# Measuring the Effects of Federal Reserve Forward Guidance and Asset Purchases on Financial Markets

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## Abstract

I adapt the methods of Gürkaynak, Sack, and Swanson (2005) to estimate two dimensions of monetary policy during the 2009–2015 zero lower bound period in the U.S. I show that, after a suitable rotation, these two dimensions can be interpreted as "forward guidance" and "large-scale asset purchases" (LSAPs). I estimate the sizes of the forward guidance and LSAP components of each FOMC announcement between January 2009 and October 2015, and show that those estimates correspond closely to identifiable features of major FOMC announcements over that period. Forward guidance is more effective at moving short-term Treasury yields, while LSAPs are more effective at changing long-term Treasury and corporate bond yields. Both types of policies have significant effects on medium-term Treasury yields, stock prices, and exchange rates. There is some evidence that the effects of LSAPs are not persistent, but that result is driven entirely by the behavior of bond yields around the FOMC's major "QE1" announcement in March 2009.

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# 1. Introduction

On December 16, 2008, the U.S. Federal Reserve's Federal Open Market Committee (FOMC) lowered the federal funds rate—its traditional monetary policy instrument—to essentially zero in response to the most severe U.S. financial crisis since the Great Depression. Because U.S. currency carries an interest rate of zero, it is virtually impossible for the FOMC to target a value for the federal funds rate that is substantially less than zero. Faced with this zero lower bound (ZLB) constraint, the FOMC subsequently began to pursue alternative, "unconventional" monetary policies, with particular emphasis on forward guidance and large-scale asset purchases, defined below. In this paper, I propose a new method to identify and estimate the effects of these two main types of unconventional monetary policy.

Understanding the effects of unconventional monetary policy is an important topic for both policymakers and researchers. Many central banks around the world have found themselves constrained by the zero lower bound on short-term nominal interest rates. Central banks faced with this constraint must pursue unconventional monetary policy if they wish to affect financial markets and/or the economy. Understanding the effects of different types of unconventional monetary policy, then, allows policymakers and researchers to better understand the efficacy, strengths, and weaknesses of the various alternatives.

The effectiveness of unconventional monetary policy is also an important determinant of the costs of the zero lower bound constraint. If unconventional monetary policy is relatively ineffective, then the ZLB constraint is more costly, and policymakers should go to greater lengths to prevent hitting the ZLB in the first place—such as by choosing a higher target rate of inflation, as advocated by several authors (e.g., Summers, 1991; Blanchard, Dell'Ariccia, and Mauro, 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 much less costly and policymakers do not need to take such drastic action to avoid hitting it in the future.

In the present paper, I focus on measuring the effects of forward guidance and large-scale asset purchases in particular, since those were the two types of unconventional monetary policy used most extensively by the Federal Reserve during the recent ZLB period in the U.S. The term "forward guidance" refers to communication by the FOMC about the likely future path of the federal funds rate over the next several quarters or years. "Large-scale asset purchases" (or LSAPs) refers to purchases by the Federal Reserve of hundreds of billions of dollars' worth of longer-term assets, such as long-term U.S. Treasuries and mortgage-backed securities. The

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Table 1: Major Unconventional Monetary Policy Announcements
by the Federal Reserve, 2009–2015

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| | |
|---|---|
| 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 percent 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" |

goals of both policies was to lower longer-term U.S. interest rates using methods other than changes in the current federal funds rate. Both types of unconventional monetary policy were used extensively by the Federal Reserve, as can be seen in Table 1. Note that, in addition to the major unconventional monetary policy announcements listed in Table 1, there was incremental news about these policies that was released to financial markets at almost every FOMC meeting, such as updates that a policy was ongoing, was likely to be continued, or might be adjusted.

A major challenge in identifying and estimating the effects of the FOMC's unconventional monetary policy announcements is determing the size and type of each announcement. For example, many of the statements in Table 1 were at least partially anticipated by financial markets prior to their official release. Because financial markets are forward-looking, the anticipated component of each announcement should not have any effect on asset prices; only the unanticipated component should be news to financial markets and 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.[1]

A closely related issue 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.[2] 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.

Determining the type—forward guidance vs. LSAP— of any given announcement can also be very difficult. For example, many announcements in Table 1 clearly contain significant news about both types of policies, which makes disentangling the news on those dates challenging. Even in the case of a seemingly clear-cut announcement, both types of policies may be at work: In particular, several authors have argued that LSAPs affect the economy by changing financial markets' expectations about the future path of the federal funds rate (see, e.g., Woodford, 2012; and Bauer and Rudebusch, 2014). To the extent that this channel is operative, even a pure LSAP announcement would have important forward guidance implications. This makes disentangling the two types of policies even harder than it might seem at first pass.

In this paper, I address these problems by adapting the methods of Gürkaynak, Sack, and Swanson (2005, henceforth GSS) to the zero lower bound period in the U.S., from 2009 to 2015. The problem GSS faced was similar to the problem I face here, in that GSS were interested in separately identifying the effects of two dimensions of monetary policy: changes in the current federal funds rate vs. changes in the FOMC's forward guidance. In the zero lower bound environment considered in the present paper, there are also two dimensions of monetary policy, except that those two dimensions are different: changes in forward guidance and LSAPs. (Changes in the current federal funds rate are not a significant component of monetary policy during this period because of the zero lower bound constraint on the funds rate.)

