Journal of Monetary Economics 118 (2021) 32–53

Contents lists available at ScienceDirect

Journal of Monetary Economics

journal homepage: www.elsevier.com/locate/jmoneco

Measuring the effects of federal reserve forward guidance and asset purchases on financial markets☆

Eric T. Swanson

Department of Economics, University of California, Irvine, 3151 Social Science Plaza, Irvine, CA, United States

ARTICLE INFO

Article history:
Received 26 September 2019
Revised 16 September 2020
Accepted 17 September 2020
Available online 29 September 2020

JEL classification:
E52
E58
E44

Keywords:
Quantitative easing
High-frequency
Zero lower bound
Unconventional monetary policy
Persistence

ABSTRACT

The methods of Gürkaynak et al. (2005a) are extended to separately identify surprise changes in the federal funds rate, forward guidance, and large-scale asset purchases (LSAPs) for each FOMC announcement from July 1991 to June 2019. Forward guidance and LSAPs had substantial and highly statistically significant effects on Treasury yields, corporate bond yields, stock prices, and exchange rates, comparable in magnitude to the effects of the federal funds rate in normal times. These effects were all very persistent, with the exception of the very large and perhaps special March 2009 "QE1" announcement for LSAPs.

1. Introduction

Physical currency offers a nominal return of zero, so it is essentially impossible for a central bank to set the short-term nominal interest rate—its conventional monetary policy instrument—substantially below zero.[1] This zero lower bound (ZLB) constraint has required many central banks to pursue unconventional monetary policies to stimulate their economies after

☆ I thank Mike Woodford for encouraging me to start this project, and Sofía Bauducco, Cody Couture, Joe Gagnon, SungJun Huh, Youngseung Jung, Don Kim, Ken Kuttner, Pascal Paul, Matt Roberts-Sklar, Alexandre Ziegler, and seminar participants at the Banca d'Italia, Banque de France, Boston College, Cal State Fullerton, the Federal Reserve Banks of Boston, Chicago, Cleveland, Dallas, and Kansas City, the London School of Economics, National Bank of Belgium, Norges Bank, Swiss National Bank, UC Irvine, UC Riverside, UC Santa Cruz, University of Southern California, University of Zurich, the California Macroeconomics Conference, Central Bank of Chile Annual Conference, Central Bank Research Association Conference, Econometric Society World Congress, Federal Reserve Board Conference on Empirical Monetary Economics, Joint Conference of the Korean Economic Association and Social Science Korea Research Team, NBER Summer Institute Forecasting and Empirical Methods and Monetary Economics Workshops, Society for Computational Economics Conference, Society for Economic Dynamics Conference, and EABCN Conference on Unconventional Monetary Policy for helpful discussions, comments, and suggestions. Earlier work on this project was supported in part by the Central Bank of Chile. The views expressed in this paper, and all errors and omissions, are my own and are not necessarily those of the individuals or groups listed above; http://www.ericswanson.org.

E-mail address: eric.swanson@uci.edu

[1] A few central banks have recently set short-term nominal interest rates slightly below zero by charging banks a fee to hold electronic cash reserves at the central bank. This implies that the "zero lower bound" is not a hard constraint that lies exactly at zero. Nevertheless, nominal interest rates cannot fall too far below zero without leading to widespread conversion of electronic reserves into physical currency. Traditionally, this constraint is still referred to as the "zero lower bound".

https://doi.org/10.1016/j.jmoneco.2020.09.003
0304-3932/

Table 1
Major unconventional monetary policy announcements by the federal reserve, 2009–2015.

March 18, 2009	FOMC announces it expects to keep the federal funds rate between 0 and 25 basis points (bp) for "an extended period", and that it will purchase $750B of mortgage-backed securities, $300B of longer-term Treasuries, and $100B of agency debt (a.k.a. "QE1")
November 3, 2010	FOMC announces it will purchase an additional $600B of longer-term Treasuries (a.k.a. "QE2")
August 9, 2011	FOMC announces it expects to keep the federal funds rate between 0 and 25 bp "at least through mid-2013"
September 21, 2011	FOMC announces it will sell $400B of short-term Treasuries and use the proceeds to buy $400B of long-term Treasuries (a.k.a. "Operation Twist")
January 25, 2012	FOMC announces it expects to keep the federal funds rate between 0 and 25 bp "at least through late 2014"
September 13, 2012	FOMC announces it expects to keep the federal funds rate between 0 and 25 bp "at least through mid-2015", and that it will purchase $40B of mortgage-backed securities per month for the indefinite future
December 12, 2012	FOMC announces it will purchase $45B of longer-term Treasuries per month for the indefinite future, and that it expects to keep the federal funds rate between 0 and 25 bp at least as long as the unemployment remains above 6.5% and inflation expectations remain subdued
December 18, 2013	FOMC announces it will start to taper its purchases of longer-term Treasuries and mortgage-backed securities to paces of $40B and $35B per month, respectively
December 17, 2014	FOMC announces that "it can be patient in beginning to normalize the stance of monetary policy"
March 18, 2015	FOMC announces that "an increase in the target range for the federal funds rate remains unlikely at the April FOMC meeting"

the 2007–2009 global financial crisis. In this paper, I propose a new method to identify and estimate the effects of these unconventional monetary policies on financial markets and, ultimately, the economy. In particular, I estimate the effects of the U.S. Federal Reserve's "forward guidance" and "large-scale asset purchases" (or LSAPs), which were the two main types of unconventional policies pursued by the Fed between January 2009 and October 2015, when its traditional monetary policy instrument, the federal funds rate, was essentially zero.

Understanding the effects of unconventional monetary policy is important for both policymakers and researchers. Many central banks have found themselves increasingly constrained by the zero lower bound in recent years and have turned to a variety of unconventional policies to stimulate their economies, despite the fact that these policies' effects are not well understood. In the present paper, I provide new and improved estimates of these effects and their persistence. The efficacy of unconventional monetary policy is also an important determinant of the cost of the ZLB and the optimal inflation target for an economy. If unconventional monetary policy is relatively ineffective, then the ZLB constraint is more costly, and policymakers should go to greater lengths to avoid hitting it in the first place, such as by choosing a higher inflation target, as advocated by Summers (1991), Blanchard et al. (2010), Blanchard in The Wall Street Journal (2010), and Ball (2014). On the other hand, if unconventional monetary policy is very effective, then the ZLB constraint is not very costly and there is little reason for policymakers to raise their inflation target on that ground.

The zero lower bound period in the U.S. began on December 16, 2008, when the Federal Reserve's Federal Open Market Committee (FOMC) lowered the federal funds rate—its conventional monetary policy instrument—to essentially zero. The U.S. economy was still in a severe recession, so the FOMC began to pursue unconventional monetary policies to try to stimulate the economy further. By far the two most extensively used such policies were "forward guidance"—communication by the FOMC about the likely future path of the federal funds rate over the next several quarters—and "large-scale asset purchases", or LSAPs—purchases by the Federal Reserve of hundreds of billions of dollars of longer-term U.S. Treasury bonds and mortgage-backed securities. The goal of both policies was to lower longer-term U.S. interest rates by methods other than changes in the current federal funds rate, and thereby stimulate the economy.

Table 1 reports some of the most notable examples of the FOMC's forward guidance and LSAP announcements during this period. In addition to the examples in the table, incremental news about these policies was released to financial markets at virtually every FOMC meeting, such as updates that a policy was ongoing, was likely to be continued, or might be adjusted. Throughout 2015, for example, the FOMC gave numerous updates about whether a tightening of the federal funds rate was likely to take place at the next one or two FOMC meetings. Finally, the U.S. zero lower bound period ended on December 16, 2015, when the FOMC raised the federal funds rate for the first time since the financial crisis, to a range of 0.25 to 0.5%.

It's apparent from Table 1 that separately identifying the effects of forward guidance and LSAPs is difficult, because many of the FOMC's announcements provide information about both types of policies simultaneously. Moreover, even in the case of a seemingly clear-cut announcement, such as the LSAP-focused "QE2" announcement on Nov. 3, 2010, both types of policies may still have been at work: in particular, several authors have argued that LSAPs affect the economy either partly or wholly by changing financial markets' expectations about the future path of the federal funds rate (e.g., Woodford, 2012; Krishnamurthy and Vissing-Jorgensen, 2011; Bauer and Rudebusch, 2014). To the extent that this "signaling" channel is operative, even a pure LSAP announcement would have important forward guidance implications. This makes disentangling the two types of policies even more difficult than it might seem at first.

A second major challenge in estimating the effects of unconventional monetary policy announcements is that financial markets are forward-looking, and thus should not react to the component of an FOMC announcement that is expected *ex ante*; only the unanticipated component should have an effect. But determining the size of the unexpected component of each announcement in Table 1 is very difficult, because there are no good data on what financial markets expected the outcome of each FOMC announcement to be.[2]

A third, related challenge is that the FOMC can sometimes surprise markets through its *in*action rather than its actions. For example, on September 18, 2013, financial markets widely expected the FOMC to begin tapering its LSAPs, but the FOMC decided not to do so, surprising markets and leading to a large effect on asset prices despite the fact that no action was announced.[3] This implies that even dates *not* listed in Table 1 could have produced a significant surprise in financial markets and led to large effects on asset prices and the economy.

In this paper, I address these challenges by extending the high-frequency approach of Gürkaynak et al. (2005a, henceforth GSS). I first look at the high-frequency (30-minute) responses of asset prices to FOMC announcements to identify the immediate causal effect of those announcements on financial markets. I then test for the number of dimensions underlying those announcement effects and show that they are well described by three dimensions over my sample, July 1991 to June 2019. These dimensions represent the three aspects of FOMC announcements that had the greatest systematic effect on asset prices over the sample. Intuitively, it's reasonable to think that these three dimensions correspond to changes in the federal funds rate, changes in forward guidance, and changes in LSAPs, although I conduct several checks that this interpretation is valid in my results, below.

I collect the 30-minute asset price responses to each FOMC announcement between 1991 and 2019 and compute the first three principal components of those responses. This estimates the three factors that had the greatest explanatory power for these high-frequency asset price changes. I search over all possible rotations of these three principal components to find one in which the first factor corresponds to changes in the federal funds rate, the second to changes in forward guidance, and the third to changes in LSAPs. I build on the earlier work of GSS (2005a) to separately identify changes in the federal funds rate from forward guidance, and add a new identifying assumption that the LSAP factor is as close to zero as possible during the pre-ZLB period. I show that this identification is robust and produces estimates that agree closely with observable characteristics of major FOMC announcements during the ZLB period. In this way, I separately identify the federal funds rate, forward guidance, and LSAP components of every FOMC announcement from July 1991 to June 2019.

Once the different components of each FOMC announcement are identified, it's straightforward to estimate the response of different asset prices to each of those components using high-frequency (30-minute or 1-day) regressions. I find that both forward guidance and LSAPs had highly statistically significant effects on a wide variety of assets, including Treasuries, corporate bonds, stocks, and foreign exchange. The sizes of these effects are comparable to those of conventional monetary policy (changes in the federal funds rate), suggesting that these policies are reasonable substitutes. Forward guidance was relatively more effective at moving short-term Treasury yields and stock prices, while LSAPs were more effective at moving longer-term Treasury and corporate bond yields.

Finally, I investigate whether these effects were persistent—i.e., did they die out quickly as some models of slow-moving capital (e.g., Duffie, 2010; Fleckenstein et al., 2014) suggest, or were the high-frequency impact effects more permanent? I find that all three of these monetary policy instruments generally had very persistent effects: the estimated "decay rates" are typically small and insignificantly different from zero. The exception to this is the very influential March 2009 "QE1" announcement for LSAPs, after which bond yields fell sharply on impact but then rebounded strongly over subsequent weeks as financial markets turned around and rallied from their crisis lows.

The remainder of the paper proceeds as follows. In Section 2, I describe the data and extend the analysis in GSS to allow for additional dimensions of monetary policy. I show that three factors fit the 1991–2019 financial market responses to FOMC announcements very well. I use the identifying assumptions in GSS to separately identify forward guidance from changes in the federal funds rate, and propose a new identifying restriction to separately identify LSAPs from the other two factors. In Section 3, I discuss the results of this identification strategy and show that it is robust. I also show that my estimated forward guidance and LSAP factors correspond closely to observable features of major FOMC announcements during the ZLB period. In Section 4, I estimate the effects of forward guidance and LSAPs on Treasury yields, stock prices, exchange rates, and corporate bond yields using high-frequency regressions. In Section 5, I estimate and discuss the persistence of these FOMC announcement effects over the next several months. Finally, in Section 6, I discuss the broader implications of my findings for U.S. monetary policy going forward and for estimating the effects of unconventional monetary policy in other economies. Two technical Appendices contain mathematical details of the identifying assumptions used in Section 2 and the bootstrap procedure used to calculate standard errors in Sections 3–5.

1.1. Related literature

There are now a number of studies that investigate the effects of forward guidance or LSAPs on financial markets, especially during the U.S. zero lower bound period. Gürkaynak et al. (2005a) is an early example that measured the effects of

[2] This is in sharp contrast to the case of conventional monetary policy—changes in the federal funds rate—for which we have very good data on financial market expectations through federal funds futures and other short-term financial market instruments, as discussed by Kuttner (2001), Gürkaynak et al. (2005a,2005b,2007a), and others.

[3] The Wall Street Journal (2013b,2013c) reported that "No Taper Shocks Wall Street," and "Bernanke had a free pass to begin that tapering process and chose not to follow [through]... The Fed had the market precisely where it needed to be. The delay today has the effect of raising the benchmark to tapering..."

the FOMC's pre-2005 forward guidance announcements. In contrast to GSS, I also estimate the effects of the FOMC's LSAP announcements, study the peristence of those announcement effects, and investigate the effects on corporate bond yields and exchange rates as well as stocks, Treasuries, and interest rate futures.

More recently, Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011, 2013), and others use high-frequency event studies around a few of the Fed's largest LSAP announcements to show that those announcements had economically and statistically significant effects on a variety of asset prices. In contrast to these papers, I look at every FOMC announcement from 1991–2019, including announcements that focused on forward guidance rather than LSAPs. I also separately identify the effects of LSAPs and forward guidance to compare and contrast the effects of the two policies and investigate which one was more effective overall.

