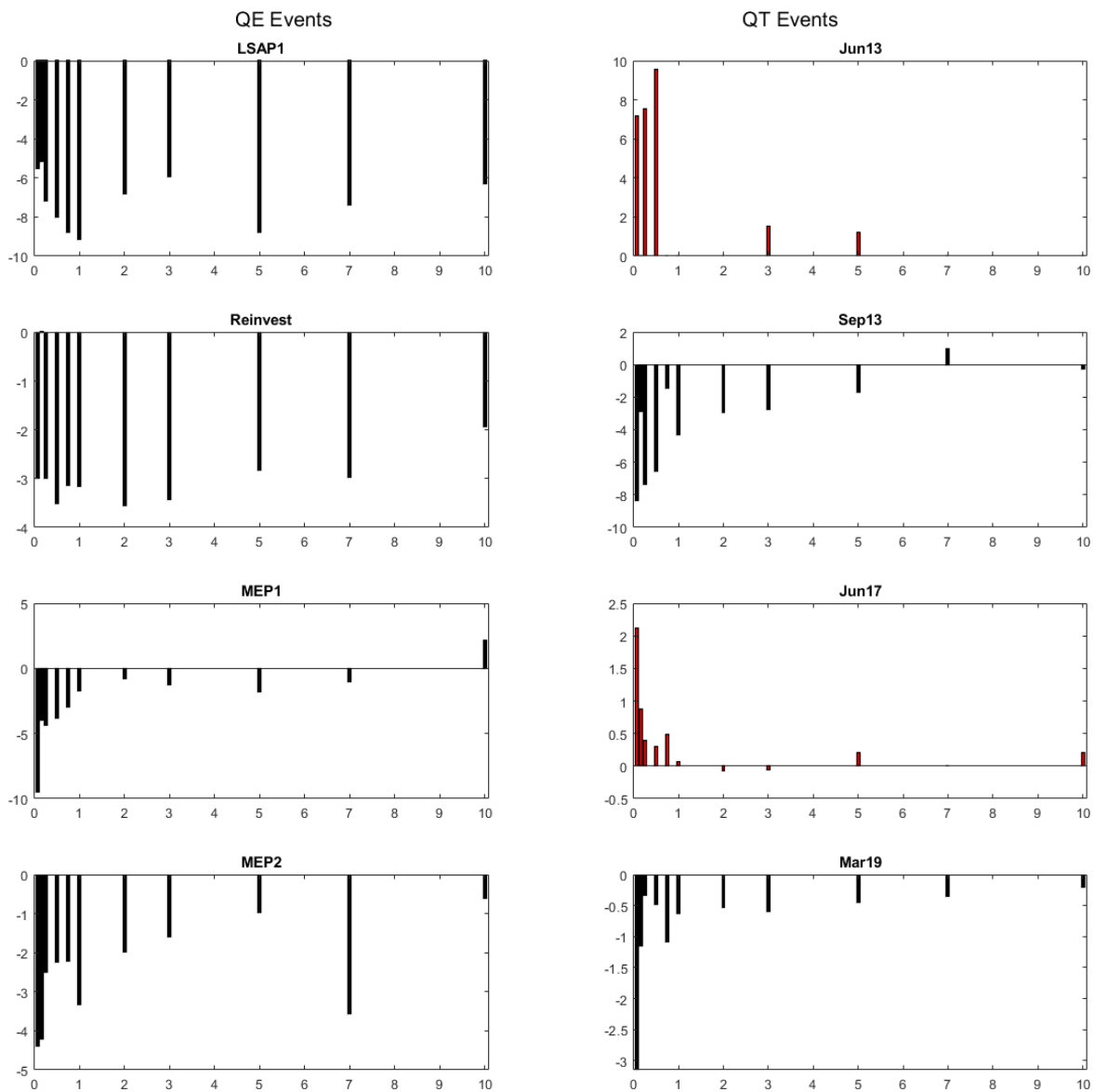


Figure 8: Change in the Term Structure of the 10-Year Rate Uncertainty on the Day of each BSP Announcement: each panel shows the change in the swaption-implied volatility of the 10-year rate across different forecasting horizons on the day of the FOMC announcement.