Wright (2012) uses identification by heteroskedasticity in a daily-frequency VAR from November 2008 to September 2011 to show that Fed announcements had economically and statistically significant effects on longer-term Treasury and corporate bond yields. In contrast to Wright (2012), I distinguish between forward guidance and LSAPs and separately estimate the effects of each type of announcement. Wright also estimates that the effects of these unconventional monetary policy announcements tended to die out over time, with a half-life of 2–3 months. In contrast, I find that only the very large "QE1" LSAP announcement had effects that died out over time. Forward guidance and LSAP announcements more generally seemed to have very persistent effects.

A number of studies also devote considerable attention to identifying and estimating the different channels through which forward guidance and LSAPs affect financial markets. For example, Krishnamurthy and Vissing-Jorgensen (2011) decompose the effects of LSAPs into signaling, duration risk, liquidity, safety, prepayment risk, default risk, and inflation channels, while D'Amico et al. (2012) differentiate between signaling, local scarcity, and duration risk. Campbell et al. (2012), Nakamura and Steinsson (2018), and Miranda-Agrippino and Ricco (2020) investigate a "Fed information effect" channel of forward guidance, through which FOMC announcements convey information to financial markets about the Fed's internal forecasts for unemployment or GDP, and this information causes asset prices to move. In the present paper, I do not try to separately estimate the effects of these different channels. Instead, I estimate the average "total forward guidance" effect and "total LSAP" effect. This is because my focus here is to compare and contrast the overall effectiveness of these two types of policies, rather than the effects of idiosyncratic variations in each type of policy (such as which Treasury or mortgage-backed securities were purchased, or what type of wording was used in the FOMC's forward guidance). While the effects of these variations are interesting and important in their own right, I leave them to these other papers and to future research. I do show in my results, however, that my identifying assumptions produce robust estimates of the average total effect of forward guidance and the average total effect of LSAPs (and also the average total effect of changes in the federal funds rate), which are clearly distinguishable from each other and are clearly very important movers of financial markets.

2. Data and identifying assumptions

To separately identify the forward guidance and asset purchase component of each FOMC announcement, I extend the approach of Gürkaynak et al. (2005a). First, I extend the GSS dataset through June 2019 using data obtained from staff at the Federal Reserve Board. The extended data includes the date of every FOMC announcement from July 1991 through June 2019 together with the change in a number of asset prices in a 30-minute window bracketing each announcement.[4] The asset prices include federal funds futures (the current-month contract rate and the contract rates for each of the next six months), Eurodollar futures (the current-quarter contract rate and the contract rates for each of the next eight quarters), Treasury bond yields (3-month, 6-month, and 2-, 5-, 10-, and 30-year maturities), the stock market (S&P 500), and exchange rates (yen/dollar and dollar/euro).

I collect these asset price responses into a $T \times n$ matrix X, with rows corresponding to FOMC announcements and columns to different assets; each element x_{ij} of X then reports the 30-minute response of the jth asset to the ith FOMC announcement. As in GSS, we can think of these data in terms of a factor model,

$$X = F\Lambda + \varepsilon, \tag{1}$$

where F is a $T \times k$ matrix containing $k \leq n$ unobserved factors, Λ is a $k \times n$ matrix of loadings of asset price responses on the k factors, and ε is a $T \times n$ matrix of white noise residuals that is uncorrelated over time and across assets.[5] If $k = 0$, the data X would be well described by n uncorrelated white noise processes; if $k = 1$, X would be well described as responding linearly to a single factor (such as the change in the federal funds rate) plus uncorrelated white noise; if $k = 2$, X would be responding to two underlying dimensions of FOMC announcements plus uncorrelated white noise; and so on. Natural candidates for the columns of F would be: i) the surprise component of the change in the federal funds rate at each FOMC meeting, ii) the surprise component of the change in forward guidance, iii) the surprise component of any LSAP

[4] The window begins 10 minutes before the FOMC announcement and ends 20 minutes after. The dataset also includes some intraday asset price responses to FOMC announcements going back to January 1990, but the data for Treasury yield responses begins in July 1991, and those are an important part of my analysis. Also, as is standard in the literature, I exclude the FOMC announcement on September 17, 2001, which took place before markets opened but after financial markets had been closed for several days following the 9/11 terrorist attacks.

[5] Thus, if we write the factor model (1) as $X_t = \Lambda' F_t + \varepsilon_t$, $t = 1, 2, \ldots, T$, where X_t and ε_t are $n \times 1$ vectors and F_t is $k \times 1$, the variance matrix of ε_t is diagonal in each period t as well as being serially uncorrelated over time.

Table 2
Tests for the number of factors underlying interest rate responses to FOMC announcements, 1991–2019.

H_0: number of factors equals	degrees of freedom	Wald statistic	p-value
0	28	92.8	7.2×10^{-9}
1	20	56.8	0.00002
2	13	28.5	0.008
3	7	11.7	0.111

Results from the Cragg and Donald (1997) test for the number of factors k underlying the 241×8 matrix X of 30-minute asset price responses to FOMC announcements from July 1991 to June 2019. The test is for H_0: $k = k_0$ vs. H_1: $k > k_0$. See text for details.

announcements, and iv) any additional dimensions of news about monetary policy or the economy that are systematically revealed in FOMC announcements.

We are interested in estimating and identifying the columns of F. For the estimation, I take X to include the first and third federal funds futures contracts, the second, third, and fourth Eurodollar futures contracts, and the 2-, 5-, and 10-year Treasury yields, to focus on the assets that are the most closely related to monetary policy. The first and third federal funds futures contracts provide good estimates of the market expectation of the federal funds rate after the current and next FOMC meetings.[6] The second through fourth Eurodollar futures contracts provide information about the market expectation of the path of the federal funds rate over a horizon from about 5 to 14 months ahead.[7] The 2-, 5-, and 10-year Treasury yields provide information about interest rate expectations and risk premia over longer horizons, out to 10 years. The reason for focusing on some rather than all possible futures contracts is to avoid overlapping contracts, since those are highly correlated for technical rather than policy-related reasons.[8] In the factor model (1), futures contracts that are highly correlated will show up as a common factor—a column of F—which is not interesting if the correlation is generated by overlapping contracts rather than the way monetary policy is conducted.

Note that, to estimate the factors F, I do not need to take a stand on *why* the interest rates above move in response to FOMC announcements, only that they do so systematically. For example, medium- or longer-term interest rates might change for any of the reasons described in Krishnamurthy and Vissing-Jorgensen (2011) or Campbell et al. (2012). As long as the interest rate responses to FOMC announcements are systematic, they will be identified as responses to the monetary policy factors F rather than the residuals ε_t.

As a guideline for estimating F, I first investigate its rank following GSS (2005a) and Cragg and Donald (1997). Given a null hypothesis of rank k_0 versus an alternative $k > k_0$, the Cragg-Donald test searches over all possible factor models with k_0 factors to find the one that brings the residuals ε as close to uncorrelated white noise as possible; the test then measures the distance between the residuals and white noise using a Wald statistic. There are 241 FOMC announcements from July 1991 to June 2019, and eight different assets in X, so X has dimensions 241×8. The results of this test are reported in Table 2. The data overwhelmingly reject the hypothesis of rank zero (uncorrelated white noise), so clearly the yield curve responds systematically to FOMC announcements. The hypothesis of rank one is also rejected very strongly, which implies that interest rates respond to FOMC announcements in a multidimensional way—thus, the surprise change in the federal funds rate (or any other single dimension of monetary policy) is insufficient to explain the responses of interest rates to FOMC announcements.[9] The hypothesis that F has rank two is also rejected at standard significance levels (p-value of .008), suggesting that even two dimensions of monetary policy are insufficient to explain the response of the yield curve over this sample.[10] However, the hypothesis of rank three is not rejected at even the 10% level, suggesting the data are well explained by a factor model with three factors.

The results in Table 2 are interesting for several reasons. First, the finding that FOMC announcements are not one-dimensional casts doubt on some authors' use of changes in the 1- or 2-year Treasury yield, or the first principal component of a set of interest rates, as a sufficient statistic for monetary policy (e.g., Gertler and Karadi, 2015; Hanson and Stein, 2015; Wu and Xia, 2016; Nakamura and Steinsson, 2018). Monetary policy seems to have more than one dimension, at least in terms of its effects on financial markets. Second, as noted by GSS (2005a), FOMC announcements are poten-

[6] As in GSS (2005a) and Kuttner (2001), these contracts are scaled by the number of days remaining in the month to provide the best estimate of the surprise change in the federal funds rate at the FOMC meeting. See GSS (2005a) and Kuttner (2001) for details.

[7] I follow GSS and switch from federal funds futures to Eurodollar futures at a horizon of about two quarters because Eurodollar futures were much more liquid than longer-maturity fed funds futures over this sample and are thus likely to provide a better measure of financial market expectations at those longer horizons (see Gürkaynak et al., 2007a).

[8] For example, FOMC announcements are spaced 6 to 8 weeks apart, so the second federal funds futures contract is essentially perfectly correlated with the first (once the latter has been scaled to represent the outcome of the FOMC meeting, as discussed above). Similarly, including the first Eurodollar futures contract provides essentially no additional information beyond the first and third federal funds futures contracts.

[9] GSS (2005a) showed that this was also true for their sample, 1991–2004, and that a second dimension of monetary policy was needed to explain the data.

[10] Note that the rejection of two factors in Table 2 is not driven by the influential FOMC announcement on 3/18/2009, discussed below: excluding that one announcement, the Cragg-Donald test still strongly rejects two factors.

tially very high-dimensional objects, containing information about the future paths of interest rates, asset purchases, and the economy. Despite this potential complexity, the effects of monetary policy on the yield curve are surprisingly well summarized by just three factors. Third, even though there may be some idiosyncratic variation in the way the FOMC described its forward guidance and conducted its LSAPs over the sample, these idiosyncracies are not systematic enough to require additional factors to fit the data.[11] Three factors seems to fit the data well.

Intuitively, it's natural to think of these three dimensions of monetary policy as corresponding to (the surprise component of) changes in the federal funds rate, forward guidance, and LSAPs, since these were the features of FOMC announcements that received the most attention in financial markets and the financial press. I will focus on this interpretation below, but one might argue that other features of FOMC announcements are even more important than LSAPs (say) and could also be a candidate for one of the three factors. For example, Campbell et al. (2012), Nakamura and Steinsson (2018), and Miranda-Agrippino and Ricco (2020) argue that there is an "information effect" component of FOMC announcements, which communicates to the private sector substantial new information about future unemployment or GDP.[12] At this point, any interpretation of the three factors is possible, although I will present evidence below that the three factors do correspond very well to changes in the federal funds rate, forward guidance, and LSAPs.

To estimate the unobserved factors F, I begin by extracting the first three principal components of the data X. These principal components correspond to the three elements of FOMC announcements that had the greatest systematic impact on the assets in X over the sample, and together explain about 94% of the variation in X.

However, principal components are only a statistical decomposition and do not have a structural interpretation. For example, there is no reason why the first principal component should correspond to the surprise change in the federal funds rate, or forward guidance, or LSAPs—instead, the first principal component is likely to be some combination of two or even all three of these factors. Mathematically, if F and Λ characterize the data X in Eq. (1), and U is any 3×3 orthogonal matrix, then the matrix $\widetilde{F} \equiv FU$ and loadings $\widetilde{\Lambda} \equiv U'\Lambda$ represent an alternative factor model that fits the data X exactly as well as F and Λ, since it produces exactly the same residuals ε in Eq. (1).[13]

Among all these observationally equivalent factor models, I look to see if there is one in which the three columns of F correspond to (the surprise component of) changes in the federal funds rate, forward guidance, and LSAPs, respectively. Note that there is no guarantee that these are the three factors that necessarily explain the data X the best, as discussed above, so after imposing my identifying assumptions below, I will check that the results do in fact look like changes in the funds rate, forward guidance, and LSAPs. Choosing a particular $\widetilde{F}$ matrix amounts to choosing a rotation matrix U such that the rotated factors $\widetilde{F}$ have this structural interpretation. A 3×3 orthogonal matrix U is completely determined by three parameters, so identification of U (and hence $\widetilde{F}$ and $\widetilde{\Lambda}$) requires three restrictions.

First, following GSS (2005a), I impose that changes in forward guidance have no effect on the current federal funds rate—i.e., $\widetilde{\lambda}_{21} = 0$, where $\widetilde{\lambda}_{ij}$ denotes the (i, j)th element of $\widetilde{\Lambda}$. This identifying assumption is justified by defining forward guidance to be the component of FOMC announcements that conveys information about the future path of short-term interest rates *above and beyond* changes in the target federal funds rate itself.[14] This is the definition of forward guidance (or the path factor) used by GSS and that I also use in this paper.

Second, I impose that changes in LSAPs also have no effect on the current federal funds rate—i.e., $\widetilde{\lambda}_{31} = 0$. Since the FOMC's major LSAP announcements all occurred during the ZLB period, this should be relatively uncontroversial.[15]

Third and finally, I impose the restriction that the LSAP factor is as small as possible in the pre-ZLB period. In other words, I compute the sum of squared values of the third factor, $\widetilde{F}_3 = FU_3$, where U_3 denotes the third column of U, over the subsample from 1991 to 2008, and choose the elements of U_3 to minimize this sum of squares subject to the first two constraints above. The idea is that FOMC announcements before the ZLB period did not have major LSAP implications in general and thus the LSAP factor should be small during this period.[16]

---

[11] For example, the FOMC varied the composition of its LSAPs over time, with the "QE1" announcement in March 2009 containing large purchases of mortgage-backed securities and the "QE2" announcement in November 2010 focused only on Treasuries. The results in Table 2 suggest that this variation was not systematic enough to appear as an additional factor in the interest rate futures and Treasuries data underlying Table 2.

[12] However, Bauer and Swanson (2020) present evidence that this "Fed information effect" is small and that the empirical evidence in previous studies can be explained by the Fed responding to publicly available macroeconomic news by more than the private sector expected.

[13] The scale of F and Λ are also indeterminate: if α is any scalar, then αF and Λ/α also fit the data X exactly as well as F and Λ. I follow the standard practice of normalizing each column of F to have unit variance.

[14] An increase in the federal funds rate is typically not a one-off decision, but is usually followed by additional funds rate hikes down the road. Thus, a surprise change in the federal funds rate today has implications for future values of the federal funds rate as well. What distinguishes the forward guidance factor is that it moves market expectations of future values of the federal funds rate *without* any change in the current federal funds rate.

[15] Even in the post-ZLB period, we can define LSAPs to be the component of FOMC announcements that conveys information about asset purchases *above and beyond* changes in the federal funds rate itself.

[16] Note that the pre-2009 LSAP factor will still have nonzero values, even though they are small. This could be due to FOMC announcements having implications for open market operations, or simply because there is some idiosyncratic variation in long-term interest rates after some FOMC announcements during this period, which my estimation attributes to an LSAP factor. Also note that we cannot impose the restriction that the federal funds rate factor—the first column of $\widetilde{F}$—is as small as possible during the ZLB period, because the first two restrictions already identify the federal funds rate factor, so this third restriction would not help to separate forward guidance from LSAPs.

Table 3
Estimated effects of conventional and unconventional monetary policy announcements on interest rates, 1991–2019.

	MP1	MP2	ED2	ED3	ED4	2y Tr.	5y Tr.	10y Tr.
(1) change in federal funds rate	8.37	5.95	5.68	5.36	4.60	3.88	2.26	1.11
(2) change in forward guidance	0.00	1.33	3.85	5.00	5.71	4.61	4.95	3.85
(3) change in LSAPs	0.00	1.07	1.70	1.68	1.34	−0.10	−3.41	−5.36

Coefficients in the table correspond to elements of the structural loading matrix $\tilde{\Lambda}$, in basis points per standard deviation change in the monetary policy instrument. MP1 and MP2 denote scaled changes in the first and third federal funds futures contracts, respectively; ED2, ED3, and ED4 denote changes in the second through fourth Eurodollar futures contracts; and 2y, 5y, and 10y Tr. denote changes in 2-, 5-, and 10-year Treasury yields. See text for details.

Together, these three restrictions uniquely identify U, and hence $\tilde{F}$ (up to a sign normalization for each column).[17] Mathematical details of these restrictions are provided in Appendix A.

3. The FOMC's forward guidance and LSAP announcements

Table 3 reports the loading matrix $\tilde{\Lambda}$ that results from the three identifying assumptions above. Each rotated factor is normalized to have a unit standard deviation, so the coefficients in the table are in units of basis points (bp) per standard deviation change in the monetary policy instrument.[18] A one-standard-deviation increase in the federal funds rate factor is estimated to raise the current federal funds rate by about 8.4bp, the expected federal funds rate at the next FOMC meeting by about 6bp, the second through fourth Eurodollar futures rates by 5.7, 5.4, and 4.6bp, respectively, and the 2-, 5-, and 10-year Treasury yields by about 3.9, 2.3, and 1.1bp, respectively. The effects of a surprise change in the federal funds rate are thus largest at the short end of the yield curve and die off monotonically as the maturity of the interest rate increases, consistent with the estimates in Kuttner (2001) and GSS (2005a).

The effects of forward guidance, in the second row, are quite different. By construction, a shock to the forward guidance factor has *no* effect on the current federal funds rate. At longer maturities, however, the forward guidance factor's effects increase, peaking at a horizon of about one year and diminishing at longer horizons.[19] Again, this is consistent with the estimates in GSS, and also Campbell et al. (2012).

The effects of LSAPs, in the third row, are quite different from the first two. Like forward guidance, a change in the LSAP factor has *no* effect on the current federal funds rate, by construction. Unlike forward guidance and changes in the federal funds rate, the effect of LSAPs is small at short maturities and much larger at the long end of the yield curve. This is consistent with several authors' findings that LSAPs have a substantial impact on longer-term Treasury yields (e.g., Gagnon et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011; Krishnamurthy and Vissing-Jorgensen, 2013; Swanson, 2011). A one-standard deviation increase in the LSAP factor causes 5- and 10-year Treasury yields to fall about 3.4 and 5.4bp, respectively, on average.[20] An increase in LSAPs also causes short-term yields to rise slightly, on average, although this effect is quantitatively small and not statistically signficant, as I show in the next section.

The results in Table 3 are important for several reasons. First, the coefficients in each row are consistent with benchmark estimates in the literature, as discussed above. This provides initial evidence that the identifying assumptions in Section 2 are reasonable and that the identified factors do correspond well to changes in the federal funds rate, forward guidance, and LSAPs.[21]

[17] The orthogonality of U and the columns of $\tilde{F}$ are additional assumptions that help achieve identification. Intuitively, these orthogonality assumptions are just part of the definition of each factor—i.e., changes in the federal funds rate factor typically have implications for future interest rates, but those changes are part of the effects of the federal funds rate itself; the forward guidance factor captures effects on longer-term interest rates that are *above and beyond* the usual effects of changes in the federal funds rate. Similarly, the LSAP factor captures effects on the yield curve that are above and beyond the usual effects of changes in the funds rate and forward guidance, etc.

[18] I normalize the scale of the federal funds rate factor to have a unit standard deviation from July 1991 to December 2008, which corresponds to the period of conventional monetary policy before the ZLB. This scale convention is more intuitive than a full-sample unit standard deviation would be, and also facilitates comparison to previous results in the literature. Similarly, I normalize the LSAP factor to have a unit standard deviation over the period from January 2009 to October 2015, the ZLB period. I normalize the forward guidance factor to have a unit standard deviation over the whole sample.

[19] Note that these estimates represent the average effect of forward guidance over the whole sample. Some FOMC announcements may have had an earlier or later peak effect than the average estimated in row 2, but these differences were not systematic enough to require another factor to fit the data.

[20] As with forward guidance, these estimates represent an average LSAP effect over the whole sample. Some FOMC announcements may have had a slightly different effect than the average estimated in row 3 because of variations in the composition of LSAPs between mortgage-backed securities and Treasuries or other assets, but these differences were not systematic enough to require another factor to fit the interest rate futures and Treasuries data in Table 3.

[21] Thus, for example, I do not need to appeal to an "information effect" or some other feature of FOMC announcements to explain the financial market responses to those announcements. One could still argue that what I call an "LSAP factor" (say) is in fact driven by some other feature of FOMC announcements that happens to affect markets in a similar way; however, the time series plots in Fig. 1 and discussion in Section 3.2, below, provide some evidence against that concern.

Second, Table 3 suggests that both forward guidance and LSAPs were effective, at least in a 30-minute window around FOMC announcements. In fact, both types of policies were about as effective as changes in the federal funds rate, in the sense that the coefficients have similar magnitudes across the three rows (although each policy had a peak effect at a different point along the yield curve). Third, the estimates in Table 3 suggest that the effects of forward guidance and LSAPs are very different from each other, which would imply that LSAPs affected financial markets through more than just a "signaling channel" (e.g., Woodford, 2012; Bauer and Rudebusch, 2014). Recall that, according to the pure signaling view, LSAPs affect financial markets only because they affect the central bank's commitment to follow through with its forward guidance. If that were the case, then the second and third rows of Table 3 should look very similar in terms of their relative effects on yields, which they do not.[22] Fourth, the substantial differences across the three rows in Table 3 raises questions about some authors' use of the 1- or 2-year Treasury yield as a sufficient statistic for monetary policy (e.g., Gertler and Karadi, 2015; Hanson and Stein, 2015). A 10bp change in the 2-year Treasury yield has very different effects on short- and long-term interest rates (and other asset prices, as shown below) if it is caused by a change in the current federal funds rate vs. a change in forward guidance or LSAPs: for example, a 21.6bp change in the federal funds rate has a 10bp effect on the 2-year Treasury yield and 2.9bp effect on the 10-year yield, while a 2.2-standard deviation change in forward guidance has the same effect on the 2-year yield but about triple the effect on the 10-year yield (8.4bp). Estimates by the above authors measure an average effect of these three different types of monetary policies, but the effects of any given change in the 2-year Treasury yield in practice depend on how that change in the 2-year yield is implemented.

3.1. Robustness of the identified factors

The federal funds rate, forward guidance, and LSAP factors identified above are very robust to reasonable variations in the identifying assumptions. For example, Swanson (2017) considers an alternative set of assumptions that splits the sample into pre-ZLB and ZLB periods, uses the GSS (2005a) identifying assumptions in the pre-ZLB period to separately identify changes in the federal funds rate and forward guidance, and then uses the ZLB period to separately identify forward guidance and LSAPs. The estimated factors from that procedure are very similar to those estimated here (correlations of 98%, 95%, and over 99% for the federal funds rate, forward guidance, and LSAPs, respectively).

Alternatively, one can simply define the federal funds rate factor to be the surprise change in the federal funds rate itself, the forward guidance factor to be any additional movements in the 2-year Treasury yield that are orthogonal to the change in the federal funds rate, and the LSAP factor to be any additional movements in the 10-year Treasury yield that are orthogonal to the first two factors.[23] This very simple set of identifying assumptions produces factors that have a correlation of 96%, 96%, and 89%, respectively, with the three factors estimated using the identifying assumptions in Section 2, above.

Intuitively, the three factors are very well identified in the data because their effects on the yield curve are so different from each other, as can be seen in Table 3. If each factor is associated with a different region along the yield curve, then each factor is easy to identify because movements in the yield curve are clearly observed. As a result, reasonable variations in the identifying assumptions have only small effects on the estimated factors.

3.2. Correspondence of factors to notable FOMC announcements

As a further check on my identifying assumptions, I plot the estimated federal funds rate, forward guidance, and LSAP factors over time and compare how they line up with FOMC announcements that had notable implications for LSAPs, forward guidance, or the federal funds rate. Fig. 1 plots the factors in two panels: panel (a) covers the period from 1991–2008, before the zero lower bound, while panel (b) covers 2009–19, the ZLB and post-ZLB periods. The gray line in each panel plots the estimated federal funds rate factor, the dashed blue line the estimated forward guidance factor, and the orange line plots -1 times the estimated LSAP factor (so that negative observations in the figure all correspond to monetary policy easings). In panel (a), the LSAP factor is the least important factor and is plotted as a dotted (orange) line, while in panel (b), the federal funds rate is the least important factor and is plotted as a dotted (gray) line.

Panel (a) of Fig. 1 is similar to Fig. 6 in Gürkaynak et al. (2005a), so the main features of that panel are only briefly summarized here for completeness. The largest changes in the federal funds rate factor occur on the dates of surprise intermeeting funds rate changes by the FOMC: December 20, 1991, October 15, 1998, January 3, 2001, April 18, 2001, and January 22, 2008. The largest changes in the forward guidance factor occur on the dates of major changes in the outlook for future interest rates, such as on January 28, 2004, when the FOMC dropped its commitment to keep interest rates low for a "considerable period" (see Gürkaynak et al., 2005a, for additional discussion). As in GSS (2005a), these episodes suggest that my identifying assumptions are working as intended and are accurately capturing changes in the federal funds rate and forward guidance. Finally, the LSAP factor is generally small and is much less important than the other two factors over this pre-ZLB sample; nevertheless, it is not identically zero because FOMC announcements may have implications for

[22] This observation is also supported by Table 2, which showed that no two factors (such as changes in the federal funds rate and forward guidance) are sufficient to explain financial markets' reactions to FOMC announcements—a third factor is required.

[23] This is essentially the same approach taken in recent papers by Rogers et al. (2018) and Gilchrist et al. (2018), although the latter authors do not distinguish between changes in the federal funds rate and forward guidance.

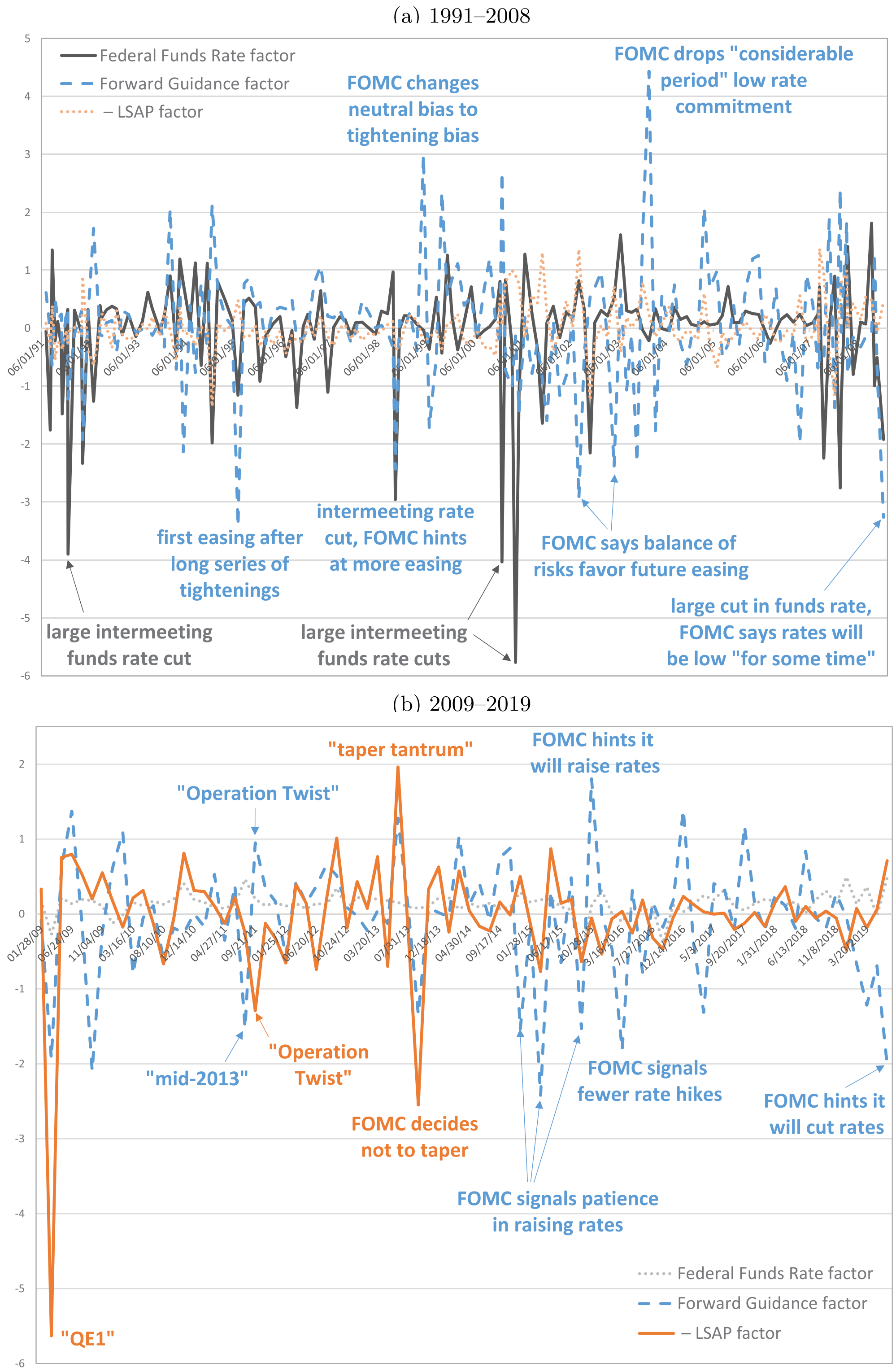

Fig. 1. Estimated federal funds rate, forward guidance, and LSAP factors from 1991 to 2019. The LSAP factor is multiplied by −1 so that positive values in the figure correspond to interest rate increases. The LSAP factor is less important and is plotted as a dotted line in panel (a), while the funds rate factor is less important and is dotted in panel (b). Notable FOMC announcements are labeled for reference. See text for details.

open market operations (which may affect the long end of the yield curve) or because idiosyncratic variation in longer-term yields may sometimes get attributed by my estimation to a change in the LSAP factor.

Turning to panel (b) of Fig. 1, the federal funds rate factor is now the least important and is plotted as a dotted (gray) line. Throughout the 2009–15 ZLB period, the funds rate was close to zero and barely changed, even in response to FOMC announcements; nevertheless, the factor is not identically zero because there are still some minor fluctuations in the funds rate that get attributed by my estimation to a change in the federal funds rate factor. More interestingly, the federal funds rate factor remains very small even after 2015, as the FOMC raised rates gradually and very predictably (similar to the period from 2003–07).[24]

The most striking observation in Fig. 1(b) is the negative 5.6-standard-deviation LSAP announcement on March 18, 2009, which corresponds to the FOMC's first LSAP program, often referred to as "QE1" in the press.[25] The key elements of this program are listed in Table 1, and the announcement seems to have been a major surprise to financial markets, given the huge estimated size of the factor on that date. According to my identification, this announcement is dominated by its LSAP implications, although I also estimate a 1.9-standard-deviation forward guidance easing as well. Given that this FOMC announcement placed such a large emphasis on asset purchases, and implicitly raised the possibility that there could be additional asset purchase programs in the future, these results seem very reasonable.[26]

A second striking feature of Fig. 1(b) is the significant movement in the dashed blue line throughout 2015–19, representing forward guidance surprises. Each of these observations corresponds to significant FOMC communication about the future path of interest rates: for example, the three observations on December 17, 2014, March 18, 2015, and September 17, 2015, correspond to cases where markets expected the FOMC to signal that a hike in the federal funds rate was imminent, but the FOMC instead signaled it would be patient in raising the funds rate.[27] Then, on October 28, 2015, the FOMC stated that it would consider raising the funds rate at its next meeeting in December—an unusually explicit signal that significantly raised markets' expectations of a rate hike at the next meeting.[28] On March 16, 2016, the FOMC reduced its forecast for the number of interest rate hikes in 2016 from 4 down to 2, and at the very end of the sample, on June 19, 2019, the FOMC strongly hinted that it would *cut* the federal funds rate for the first time since the financial crisis if the economic outlook didn't improve. Both of these announcements signaled an easier path for monetary policy going forward.[29] Thus, my identifying assumptions produce very reasonable estimates for all of these announcements, in line with the financial press commentary at the time.

A few other observations in Fig. 1(b) are also notable. The middle of 2013 corresponds to the "taper tantrum" in financial markets: on June 19, 2013, the FOMC released a hawkish growth forecast for the economy, and given earlier remarks by then-Chairman Bernanke that the FOMC could begin tapering its asset purchases soon, markets interpreted this as a signal that a tapering was imminent.[30] The flip side of this announcement occurred on September 18, 2013, when the FOMC was widely expected to begin tapering its asset purchases but opted not to do so, surprising markets in the other direction.[31]

[24] However, in March 2020, which is outside my sample, the FOMC surprised markets with two very large federal funds rate cuts, so the federal funds rate factor can still be an important dimension of monetary policy.

[25] The "QE1" program began on November 25, 2008, when the Federal Reserve Board (rather than the FOMC) announced it would purchase $600 billion of mortgage-backed securities and $100 billion of debt issued by the mortgage-related government-sponsored enterprises. The term "QE1" typically refers to both this earlier program and the huge expansion of that program announced on March 18, 2009. My analysis in this paper excludes the 11/25/08 announcement because it is not an FOMC announcement, but my results are not sensitive to its inclusion.

[26] It's also interesting that the FOMC's subsequent "QE2" program, described in Table 1, does not show up as a major event in Fig. 1, probably because it was anticipated by financial markets (e.g., Forbes, 2010). Looking at Fig. 1 around the November 3, 2010, announcement date of the program, there is essentially no effect because interest rates responded very little to the announcement. Thus, even though the QE2 announcement was roughly one-half as large as the earlier QE1 announcement in terms of the quantity of purchases, the surprise component of that announcement appears to have been dramatically smaller.

[27] On Dec. 17, 2014, markets expected the FOMC to remove its statement that it would keep the federal funds rate at essentially zero "for a considerable time"; not only did the FOMC leave that phrase intact, it announced that "the Committee judges it can be patient in beginning to normalize the stance of monetary policy," which was substantially more dovish than markets had expected (e.g., "U.S. stocks surged...after the Federal Reserve issued an especially dovish policy statement," The Wall Street Journal, 2014). On Mar. 18, 2015, the FOMC revised its projections for U.S. output, inflation, and the federal funds rate substantially below what markets had expected; the revised forecast was read by financial markets "as a sign that the central bank would take its time in raising [rates]" (The Wall Street Journal, 2015a; 2015b). On Sep. 17, 2015, the FOMC declined to raise the federal funds rate, issued a statement that was widely regarded as more dovish than expected, and released interest rate forecasts that were substantially lower than before (The Wall Street Journal, 2015c; 2015d; 2015e).

[28] See The Wall Street Journal (2015f,g). This forward guidance tightening signal was subsequently confirmed when the FOMC raised the funds rate for the first time since the financial crisis on December 16, 2015.

[29] For example, The Wall Street Journal (2019) reported that "'The market now knows the Fed is going to ease unless the data dramatically reverse,'" and "The central bank's rate-setting committee...said uncertainties about the outlook have increased, a phrase it has used during past periods of rate cuts." See also The Wall Street Journal (2016).

[30] For example, The Wall Street Journal (2013a) reported that "Bond prices slumped, sending the yield on the 10-year Treasury note to its highest level in 15 months, as the Federal Reserve upgraded its growth projections for the U.S. economy... Stronger U.S. growth is widely perceived in the market as heralding an earlier end to the Fed's program of purchasing $85 billion in bonds each month..."

[31] For example, The Wall Street Journal (2013b,c) reported that "No Taper Shocks Wall Street;" "The move, coming after Fed officials spent months alerting the public that they might begin to pare their $85 billion-a-month bond-buying program at the September policy meeting, marks the latest in a string of striking turnabouts from Washington policy makers that have whipsawed markets in recent days;" and "'Bernanke had a free pass to begin that tapering process and chose not to follow [through]... The Fed had the market precisely where it needed to be. The delay today has the effect of raising the benchmark to tapering...'"

According to my identification, both of these announcements were dominated by their LSAP implications, which is consistent with the press commentary at the time. Earlier, on August 9, 2011, the FOMC gave explicit, date-based forward guidance for the first time, stating that the current (essentially zero) level of the federal funds rate would be appropriate "at least through mid-2013", almost two years in the future. My identification characterizes this announcement as a substantial, 1.5-standard-deviation forward guidance easing, which also seems very reasonable. Finally, on September 21, 2011, the FOMC announced an "Operation Twist" program, where it would sell $400 billion of short-term Treasuries from its portfolio and buy a like quantity of long-term Treasuries. My identification estimates this announcement caused a 1.3-standard-deviation LSAP easing (which is intuitive) and a 1-standard-deviation forward guidance *tightening*, which is perhaps surprising, but is due to shorter-maturity interest rates rising in response to the announcement (presumably due to a change in risk premia on those securities resulting from the large increase in supply by the Fed). Although this is probably not an example of forward guidance *per se*, it nevertheless looks like forward guidance in the data because of the effects of the announcement on short-term yields. Thus, even though my identification arguably misses some subtleties of this particular announcement, the estimates coming out of the identification are very sensible.

Overall, these episodes suggest that my identifying assumptions are working as intended and are accurately capturing changes in the federal funds rate, forward guidance, and LSAPs.

3.3. Scale of forward guidance and LSAP factors

The three monetary policy factors estimated above are normalized to have unit standard deviations. Similarly, the loadings in Table 3 are for these normalized factors and thus represent a basis points per standard deviation effect. In some cases, however, it's useful to be able to express these effects in terms of units that are more directly observable.

A natural scale for the federal funds rate is a 25bp change in the current federal funds rate target, which is a 2.98-standard-deviation surprise in Table 3. Multiplying the first row of Table 3 by 2.98 provides the estimated effects of such a 25bp surprise.

For forward guidance, a natural scale is a 25bp change in the expected federal funds rate one year ahead, as measured by the 4-quarter-ahead Eurodollar futures contract, ED4. Note that a forward guidance announcement of this size would be very large by historical standards, about 4.4 standard deviations. Multiplying the coefficients in the second row of Table 3 by 4.4 provides the estimated effects of a forward guidance surprise of this magnitude.

Finally, for LSAPs, we would like the units to be in billions of dollars of purchases, which is a more difficult transformation. Nevertheless, a number of estimates in the literature suggest that a $600 billion LSAP operation in the U.S., distributed across medium- and longer-term Treasury securities, leads to a roughly 15bp decline in the 10-year Treasury yield (see, e.g., the survey of estimates in Swanson (2011), and Table 1 of Williams (2013)). Using this estimate as a benchmark implies that the coefficients in the third row of Table 3 correspond to a roughly $215 billion surprise LSAP announcement. In other words, if the FOMC announced a new LSAP program that was about $215 billion larger than markets expected, the effects should be about the same as those reported in the third row of Table 3, on average.

4. The effects of forward guidance and LSAPs on asset prices

Once we've estimated the federal funds rate, forward guidance, and LSAP components of each FOMC announcement, above, it's straightforward to estimate the effects of these policies on a variety of asset prices using high-frequency regressions, as follows.

4.1. Treasury yields

Table 4 reports the responses of 6-month and 2-, 5-, 10-, and 30-year Treasury yields to changes in the federal funds rate, forward guidance, and LSAP factors over four different sample periods: the full sample from July 1991 to June 2019 (panel A); the pre-ZLB sample from July 1991 to December 2008 (panel B); the ZLB sample from January 2009 to October 2015 (panel C); and the post-ZLB sample from December 2015 to June 2019 (panel D). Changes in the federal funds rate are close to zero and have insignificant effects during the ZLB period, so that factor is omitted from the regressions in panel (C), and changes in LSAPs are small and have insignificant effects during the pre-ZLB period, so that factor is omitted from the regressions in panel (B).

Each column of Table 4 reports estimates from an OLS regression of the form

$$\Delta y_t = \alpha + \beta \widetilde{F}_t + \varepsilon_t, \tag{2}$$

where t indexes FOMC announcements, y denotes a particular Treasury yield, Δ the change in a 30-minute window bracketing each FOMC announcement, $\widetilde{F}$ the monetary policy factors estimated above, and ε a regression residual. As in Table 3, the coefficients in Table 4 are in units of basis points per standard deviation surprise in each monetary policy instrument.[32]

[32] Note that the 2-, 5-, and 10-year Treasury yield responses were used to construct the factors; thus, the factor loadings in Table 3 agree exactly with the full-sample responses in panel A of Table 4. In contrast to Table 3, Table 4 reports standard errors and t-statistics, so we can assess statistical significance,

Table 4
Estimated effects of changes in the federal funds rate, forward guidance, and LSAPs on U.S. Treasury yields.

	6-month	2-year	5-year	10-year	30-year
(A) full sample, Jul. 1991–Jun. 2019 (241 observations)					
change in federal funds rate	4.39***	3.88***	2.26***	1.11***	0.04
(std. err.)	(0.211)	(0.224)	(0.155)	(0.195)	(0.217)
[t-stat.]	[20.86]	[17.30]	[14.53]	[5.69]	[0.20]
change in forward guidance	2.23***	4.61***	4.95***	3.85***	2.34***
(std. err.)	(0.546)	(1.14)	(1.30)	(1.09)	(0.704)
[t-stat.]	[4.09]	[4.05]	[3.80]	[3.54]	[3.33]
change in LSAPs	0.67**	−0.10	−3.41***	−5.36***	−4.50***
(std. err.)	(0.270)	(0.269)	(0.782)	(1.17)	(1.04)
[t-stat.]	[2.46]	[−0.38]	[−4.36]	[−4.59]	[−4.31]
Regression R^2	0.81	0.94	0.96	0.97	0.75
(B) pre-ZLB sample, Jul. 1991–Dec. 2008 (157 observations)					
change in federal funds rate	4.39***	3.91***	2.24***	0.97***	−0.11
(std. err.)	(0.213)	(0.228)	(0.252)	(0.214)	(0.210)
[t-stat.]	[20.62]	[17.16]	[8.91]	[4.56]	[−0.50]
change in forward guidance	2.55***	4.59***	4.44***	3.37***	2.25***
(std. err.)	(0.620)	(1.13)	(1.12)	(0.871)	(0.604)
[t-stat.]	[4.11]	[4.06]	[3.95]	[3.87]	[3.73]
Regression R^2	0.82	0.95	0.88	0.81	0.56
(C) ZLB sample, Jan. 2009–Nov. 2015 (55 observations)					
change in forward guidance	1.10***	4.85***	5.95***	3.05***	0.27
(std. err.)	(0.331)	(1.20)	(1.57)	(0.99)	(0.663)
[t-stat.]	[3.34]	[4.02]	[3.79]	[3.08]	[0.40]
change in LSAPs	0.24	0.45	−2.58***	−6.27***	−5.71***
(std. err.)	(0.211)	(0.503)	(0.601)	(1.38)	(1.40)
[t-stat.]	[1.16]	[0.89]	[−4.29]	[−4.54]	[−4.07]
Regression R^2	0.39	0.92	0.95	0.98	0.81
(D) post-ZLB sample, Dec. 2015–Jun. 2019 (29 observations)					
change in federal funds rate	3.27***	4.55***	3.08***	0.44	−1.74*
(std. err.)	(0.487)	(0.564)	(0.366)	(0.373)	(0.932)
[t-stat.]	[6.73]	[8.08]	[8.40]	[1.18]	[−1.87]
change in forward guidance	1.76***	4.91***	5.32***	3.55***	1.37***
(std. err.)	(0.429)	(1.23)	(1.37)	(0.953)	(0.464)
[t-stat.]	[4.11]	[3.99]	[3.88]	[3.73]	[2.95]
change in LSAPs	0.29	−0.96*	−3.99***	−4.72***	−4.10***
(std. err.)	(0.435)	(0.561)	(0.915)	(1.00)	(1.06)
[t-stat.]	[0.68]	[−1.72]	[−4.36]	[−4.70]	[−3.88]
Regression R^2	0.91	0.98	0.99	0.99	0.72

Coefficients β from regressions $\Delta y_t = \alpha + \beta \widetilde{F}_t + \varepsilon_t$, where t indexes FOMC announcements, y denotes a given Treasury yield, $\widetilde{F}$ denotes the monetary policy factors estimated previously, and Δ is the intraday change in a 30-minute window bracketing each FOMC announcement. Coefficients are in units of basis points per standard deviation change in the monetary policy instrument. Bootstrapped standard errors in parentheses and t-statistics in square brackets; ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See text for details.

Standard errors and t-statistics are computed using 10,000 bootstrap simulations to account for the fact that the monetary policy factors $\widetilde{F}$ are generated regressors (see Appendix B for details).

The results in panel (A) summarize the effects of the three monetary policy factors over the entire sample. Before discussing these, I discuss the results for each subsample.

The coefficients in panel (B) are very similar to those estimated previously by Kuttner (2001) for the federal funds rate and GSS (2005a) and Campbell et al. (2012) for the federal funds rate and forward guidance. A one-standard-deviation surprise increase in the federal funds rate (about 8.4bp, recall) causes the 6-month Treasury yield to rise about 4.4bp, with effects on longer-term yields that decrease monotonically with maturity. Meanwhile, a one-standard-deviation increase in forward guidance has a hump-shaped effect on the yield curve, with a peak at the two- to five-year maturity. These effects are generally highly statistically significant, with t-statistics ranging from 3.5 up to 20. There is essentially no question that Treasury yields respond systematically to FOMC announcements over this period.

Panel (C) reports results for the ZLB sample. The effects of forward guidance are similar to the pre-ZLB period, although the effects on the 6-month and 30-year yields are smaller. The attenuated effect on the 6-month yield is not surprising, however, once we recognize that it was very close to zero throughout this sample and thus did not respond much to

and Table 4 reports responses for the pre-ZLB, ZLB, and post-ZLB periods (panels B, C, and D), so we can see how those responses have changed across regimes. Finally, Table 4 reports responses for the 6-month and 30-year yields, which were not included in the factor estimation. Econometrically, there's nothing spurious in regressing Treasury yields on factors estimated using Treasury yields—for example, dynamic affine term structure models follow this approach. Also note that in Table 4, the 2-year Treasury yield does not respond significantly to the LSAP factor, so just because that yield was used to help estimate the factors doesn't mean it necessarily responds significantly to them.

incoming news (e.g., Swanson and Williams, 2014).[33] Turning to LSAPs, the effects of an increase on short-term Treasury yields are positive but small and statistically insignificant, while the effects on longer-term Treasury yields are negative, large, and highly statistically significant, with t-statistics in excess of 4.5. One reason for the positive estimated responses of 6-month and 2-year yields to LSAPs is that the Fed may have reduced its demand or even sold off short-term Treasuries in order to buy longer maturities, as in its "Operation Twist" policy of 2011–12.

Panel (D) reports results for the post-ZLB sample, December 2015 to June 2019. The coefficients here are generally very similar to those in panels (B) and (C), suggesting that forward guidance and LSAPs have continued to work in much the same way even after the federal funds rate rose back above zero.[34] The effects of LSAPs on the 2-year Treasury yield are negative and marginally significant over this more recent sample, though.

Returning to the full sample estimates in panel (A), the coefficients are very similar to panels (B), (C), and (D), with similarly high degrees of statistical significance. Overall, the results in Table 4 imply that both forward guidance and LSAPs are effective policies for changing interest rates, at least in a 30-minute window around FOMC announcements. In fact (and as noted in Table 3), they are about as effective as changes in the federal funds rate in normal times, in the sense that the coefficients in Table 4 have broadly similar magnitudes, although the peak effects occur at different points along the yield curve.

4.2. Stock prices and exchange rates

Table 5 reports analogous results for the S&P 500 stock index and dollar-euro and dollar-yen exchange rates. The form of the regressions is the same as Eq. (2), except the dependent variable in each regression is now 100 times the change in the log asset price in each column. As before, panel (A) summarizes the effects of the three monetary policy factors over the entire sample. Before discussing these, I discuss the results for each subsample.

Panel (B) reports estimates for the pre-ZLB period. A one-standard-deviation increase in the federal funds rate (about 8.4bp) causes stock prices to fall about 0.4% and the dollar to appreciate about 0.1 to 0.15%, and these estimates are highly statistically significant. A one-standard-deviation tightening of forward guidance causes stocks to fall a bit less, about 0.1%, but the dollar to appreciate by about the same amount, and these effects are also statistically significant. The R^2 for these regressions are much lower than for the Treasury yields in Table 4 due to the larger idiosyncratic volatility of stocks and exchange rates relative to Treasuries. The estimated effect of the federal funds rate on stocks is very similar to the estimates in Bernanke and Kuttner (2005) and GSS (2005a), and the estimated effect of forward guidance on stocks is very similar to GSS (2005a) and D'Amico and Farka (2011), again corroborating the identifying assumptions in Section 2.[35] For the dollar, the effects have the signs one would expect: an increase in U.S. interest rates makes U.S. dollar investments more attractive and drives the value of the dollar higher.

Panel (C) reports estimates for the ZLB period. The effects of forward guidance were larger over this period, causing stock prices to fall about 0.25% and the dollar to appreciate 0.25–0.35%, and these effects are highly statistically significant. A one-standard-deviation increase in LSAPs (which causes interest rates to fall) raises stock prices about 0.1% and depreciates the dollar 0.2–0.3%, although the effect on stocks is not significant.[36] Again, these effects have the signs one would expect: stock prices rise when the Fed lowers interest rates, and the dollar depreciates.

Panel (D) reports results for the post-ZLB period. The effects of each monetary policy instrument are very similar to the earlier samples, although in a few cases they are not statistically significant, probably due to the short sample. Thus, forward guidance and LSAPs seem to affect financial markets in similar ways even when the federal funds rate is greater than zero.

Looking back at the full sample estimates in panel (A), the effects are similar to the subsamples (B), (C), and (D), suggesting that these policies have had consistent effects over time. Again, both forward guidance and LSAPs seem to be effective policies, about as effective as changes in the federal funds rate in normal times, with the exception that LSAPs seem to have a small and insignificant effect on stocks, while changes in the funds rate have a particularly large effect on stocks. Overall, the results again suggest that unconventional monetary policy is an effective substitute for conventional monetary policy.

4.3. Corporate bond yields and spreads

Table 6 reports the corresponding results for corporate bond yields and spreads. Corporate bonds are less frequently traded than Treasuries, stocks, and foreign exchange, so the regressions in Table 6 use the one-day change in corporate bond yields and spreads around each FOMC announcement as the dependent variable, rather than the 30-minute change.

[33] The peak effect of forward guidance is also a little bit larger and later than in the pre-ZLB period, on average, consistent with the view that the FOMC's forward guidance extended out a little bit further during this period.

[34] One difference from the earlier samples is that a federal funds rate tightening now has a statistically significant *negative* effect on the 30-year Treasury yield. This is consistent with the findings in Gürkaynak et al. (2005b) for the response of far-ahead forward interest rates to federal funds rate surprises.

[35] The estimated effect of forward guidance on stock prices in GSS (2005a) was not statistically significant over their shorter sample, but the coefficient was very similar to my estimate here. D'Amico and Farka (2011) used the same methods as GSS over a longer sample, through Sep. 2006, and found the effect was statistically significant.

[36] Interestingly, the regression R^2 for the exchange rate are much higher during the ZLB and post-ZLB periods than before.

Table 5
Estimated effects of changes in the federal funds rate, forward guidance, and LSAPs on stock prices and exchange rates.

	S&P500	$/euro	$/yen
(A) full sample, Jul. 1991–Jun. 2019 (241 observations)			
change in federal funds rate	−0.37***	−0.12***	−0.15***
(std. err.)	(0.042)	(0.038)	(0.039)
[t-stat.]	[−9.00]	[−3.22]	[−3.74]
change in forward guidance	−0.14***	−0.21***	−0.18***
(std. err.)	(0.049)	(0.063)	(0.058)
[t-stat.]	[−2.83]	[−3.40]	[−3.16]
change in LSAPs	0.03	0.16**	0.23***
(std. err.)	(0.059)	(0.054)	(0.068)
[t-stat.]	[0.48]	[2.90]	[3.41]
Regression R^2	0.31	0.26	0.29
(B) pre-ZLB sample, Jul. 1991–Dec. 2008 (157 observations)			
change in federal funds rate	−0.39***	−0.11***	−0.14***
(std. err.)	(0.042)	(0.038)	(0.039)
[t-stat.]	[−9.29]	[−2.95]	[−3.58]
change in forward guidance	−0.09**	−0.15***	−0.13***
(std. err.)	(0.044)	(0.052)	(0.047)
[t-stat.]	[−2.13]	[−2.92]	[−2.68]
Regression R^2	0.37	0.15	0.14
(C) ZLB sample, Jan. 2009–Nov. 2015 (55 observations)			
change in forward guidance	−0.25**	−0.36***	−0.24***
(std. err.)	(0.101)	(0.103)	(0.075)
[t-stat.]	[−2.50]	[−3.45]	[−3.18]
change in LSAPs	0.10	0.19***	0.28***
(std. err.)	(0.080)	(0.065)	(0.071)
[t-stat.]	[1.27]	[2.96]	[3.87]
Regression R^2	0.28	0.68	0.79
(D) post-ZLB sample, Dec. 2015–Jun. 2019 (29 observations)			
change in federal funds rate	−0.37	−0.46**	−0.33**
(std. err.)	(0.261)	(0.197)	(0.154)
[t-stat.]	[−1.41]	[−2.35]	[−2.12]
change in forward guidance	−0.15**	−0.39***	−0.40***
(std. err.)	(0.071)	(0.107)	(0.109)
[t-stat.]	[−2.13]	[−3.61]	[−3.67]
change in LSAPs	−0.19	0.08	0.34***
(std. err.)	(0.185)	(0.138)	(0.124)
[t-stat.]	[−1.04]	[0.56]	[2.78]
Regression R^2	0.25	0.72	0.82

Coefficients β from regressions $\Delta \log x_t = \alpha + \beta \widetilde{F}_t + \varepsilon_t$, where t indexes FOMC announcements, x is the asset price, $\widetilde{F}$ denotes the monetary policy factors estimated previously, and Δ is the intraday change in a 30-minute window bracketing each FOMC announcement. Coefficients are in units of percentage points per standard deviation change in the monetary policy instrument. Bootstrapped standard errors in parentheses and t-statistics in square brackets; ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See text for details.

To measure corporate yields, I use the Aaa and Baa indexes of long-term seasoned corporate bond yields from Moody's. As before, panel (A) summarizes the effects of the three monetary policy factors over the entire sample, but I first discuss the results for each subsample.

Panel (B) reports results for the pre-ZLB period. The federal funds rate has no significant effect on either corporate bond yields or spreads, which is not extremely surprising given that the bonds in the Moody's indexes have maturities of 20 years or more. In contrast, forward guidance has positive and highly significant effects on corporate bond yields. However, the effects of forward guidance on corporate bond yields are not as large as for the 10-year Treasury, so the effect on corporate bond spreads is slightly *negative*, and highly statistically significant.[37]

Panel (C) reports the estimates for the ZLB period. Surprisingly (compared to panel B), forward guidance had smaller and less significant effect on corporate bond yields during this period, although the effect on corporate spreads is larger and remains generally significant because 10-year Treasury yields responded to those announcements. The effect of LSAPs on corporate bond yields and spreads was large and highly statistically significant during this period, about a −5bp change in

[37] Note that, even though a forward guidance easing causes corporate bond spreads to rise, this does not mean the policy is contractionary for the corporate sector. In fact, corporate bond yields fall significantly in response to easier forward guidance, so corporate financing costs are lower. The increase in spreads is just due to the technical fact that the 10-year Treasury yield falls by more than the long-term corporate bond yield. Also note that the effect of forward guidance on the 10-year Treasury in Table 4 is about 3.1bp per standard deviation over this sample, while the effect implied in Table 6 is a bit smaller, about 2.2bp. There are two reasons for this difference: first, the responses in Table 4 are 30-minute responses, while those in Table 6 are one-day responses, and second, Table 4 uses the on-the-run coupon-bearing 10-year Treasury note, while Table 6 uses the 10-year constant-maturity zero-coupon yield estimated by Gürkaynak et al. (2007b).

Table 6
Estimated effects of changes in the federal funds rate, forward guidance, and LSAPs on corporate bond yields and spreads.

	Corporate Yields		Spreads	
	Aaa	Baa	Aaa - 10-yr.	Baa - 10-yr.
(A) full sample, Jul. 1991–Jun. 2019 (241 observations)				
change in federal funds rate	0.49	0.49	−0.21	−0.21
(std. err.)	(0.344)	(0.345)	(0.309)	(0.260)
[t-stat.]	[1.42]	[1.42]	[−0.68]	[−0.81]
change in forward guidance	2.16***	2.05***	−1.27***	−1.38***
(std. err.)	(0.679)	(0.662)	(0.451)	(0.449)
[t-stat.]	[3.19]	[3.10]	[−2.82]	[−3.08]
change in LSAPs	−3.56***	−3.82***	2.59***	2.33***
(std. err.)	(0.918)	(1.00)	(0.693)	(0.613)
[t-stat.]	[−3.88]	[−3.86]	[3.73]	[3.80]
Regression R^2	0.32	0.34	0.22	0.27
(B) pre-ZLB sample, Jul. 1991–Dec. 2008 (157 observations)				
change in federal funds rate	0.34	0.38	−0.25	−0.21
(std. err.)	(0.357)	(0.347)	(0.285)	(0.241)
[t-stat.]	[0.94]	[1.10]	[−0.89]	[−0.87]
change in forward guidance	2.21***	2.10***	−0.71**	−0.82***
(std. err.)	(0.646)	(0.619)	(0.322)	(0.306)
[t-stat.]	[3.41]	[3.39]	[−2.20]	[−2.68]
Regression R^2	0.24	0.24	0.05	0.09
(C) ZLB sample, Jan. 2009–Nov. 2015 (55 observations)				
change in forward guidance	0.52	−0.39	−1.65*	−2.57***
(std. err.)	(1.01)	(0.975)	(0.891)	(0.971)
[t-stat.]	[0.51]	[−0.40]	[−1.86]	[−2.64]
change in LSAPs	−4.47***	−5.26***	3.43***	2.65***
(std. err.)	(1.20)	(1.34)	(0.937)	(0.791)
[t-stat.]	[−3.73]	[−3.92]	[3.66]	[3.35]
Regression R^2	0.45	0.50	0.54	0.55
(D) post-ZLB sample, Dec. 2015–Jun. 2019 (29 observations)				
change in federal funds rate	−6.33*	−4.53	−1.99	−0.19
(std. err.)	(3.44)	(3.22)	(2.62)	(2.17)
[t-stat.]	[−1.84]	[−1.41]	[−0.76]	[−0.09]
change in forward guidance	−0.11	0.62	−2.58***	−1.85***
(std. err.)	(0.829)	(0.806)	(0.898)	(0.712)
[t-stat.]	[−0.13]	[0.77]	[−2.87]	[−2.60]
change in LSAPs	−3.29	−2.91	2.30	2.68*
(std. err.)	(2.56)	(2.34)	(1.92)	(1.62)
[t-stat.]	[−1.29]	[−1.24]	[1.20]	[1.65]
Regression R^2	0.15	0.50	0.38	0.33

Coefficients β from regressions $\Delta y_t = \alpha + \beta \widetilde{F}_t + \varepsilon_t$, where t indexes FOMC announcements, y denotes the corporate bond yield or spread, $\widetilde{F}$ denotes the monetary policy factors estimated previously, and Δ is the change in a one-day window bracketing each FOMC announcement. Coefficients are in units of basis points per standard deviation change in the monetary policy instrument. Bootstrapped standard errors in parentheses and t-statistics in square brackets; ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See text for details.

yields per standard deviation increase. This estimate is somewhat larger than in Krishnamurthy and Vissing-Jorgensen (2011, 2013, henceforth KVJ)) and Swanson (2011), who estimate a decline in corporate yields of about 4–5bp per $600 billion LSAP announcement, while the estimates in Table 6 are about 14bp for the same size operation (using the scaling discussed in Section 3.3, above).[38] One reason for the larger effects here is probably that the Fed's LSAPs during this period often included a substantial amount of mortgage-backed securities (MBS), while the smaller, 4–5bp estimates in KVJ and Swanson (2011) are for the case of a Treasury-only LSAP; since MBS are closer substitutes for corporate bonds than Treasuries, MBS purchases could have a larger effect on corporate yields. As with forward guidance, the effect of LSAPs on corporate bond spreads has the opposite sign, because the 10-year Treasury yield responded to LSAPs by more than corporate yields did.[39] This result also echoes KVJ and Swanson (2011), who found that the Fed's LSAP announcements pushed Treasury yields down more than private-sector yields, probably because the Fed concentrated many of its purchases on longer-term Treasuries in particular. Note that, even though an increase in LSAPs caused corporate bond spreads to rise, this does not mean the policy was contractionary for the corporate sector; in fact, corporate bond yields fell significantly in response to LSAPs, so corporate financing costs are clearly lower in response to the policy, which is stimulative for the economy.

[38] Krishnamurthy and Vissing-Jorgensen (2011, 2013) and Swanson (2011) estimate that LSAPs decrease 10-year Tresury yields by about 15bp per $600 billion, but the effect on corporate bond yields is smaller, only 4–5bp.

[39] The 10-year yield response in Table 4 is estimated to be about −6.3bp, while the effect implied in Table 6 is somewhat larger, about −7.9bp, driven by the same two reasons as in footnote 37.

Panel (D) reports results for the post-ZLB sample. The effects of the federal funds rate are not precisely measured during this period, while the effects of forward guidance and LSAPs are similar to the ZLB period in panel (C). This is consistent with the view that forward guidance and LSAPs have continued to affect corporate bond markets in much the same way after the federal funds rate rose above zero.

Finally, returning to the full-sample estimates in panel (A), the effects of changes in the federal funds rate and LSAPs are consistent across subsamples. The federal funds rate has no significant effect on long-term corporate bond yields or spreads, while LSAPs have large and highly significant effects. The effects of forward guidance on corporate bond yields are positive and statistically significant overall, but differ across the pre-ZLB vs. post-2008 samples. Forward guidance was much more effective at moving corporate bond yields before the financial crisis, and has not been significant since, although the effect on corporate bond spreads has been consistent. Over the sample as a whole, LSAPs were generally the most effective movers of corporate bond yields and spreads.

5. The persistence of forward guidance and LSAP effects

The regressions above measure the 30-minute or one-day responses of yields and asset prices to FOMC announcements. If yields and asset prices are martingales, then these very short-term responses are representative of the responses over longer windows as well. However, some recent studies suggest the effects of unconventional monetary policy may not be persistent: for example, Duffie (2010) cites several examples where large movements of capital (e.g., due to stocks entering or leaving the S&P500, or auctions of new Treasury securities) can have transitory effects on asset prices that dissipate over a period of time, up to several months in length. The idea is that arbitrage capital can be "slow-moving" and is not reallocated instantaneously to take advantage of asset price distortions caused by idiosyncratic changes in demand or supply for a given asset. Fleckenstein et al. (2014) find support for this theory in the pricing of TIPS securities during the 2007–9 global financial crisis.

Taylor (2012) and Woodford (2012) argue against the effectiveness of the Fed's LSAPs for essentially the same reasons: although the Fed's announcement of an LSAP causes short-term changes in asset prices around the announcement, the argument goes, these changes will disappear eventually as arbitrageurs react and adjust their positions, but this process takes time because the Fed's expected asset purchases are so large. The empirical evidence in Wright (2012) supports this view: using a daily-frequency VAR, Wright (2012) estimates that the effects of FOMC unconventional monetary policy announcements on U.S. long-term bond yields had a half-life of only about 2–3 months.

5.1. Unconstrained h*-day yield changes*

To examine the persistence of the effects of the FOMC's monetary policy announcements, I run a series of regressions at multiple horizons, indexed by h, of the form

$$y_{t-1+h} = \alpha_h + \beta_h y_{t-1} + \gamma_h \widetilde{F}_t + \varepsilon_t^{(h)}, \tag{3}$$

where t takes on the dates of FOMC announcements, $t-1$ denotes the business day before an FOMC announcement, y_τ denotes a given bond yield or log asset price at the close of day τ, $\widetilde{F}_t$ denotes the three monetary policy factors on FOMC date t estimated previously, and each forecast horizon h is measured in business days and is associated with its own regression.[40] Thus, α_h and β_h are scalars and γ_h is a vector of parameters that may vary across regressions h, and $\varepsilon_t^{(h)}$ is the residual for the FOMC announcement on date t in regression h. This is essentially the (Jordà, 2005) local projections method of estimating impulse response functions, without any additional lags on the right-hand side (since additional lags aren't significant). As discussed by Jordà (2005), the direct projections in (3) have several advantages over extrapolating the results of a daily-frequency VAR(1) as in Wright (2012): in particular, extrapolation compounds any errors in the parameter estimates as the horizon h increases, while the local projections method avoids extrapolation and compounding and is thus more robust to model misspecification.

I estimate that the coefficients α_h and β_h are essentially always close to zero and one, respectively, so I impose those restrictions in the analysis below. Then (3) is just a regression of the h-day change, $y_{t-1+h} - y_{t-1}$, on the factors $\widetilde{F}_t$, for each FOMC announcement date t. The estimated coefficients $\hat{\gamma}_h$ vary across forecast horizons h, so we can plot those coefficients as a function of the horizon h to see whether they tend to diminish as h increases. Of course, for longer horizons h, there will also be a greater amount of non-monetary-policy news that impacts yields and asset prices, so the residuals $\varepsilon_t^{(h)}$ and standard errors surrounding the coefficient estimates $\hat{\gamma}_h$ will tend to be larger.

Fig. 2 plots the results of these regressions for the effects of the federal funds rate on the 6-month Treasury yield (left-hand panel) and the effects of forward guidance on the 5-year Treasury yield (right-hand panel); results for LSAPs are reported in a separate figure, below. The solid blue line in each panel plots the point estimates of $\hat{\gamma}_h$ as a function of horizon h, and the dashed red lines plot bootstrapped ± 1.96-standard-error bands around those point estimates using 10,000 bootstrap simulations (see Appendix B for details).[41]

[40] Thus, for each horizon h, regression (3) has one observation per FOMC announcement.

[41] The sample period for these regressions is May 1999 to June 2019. Results for the federal funds rate and LSAPs are essentially identical for the full sample, July 1991 to June 2019, but the results for forward guidance show a greater tendency to die out over the full sample. Since the FOMC did not

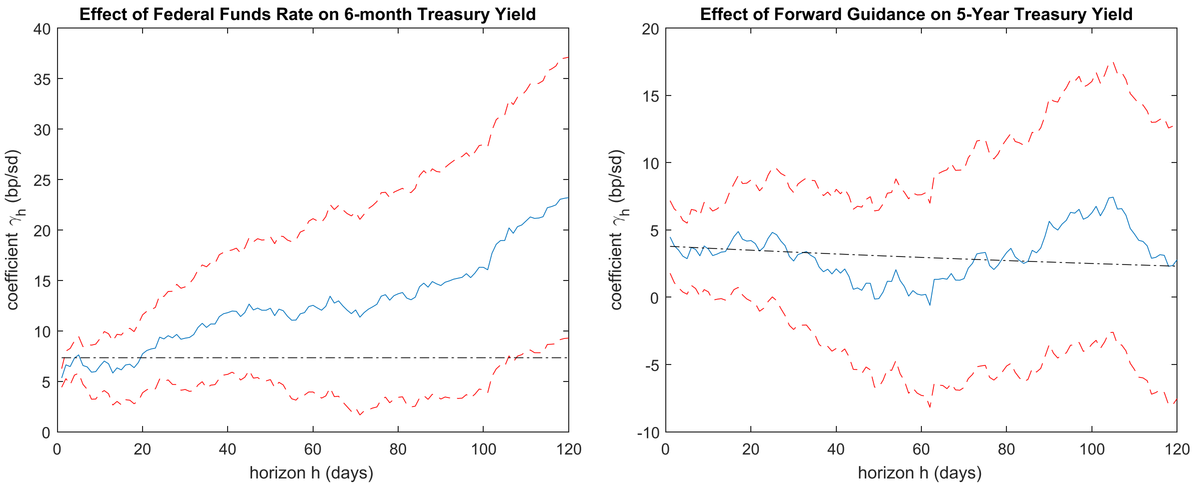

Fig. 2. Estimated effects of federal funds rate and forward guidance on 6-month and 5-year Treasury yields, respectively, for different horizons h ranging from 1 to 120 business days. Estimated coefficients $\hat{\gamma}_h$ (solid blue line) and bootstrapped $\pm$1.96-standard-error bands (dashed red lines) are from regressions $y_{t-1+h} - y_{t-1} = \gamma_h \tilde{F}_t + \varepsilon_t^{(h)}$. Restricted coefficient estimates $\gamma_h = ae^{-b(h-1)}$ (dash-dotted black lines) are from the same set of regressions estimated jointly via nonlinear least squares. See text for details. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The estimated effect of a one-standard-deviation increase in the federal funds rate on the 6-month Treasury yield (left-hand panel) is about 5bp on the first day and is highly statistically significant. The effect is a little larger, about 7bp, out to a horizon of about 20 business days before drifting even higher to 20–25bp at a horizon of 120 business days. These point estimates are all statistically greater than zero, although the standard errors of the estimates increase with the horizon h.

The effect of forward guidance on the 5-year Treasury yield (right-hand panel of Fig. 2) is a bit less than 5bp on the first day, and is statistically significant. The effect is a bit smaller, 3–4bp, over the next 15 days and generally remains significant. After about 20 days, the estimated effect varies between 0 and 7bp and is no longer significantly different from zero.

To determine whether this attenuation is statistically significant, and get a more precise estimate of the rate of attenuation (if any) in these figures, I re-estimate regressions (3) imposing that the coefficients γ_h have an exponentially decaying functional form,

$$\gamma_h = ae^{-b(h-1)}, \tag{4}$$

where a and b are parameters denoting the impact effect on the first day and the exponential decay rate, respectively.[42] I stack the regressions (3) into a single system, impose the restriction (4) on the coefficients γ_h, and estimate the parameters a and b in a single step via weighted nonlinear least squares with two restrictions: that $b > 0$ and that a must lie within the range of unrestricted responses γ_h over the first four business days.[43] The dash-dotted black lines in Fig. 2 depict the results of this restricted specification, and coefficient estimates and bootstrapped standard errors are reported in Table 7.

I estimate that the effects of the federal funds rate on the 6-month Treasury yield (left-hand panel of Fig. 2) are completely persistent, with no tendency to die out over time. The effect of the federal funds rate on other yields (first two columns of Table 7) is also estimated to be completely persistent ($b = 0$), with the exception of the 10-year Treasury yield. For the 10-year Treasury, the impact effect of 0.9bp is not statistically significant, and the decay rate b of 0.007 implies a half-life of about 100 business days (4.5 months), although this decay rate is not significant.

The effect of forward guidance on the 5-year Treasury yield (right-hand panel of Fig. 2) is estimated to diminish over time, with a half-life of about 140 business days (6.5 months), according to the estimated decay rate of 0.004 in Table 7. This decay rate is not statistically significant, however, due to the fairly large standard errors surrounding it. The effect of

conduct explicit forward guidance until May 1999, I begin the estimation then. Before May 1999, my estimated forward guidance factor picks up a few monetary policy turning points, where the Fed switched from tightening to easing or vice versa, which had a large effect on the expected future path of interest rates above and beyond the usual effect of changes in the funds rate and are thus identified by the GSS (2005a) methodology as forward guidance (see GSS, 2005a, for additional discussion).

[42] The idea is similar to Barnichon and Brownlees (2019) “smooth local projections”: unrestricted local projections can lead to excess variability of the estimates, but this variability can be reduced by imposing prior information on the impulse responses, in this case smoothness and an exponentially decaying functional form.

[43] These restrictions prevent the estimation from picking values of a and b that are implausible *a priori*. The observations for each horizon h are weighted by σ_h^{-1}, where σ_h denotes the estimated variance of the residuals for the unrestricted horizon h regression (3).

Table 7
Estimated impact and decay rate coefficients.

	Federal Funds Rate		Forward Guidance		LSAPs	
	a	b	a	b	a	b
6-month Treasury yield	7.20***	0.000	1.25*	0.000	1.80**	0.000
(std. err.)	(1.12)	(0.002)	(0.71)	(0.180)	(0.90)	(0.003)
[t-stat.]	[6.41]	[0.00]	[1.75]	[0.00]	[2.00]	[0.00]
2-year Treasury yield	4.75***	0.000	2.85**	0.000	−1.91*	0.053
(std. err.)	(1.14)	(0.023)	(1.31)	(0.145)	(1.05)	(0.142)
[t-stat.]	[4.19]	[0.00]	[2.18]	[0.00]	[−1.81]	[0.37]
5-year Treasury yield	2.18**	0.000	3.79***	0.004	−5.61***	0.032
(std. err.)	(1.09)	(0.074)	(1.18)	(0.056)	(1.50)	(0.030)
[t-stat.]	[2.01]	[0.00]	[3.21]	[0.07]	[−3.76]	[1.04]
10-year Treasury yield	0.91	0.007	3.56**	0.015	−6.66***	0.030
(std. err.)	(1.08)	(0.045)	(1.48)	(0.026)	(1.82)	(0.027)
[t-stat.]	[0.84]	[0.16]	[2.40]	[0.57]	[−3.66]	[1.12]

Coefficients a and b for restriction $\gamma_h = ae^{-b(h-1)}$ in regressions (3), estimated jointly via nonlinear least squares. Bootstrapped standard errors in parentheses and t-statistics in square brackets; ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See text for details.

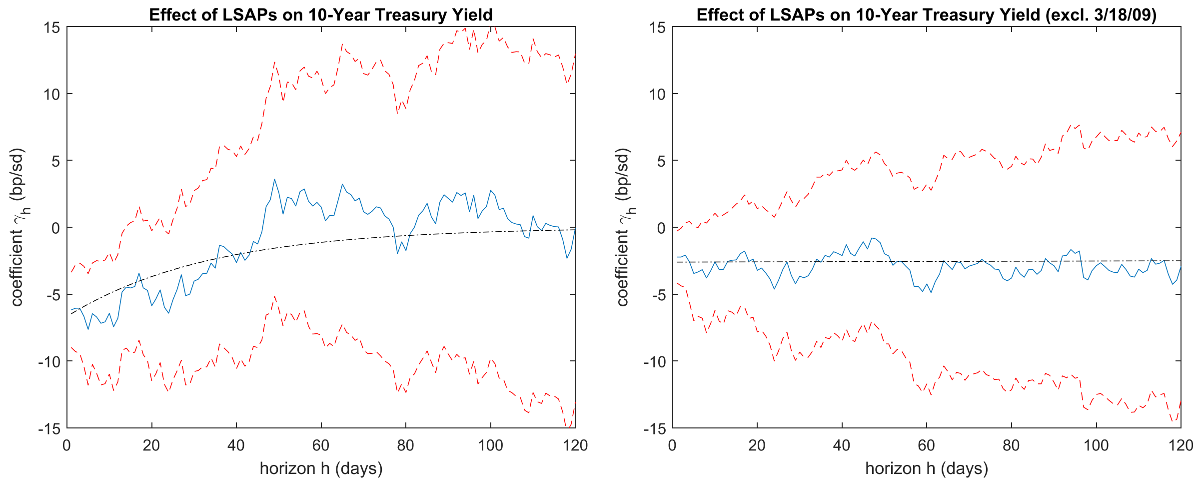

Fig. 3. Estimated effects of LSAPs on 10-year Treasury yield, for different horizons h ranging from 1 to 120 business days. The right-hand panel excludes the very influential "QE1" LSAP announcement on March 18, 2009. Estimated coefficients $\hat{\gamma}_h$ (solid blue line) and bootstrapped ±1.96-standard-error bands (dashed red lines) are from regressions $y_{t-1+h} - y_{t-1} = \gamma_h \widetilde{F}_t + \varepsilon_t^{(h)}$. Restricted coefficient estimates $\gamma_h = ae^{-b(h-1)}$ (dash-dotted black lines) are from the same set of regressions estimated jointly via nonlinear least squares. See text for details. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

forward guidance on other yields (middle two columns of Table 7) is estimated to be completely persistent for the 6-month and 2-year maturities, and to die out more rapidly at the 10-year maturity, but again, this decay rate is not significant.[44]

Results for LSAPs are reported in the last two columns of Table 7, and the effects on the 10-year Treasury yield are plotted in Fig. 3. A one-standard-deviation increase in LSAPs causes the 10-year Treasury yield to fall about 6.5bp on the first day, and this effect is highly statistically significant. The impact effect persists for the next 10–15 business days and remains highly statistically significant (left-hand panel of Fig. 3). However, after about 15 days, the effect on the 10-year yield begins to die off and approach zero. The estimated decay rate in Table 7 is substantial, 0.030, implying a half-life of just 24 business days, but this attenuation is still not significant due to the large standard errors surrounding the estimate.

Despite the large standard errors, it's worth noting that the attenuation in the left-hand panel of Fig. 3 is very sensitive to whether or not the influential March 18, 2009, FOMC announcement is included in the analysis. (Recall that announcement was 5.6 standard deviations, corresponded to over $1.1 trillion of new long-term bond purchases and implicitly raised the possibility that there could be additional such operations in the future.) The right-hand panel of Fig. 3 repeats the analysis in the left-hand panel, albeit with that one influential observation excluded. In this case, the impact effect of LSAPs is smaller (2.6bp instead of 6.7bp), but is still statistically significant, while those effects are now estimated to be completely

[44] However, one might expect the effects of forward guidance to die out over time with a half-life of several months, since the FOMC's forward guidance had a typical horizon of a few months to two years.

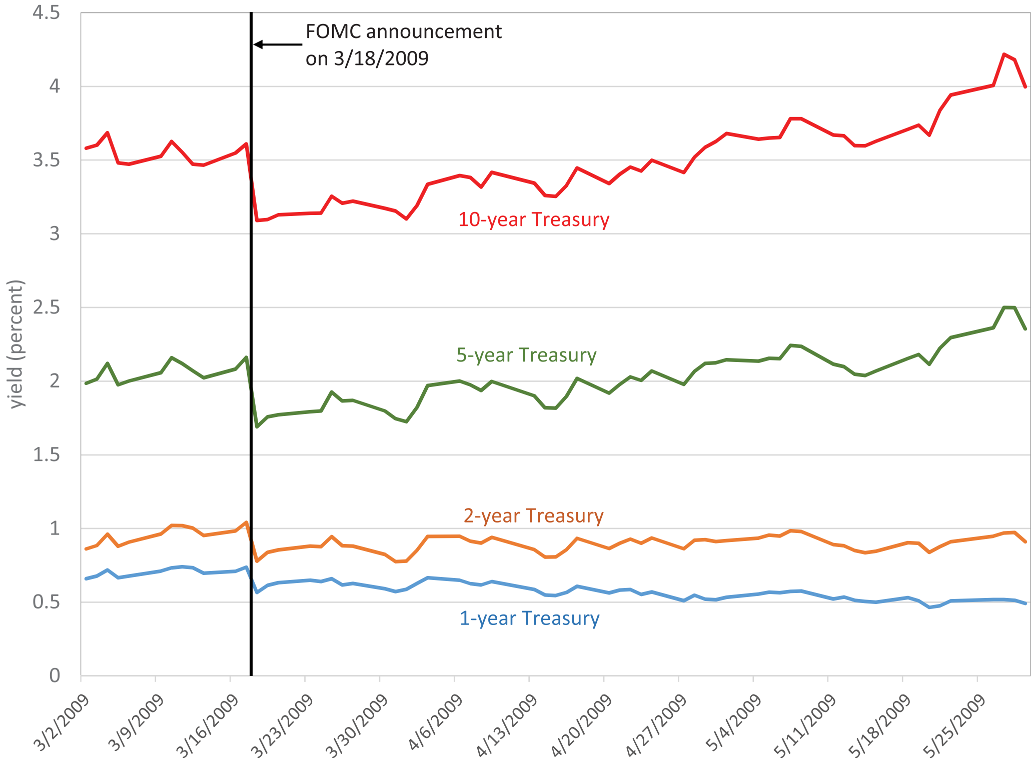

Fig. 4. 1-, 2-, 5-, and 10-year zero-coupon Treasury yields from March to May 31, 2009. See text for details.

persistent, with no tendency to die out over time. Results for the 2- and 5-year Treasury yields are similar. Thus, aside from the Fed's major "QE1" announcement, the effects of LSAPs seem to be completely persistent.

For reference, Fig. 4 reports the behavior of Treasury yields around that March 18, 2009, FOMC announcement. Yields of all maturities fell dramatically on that day, but then began to rise over subsequent weeks, erasing the entire decline in long-term yields by about the 30th business day following the announcement. However, this was also a very special period for U.S. financial markets: the U.S. stock market hit bottom in March 2009 and gradually rose about 30% over the brief period in Fig. 4. Moreover, the Fed's bank stress tests were released on May 7, 2009, and turned out better than markets expected, leading to increases in stock prices and bond yields. Thus, the markets' behavior during this period may not be representative of the longer-run effects of LSAPs more generally.

Thus, in contrast to Wright (2012), I find relatively little evidence that the effects of the Fed's unconventional monetary policy announcements died out over time. Although some of the point estimates for forward guidance and LSAPs in Table 7 do suggest some attenuation, those estimates are not statistically significant. Moreover, for LSAPs, there is no evidence of attenuation once the very influential March 2009 FOMC announcement is dropped from the analysis.

6. Conclusions

I extend the methods of Gürkaynak et al. (2005a) to separately identify the federal funds rate, forward guidance, and large-scale asset purchase component of every FOMC announcement from July 1991 to June 2019, including the forward guidance and LSAP components of FOMC announcements during the U.S. zero lower bound period from 2009 to 2015. I show that this identification is robust to variations in the identifying assumptions and that my estimated factors agree with notable features of major FOMC announcements.

I estimate the effects of changes in the federal funds rate, forward guidance, and LSAPs on a variety of assets, including Treasury bonds, corporate bonds, stock prices, and foreign exchange. Both forward guidance and LSAPs had substantial and highly statistically significant effects on these assets, with magnitudes comparable to the effects of changes in the federal funds rate before the zero lower bound (as measured by the effects per standard deviation change in each policy). Thus, I find that both of these unconventional monetary policies were effective, about as effective as conventional monetary policy in normal times.

Forward guidance was more effective than LSAPs at moving shorter-term Treasury yields and stock prices, while LSAPs were more effective than forward guidance and the federal funds rate at moving longer-term Treasury and corporate bond yields. To the extent that monetary policy affects the real economy through changes in private-sector interest rates like corporate bond yields, this suggests that LSAPs are more effective than forward guidance at stimulating the real economy.

I find little or no evidence that the effects of changes in the federal funds rate, forward guidance, or LSAPs died out over time. I estimate that the federal funds rate had effects that were completely persistent in essentially all cases. For forward guidance, my point estimates suggest there is some attenuation of its effects on longer-term yields, but those estimates are not statistically significant and have a fairly long half-life of several months.[45] For LSAPs, I estimate that the effects were completely persistent, with the exception of the very large and influential "QE1" announcement in March 2009. After that particular announcement, long-term bond yields fell sharply but then rebounded over the next two months as financial markets turned around. Given that financial markets hit bottom and were functioning very poorly in March 2009, the financial market responses to that announcement may not be representative of LSAP effects more generally.

Overall, I find that forward guidance and LSAPs are effective substitutes for conventional monetary policy. This implies that the zero lower bound should be much less of a concern for policymakers than if these alternative monetary policy instruments were not available. As a result, there is relatively little reason for the Federal Reserve to raise its inflation target to avoid hitting the zero lower bound in the future.

Going forward, there are two main avenues for future research. First, estimating the effects of forward guidance and LSAPs on macroeconomic variables such as the unemployment rate should be a top priority—after all, the FOMC's stated goal in pursuing these unconventional policies was to stimulate the economy. Measuring the response of macroeconomic rather than financial variables to monetary policy announcements is difficult, however, because of the lower frequency of macroeconomic data and the longer response lags of macroeconomic variables to those announcements. Second, studying the effects of unconventional monetary policies in other economies would be very interesting, especially since the zero lower bound period in the U.S. has ended. The methods of the present paper should be very helpful for studying the effects of unconventional monetary policies in these other economies as well.

Appendix A. Details of identifying restrictions

As discussed in Section 2, the factor model (1) is not uniquely identified by the data. Here I provide the details of the identifying restrictions in Section 2.

Given the $T \times n$ matrix X of n asset price responses to the T FOMC announcements in my sample, I first demean and scale each column of X to have zero mean and unit variance. I then extract the first three principal components of the standardized matrix to estimate the three latent factors that explain a maximal fraction of the variance of the (standardized) data. Let F denote the $T \times 3$ matrix of these first three principal components, and Λ the $3 \times n$ matrix of loadings of the data X on F (cf. eq. (1)).

It's straightforward to show that a 3×3 orthogonal matrix U is uniquely determined by three parameters. Thus, we require three identifying restrictions to uniquely identify the rotation U that maps the principal components F into three factors $F^* \equiv FU$ that have a structural interpretation as 1) the surprise change in the federal funds rate target, 2) the surprise change in forward guidance, and 3) the surprise change in LSAPs.

As discussed in Section 2, my first two identifying assumptions are that forward guidance and LSAPs have no effect on the current federal funds rate. These two zero restrictions can be written as

$$U'\Lambda_1 = \begin{bmatrix} \cdot \\ 0 \\ 0 \end{bmatrix}, \tag{A.1}$$

where Λ_1 denotes the first column of Λ, the loadings of the current-month federal funds rate on the three factors F. Letting U_i denote the ith column of U, these restrictions correspond to $\Lambda_1'U_2 = 0$ and $\Lambda_1'U_3 = 0$. Effectively, these two restrictions imply that only the first factor has any systematic effect on the federal funds rate.

My third identifying restriction is that the variance of the LSAP factor is as small as possible over the sample from 1991 to 2008. The LSAP factor is given by FU_3, so this restriction amounts to minimizing $U_3'(F^{\text{pre}})'F^{\text{pre}}U_3$, where F^{pre} denotes the 158×3 matrix of values of F from 1991–2008. This is a constraint on U_3 that does not directly affect U_1 or U_2, except via the orthogonality conditions between the columns of U.

Computationally, I implement these three restrictions as follows. First, I implement restrictions two and three above in one step as a quadratic minimization problem subject to a linear constraint: I temporarily ignore the unit length requirement on U_3 and normalize the third element of U_3 to unity;[46] I then minimize

$$\begin{bmatrix} u_{13} \\ u_{23} \\ 1 \end{bmatrix} (F^{\text{pre}})'F^{\text{pre}} \begin{bmatrix} u_{13} \\ u_{23} \\ 1 \end{bmatrix}, \tag{A.2}$$

[45] And to some extent, we would expect the effects of forward guidance to die out with a half-life of several months, since the FOMC's forward guidance typically had a horizon of a few months to two years.

[46] Note that there is nothing special about the third element here or in any of the normalizations below—if the third element happens to be close to zero, then the first or second element can be normalized to unity instead.

subject to $\Lambda_1' \, [u_{13} \;\; u_{23} \;\; 1]' = 0$, where this last constraint ensures the minimization respects the second identifying assumption. After computing the minimizing vector $[u_{13} \;\; u_{23} \;\; 1]'$, I rescale it to have unit length and call the resulting vector U_3.

To implement the first identifying restriction, I again temporarily ignore the unit length requirement on U_2 and normalize its third element to unity. I then solve the equation

$$\begin{bmatrix} \Lambda_1' \\ U_3' \end{bmatrix} \begin{bmatrix} u_{12} \\ u_{22} \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{A.3}$$

for u_{12} and u_{22}, which ensures that $[u_{12} \;\; u_{22} \;\; 1]'$ satisfies the identifying restriction and is orthogonal to U_3. I then rescale the vector $[u_{12} \;\; u_{22} \;\; 1]'$ to have unit length and call the result U_2.

Finally, I compute U_1 by an analogous procedure, normalizing the third element of U_1 to unity, solving the equation

$$\begin{bmatrix} U_{2'} \\ U_{3'} \end{bmatrix} \begin{bmatrix} u_{11} \\ u_{12} \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \tag{A.4}$$

and renormalizing $[u_{11} \;\; u_{12} \;\; 1]'$ to have unit length. This ensures U_1 is orthogonal to U_2 and U_3.

This uniquely identifies U and F^* up to a sign normalization for each column. I normalize the sign of the first column of F^* to have a positive effect on the current federal funds rate, the second column to have a positive effect on the four-quarter-ahead Eurodollar future contract ED4, and the third column to have a negative effect on the 10-year Treasury yield.

Appendix B. Bootstrap procedure

The regressions in Section 4 use the estimated monetary policy factors $\widetilde{F}$ as regressors. Because those regressors are generated from a first-stage estimation procedure, there is some additional uncertainty regarding those variables that would not be present if they were directly observed. Traditional OLS or heteroskedasticity-consistent standard errors do not take this extra sampling uncertainty into account and thus are not correct in general (e.g., Pagan, 1984).

To address this problem, I compute the standard errors in Section 4 by boostrapping, as follows. I first write the 241×8 matrix of FOMC announcement responses X in terms of the estimated factor model $X = F\Lambda + \varepsilon$, as in Section 2. For each bootstrap sample i, I draw 241 random numbers $r_j^{(i)}$, $j = 1, \ldots, 241$, between 1 and 241, with replacement. Bootstrap sample $X^{(i)}$ is then defined to be $F\Lambda + \varepsilon^{(i)}$, where the jth row of $\varepsilon^{(i)}$ is given by the $r_j^{(i)}$th row of the original ε. I repeat this procedure 10,000 times to generate bootstrap samples $X^{(i)}$, $i = 1, \ldots, 10,000$. For each boostrap sample i, I impose the three identifying assumptions in Section 2 to compute the synthetic structural factors $\widetilde{F}^{(i)}$.

Similarly, for each left-hand side variable y in Section 4, I take the residuals from the original regression $y = \alpha + \beta\widetilde{F} + \eta$ and define the bootstrap vector $y^{(i)}$ to be $\alpha + \beta\widetilde{F} + \eta^{(i)}$, where the jth element of $\eta^{(i)}$ is given by the $r_j^{(i)}$th element of the original η. For each bootstrap sample i, I run the regression $y^{(i)} = \alpha^{(i)} + \beta^{(i)}\widetilde{F}^{(i)} + \nu^{(i)}$ and store the estimated parameters $\alpha^{(i)}$ and $\beta^{(i)}$. The boostrapped standard errors for β in Section 4 are computed from the empirical distribution of the $\beta^{(i)}$.

Note that this samples the residuals ε and η with replacement rather than the raw underlying data X and y. If we were to sample the observations X and y directly, we would end up with many bootstrap samples that have multiple occcurrences of the large "QE1" announcement by the Fed, and many other bootstrap samples that have no such occurrences. In actuality, the Fed made one "QE1" announcement, and we are interested in the standard errors of our coefficients β conditional on that fact. By sampling the residuals ε and η, we preserve that feature of the data and compute the standard errors we are interested in.

Bootstrapped standard errors in Section 5 are computed in esssentially the same way. The bootstrap samples $X^{(i)}$ are the same, and for each horizon h, the left-hand side variables $\Delta_h y_{t-1} \equiv y_{t+1-h} - y_{t-1}$ are sampled in the same way as above. That is, I take the residuals from the original regression $\Delta_h y = \alpha_h + \beta_h\widetilde{F} + \eta_{(h)}$ and define the bootstrap vector $(\Delta_h y)^{(i)}$ to be $\alpha_h + \beta_h\widetilde{F} + \eta_{(h)}^{(i)}$, where the jth element of $\eta_{(h)}^{(i)}$ is given by the $r_j^{(i)}$th element of the original $\eta_{(h)}$. For each bootstrap sample i, I run the regression $(\Delta_h y)^{(i)} = \alpha_h^{(i)} + \beta_h^{(i)}\widetilde{F}^{(i)} + \nu_{(h)}^{(i)}$ and store the estimated parameters $\alpha_h^{(i)}$ and $\beta_h^{(i)}$. The boostrapped standard errors for each β_h in the figures in Section 5 are computed from the empirical distribution of the $\beta_h^{(i)}$.

References

Ball, L., 2014. The case for a long-run inflation target of four percent. IMF Working Paper 14/92.

Barnichon, R., Brownlees, C., 2019. Impulse response estimation by smooth local projections. Rev. Econ. Stat. 101, 522–530.

Bauer, M., Rudebusch, G., 2014. The signaling channel for federal reserve bond purchases. Int. J. Cent. Bank. 10, 233–289.

Bauer, M., Swanson, E., 2020. The fed's response to economic news explains the 'fed information effect'. NBER Working Paper 27013.

Bernanke, B., Kuttner, K., 2005. What explains the stock market's reaction to federal reserve policy? J. Finance 60, 1221–1257.

Blanchard, O., Dell'Ariccia, G., Mauro, P., 2010. Rethinking macroeconomic policy. IMF Staff Position Note 10/03.

Campbell, J., Evans, C., Fisher, J., Justiniano, A., 2012. Macroeconomic effects of federal reserve forward guidance. In: Brookings Papers on Economic Activity Spring, pp. 1–53.

Cragg, J., Donald, S., 1997. Inferring the rank of a matrix. J. Econom. 76, 223–250.

D'Amico, S., English, W., Lopez-Salido, D., Nelson, E., 2012. The federal reserve's large-scale asset purchase programmes: rationale and effects. Econ. J. 122, F415–F446.

D'Amico, S., Farka, M., 2011. The fed and the stock market: an identification based on intraday futures data. J. Bus. Econ. Stat. 29, 126–137.
Duffie, D., 2010. Presidential address: asset price dynamics with slow-moving capital. J. Finance 55 (4), 1237–1267.
Fleckenstein, M., Longstaff, F., Lustig, H., 2014. The TIPS-treasury bond puzzle. J. Finance 69 (5), 2151–2197.
Forbes, 2010. Bernanke runs up the sails for QE2 by Fontevecchia, Agustino. October 15, 2010, http://www.forbes.com/2010/10/15/bernanke-speech-deflation-equities-markets-housing.html.
Gagnon, J., Raskin, M., Remache, J., Sack, B., 2011. The financial market effects of the federal reserve's large-scale asset purchases. Int. J. Cent. Bank. 7, 3–43.
Gertler, M., Karadi, P., 2015. Monetary policy surprises, credit costs, and economic activity. Am. Econ. J. 7, 44–76.
Gilchrist, S., Yue, V., Zakrajsek, E., 2018. US Monetary policy and international bond markets. Federal Reserve Finance and Economics Discussion Series 2018–014.
Gürkaynak, R., Sack, B., Swanson, E., 2005a. Do actions speak louder than words? The response of asset prices to monetary policy actions and statements. Int. J. Cent. Bank. 1, 55–93.
Gürkaynak, R., Sack, B., Swanson, E., 2005b. The sensitivity of long-term interest rates to economic news: evidence and implications for macroeconomic models. Am. Econ. Rev. 95, 425–436.
Gürkaynak, R., Sack, B., Swanson, E., 2007. Market-based measures of monetary policy expectations. J. Bus. Econ. Stat. 25, 201–212.
Gürkaynak, R., Sack, B., Wright, J., 2007. The U.S. treasury yield curve: 1961 to the present. J. Monet. Econ. 54, 2291–2304.
Hanson, S., Stein, J., 2015. Monetary policy and long-term real rates. J. Financ. Econ. 115, 429–448.
Jordà, O., 2005. Estimation and inference of impulse responses by local projections. Am. Econ. Rev. 95, 161–182.
Krishnamurthy, A., Vissing-Jorgensen, A., 2011. The effects of quantitative easing on interest rates: channels and implications for policy. Brookings Papers on Economic Activity Fall 215–265.
Krishnamurthy, A., Vissing-Jorgensen, A., 2013. The ins and outs of LSAPs. In: Global Dimensions of Unconventional Monetary Policy: Federal Reserve Bank of Kansas City Symposium Proceedings from Jackson Hole, Wyoming (Kansas City: Federal Reserve Bank of Kansas City) 57–111. Available at http://www.kansascityfed.org/publications/research/escp.
Kuttner, K., 2001. Monetary policy surprises and interest rates: evidence from the fed funds futures market. J. Monet. Econ. 47, 523–544.
Miranda-Agrippino, S., Ricco, G., 2020. The transmission of monetary policy shocks. Am. Econ. J.: Macroeconomics. Forthcoming.
Nakamura, E., Steinsson, J., 2018. High-frequency identification of monetary non-neutrality: the information effect. Q. J. Econ. 133, 1283–1330.
Pagan, A., 1984. Econometric issues in the analysis of regressions with generated regressors. Int. Econ. Rev. 25, 221–247.
Rogers, J., Scotti, C., Wright, J., 2018. Unconventional monetary policy and international risk premia. Federal Reserve Board.
Summers, L., 1991. How should long-term monetary policy be determined? J. Money Credit Bank. 23 (3), 625–631. Part 2.
Swanson, E., 2011. Let's twist again: a high-frequency event-study analysis of operation twist and its implications for QE2, pp. 151–188. Brookings Papers on Economic Activity Spring 2011.
Swanson, E., 2017. Measuring the effects of federal reserve forward guidance and asset purchases on financial markets. NBER Working Paper 23311.
Swanson, E., Williams, J., 2014. Measuring the effect of the zero lower bound on medium- and longer-term interest rates. Am. Econ. Rev. 104, 3154–3185.
Taylor, J., 2012. Fiscal follies, monetary mischief interview given to Barron's april 12, 2012, by gene epstein.
The Wall Street Journal, 2010. Q&A: IMF's Blanchard thinks the unthinkable by davis, bob, february 11, 2010, real time economics.
The Wall Street Journal, 2013a. Bond markets sell off by Burne, Katy, and mike Chernev, june 19, 2013, credit markets.
The Wall Street Journal, 2013b. No taper shocks wall street: fed 'running scared' by Rusolillo, steven, september 18, 2013, money beat.
The Wall Street Journal, 2013c. Fed stays the course on easy money by hilsenrath, jon, and victoria mcgrane, september 19, 2013, economy.
The Wall Street Journal, 2014. U.S. stocks surge after fed gets dovish on policy by Vigna, Paul, december 17, 2014, money beat.
The Wall Street Journal, 2015a. U.S. government bonds rally after fed statement by zeng, min, march 18, 2015, credit markets.
The Wall Street Journal, 2015b. U.S. stocks surge as fed seen taking time on rates by WSJ staff, march 18, 2015, money beat.
The Wall Street Journal, 2015c. Dollar drops after fed keeps interest rates on hold; U.S. central bank leaves interest rates unchanged by ira iosebashvili, september 17, 2015.
The Wall Street Journal, 2015d. Rates: lower, for even longer by justin lahart, september 18, 2015, c1.
The Wall Street Journal, 2015e. Fed delays interest rate liftoff; officials still expect to move this year, but express concerns about global tumult by jon hilsenrath, september 17, 2015.
The Wall Street Journal, 2015f. U.s. bond yields jump after fed fuels rate-increase angst; fed signals it may raise rates before end of year by min zeng, october 28, 2015.
The Wall Street Journal, 2015g. Fed keeps december hike in play by jon hilsenrath, october 29, 2015.
The Wall Street Journal, 2016. Fed dials back pace of rate hikes by harriet torry and jon hilsenrath, march 16, 2016.
The Wall Street Journal, 2019. Fed holds rates steady, hints at future cuts if outlook doesn't improve by nick timiraos, june 19, 2019.
Williams, J., 2013. Lessons from the financial crisis for unconventional monetary policy panel discussion at the NBER conference on lessons from the financial crisis for monetary policy, october 18, 2013. Available at http://www.frbsf.org/our-district/press/presidents-speeches/williams-speeches/2013/october/research-unconventional-monetary-policy-financial-crisis.
Woodford, M., 2012. Methods of policy accommodation at the interest-rate lower bound. In: The Changing Policy Landscape: Federal Reserve Bank of Kansas City Symposium Proceedings from Jackson Hole, Wyoming (Kansas City: Federal Reserve Bank of Kansas City) 185–288. Available at http://www.kansascityfed.org/publications/research/escp.
Wright, J., 2012. What does monetary policy do to long-term interest rates at the zero lower bound? Economic Journal 122. F447–F466.
Wu, J.C., Xia, F.D., 2016. Measuring the macroeconomic impact of monetary policy at the zero lower bound. J. Money Credit Bank. 48, 253–291.