Following GSS, I look at how financial markets responded in a 30-minute window bracketing each FOMC announcement between 2009 and 2015, and compute the first two principal components of those asset price responses. The idea is that forward guidance and LSAPs were

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[1] In contrast, for conventional monetary policy—changes in the federal funds rate—federal funds futures and other short-term financial market instruments provide very good measures of market expectations leading up to each announcement, as discussed by Kuttner (2001), Gürkaynak, Sack, and Swanson (2005,2007), and others.

[2] For example, *The Wall Street Journal* 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 Wall Street Journal,* 2013b,c).

by far the two most important components of FOMC announcements for financial markets, and thus their effects should be captured well by the first two principal components of the asset price responses. I then search over all possible rotations of these two principal components to find the specification in which one of the two factors has the clearest interpretation as a "forward guidance" factor, using the estimated effect of forward guidance from the pre-ZLB period (computed exactly as in GSS) as the benchmark for what the effects of forward guidance should look like. The remaining, orthogonal factor can then be interpreted as the second main dimension of monetary policy during this period. I interpret this second factor as measuring the FOMC's LSAP announcements and present evidence that supports this interpretation. For example, I plot both of these factors—forward guidance and LSAPs—over time and show that they fit identifiable features of major FOMC announcements over the period quite well. In this way, I separately identify the size of the forward guidance and LSAP component of every FOMC announcement between January 2009 and October 2015.

Once the FOMC's forward guidance and LSAP announcements are identified, it's then straightforward to estimate the effects of each type of announcement on the high-frequency (30-minute or 1-day) response of different types of asset prices around those announcements.

The remainder of the paper proceeds as follows. In Section 2, I review the analysis in GSS, show how to adapt it to the recent ZLB period, and describe the data. In Section 3, I perform the principal component analysis and rotate the factors as described above. I plot the estimated factors over time and discuss their relationship to identifiable features of major announcements by the FOMC over the ZLB period, showing that my estimates of forward guidance and LSAP announcements seem to be well identified and informative. In Section 4, I estimate the effects of these announcements on Treasury yields, stock prices, exchange rates, and corporate bond yields and spreads. Section 5 investigates whether and to what extent these effects die out over time. In Section 6, I estimate the effects of forward guidance and LSAPs on interest rate uncertainty, at both the short and long end of the yield curve. Section 7 discusses the implications of my findings for monetary policy going forward, and concludes.

## 2. Methods and Data

My methods in the present paper consist of two main steps. First, I extend the analysis of Gürkaynak, Sack, and Swanson (2005) through December 16, 2008, which was the last time the

FOMC announced a change in the federal funds rate target. (After the December 16, 2008, announcement, the funds rate was essentially at a level of zero, and the FOMC was unwilling or unable to lower the federal funds rate any further.) This allows me to identify and estimate the effects of changes in the federal funds rate and changes in forward guidance in "normal times", before the ZLB began to bind.[3] Second, I adapt the methods of GSS to the ZLB period from January 2009 through October 2015, during which the FOMC never changed the current federal funds rate but made multiple unconventional monetary policy announcements involving forward guidance and large-scale asset purchases, as in Table 1. I thus use the GSS methods, applied to the ZLB sample, to identify and estimate the effects of forward guidance and LSAPs during this later period.

I extend the GSS dataset through October 2015 using data obtained from staff at the Federal Reserve Board. The combined dataset includes the date of each FOMC announcement from July 1991 through October 2015, and 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 (for the 3-month, 6-month and 2-, 5-, 10-, and 30-year maturities), the stock market (as measured by the S&P 500), and exchange rates (yen/dollar and dollar/euro).

To replicate the GSS analysis over the pre-ZLB period, I focus on the responses of 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 each FOMC announcement from July 1991 through December 2008. The two federal funds futures contracts can be scaled so as to provide good estimates of the market expectation of what the federal funds rate will be after the current and next FOMC meetings (see GSS, 2005, for details). The second through fourth Eurodollar futures contracts provide information about the market expectation of the path of the federal funds rate over the horizon from about 4 months to 1 year ahead.[5] The 2-, 5-, and 10-year

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[3] My results are very similar if I end the sample in December 2004, as GSS did, or in December 2007.

[4] The window begins 10 minutes before the FOMC announcement was released to the public and ends 20 minutes after the FOMC announcement was released. The dataset also includes the dates and times of FOMC announcements and some intraday asset price responses going back to January 1990, but the data for Treasury yield responses begins in July 1991, and those data 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 after financial markets had been closed for several days following the September 11 terrorist attacks.

[5] The reason for focusing on some rather than all of the possible futures contract rates in the dataset is to avoid overlapping contracts as much as possible, since they are highly correlated for technical rather than policy-related reasons. When I conduct the principal components analysis of the data below, futures contracts that are highly

Treasury yields provide information about interest rate expectations and risk premia over longer horizons, about 1 to 10 years.

These asset price responses to FOMC announcements can be written as a matrix $X$, with rows of $X$ corresponding to FOMC announcements and columns of $X$ corresponding to different futures rates and Treasury yields. Since there are 158 FOMC announcements from July 1991 through December 2008, and I focus on 8 asset price responses, the matrix $X$ has dimensions $158 \times 8$.

As in GSS, I use principal component analysis to estimate the two factors that make the most important contribution to the variation in $X$. The idea is that the asset price responses in $X$ are well described by a factor model,

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

where $F$ is a $158 \times 2$ matrix containing two factors, $\Lambda$ is a $2 \times 8$ matrix of loadings of the asset price responses on the two factors, and $\varepsilon$ is a $158 \times 8$ matrix of white noise residuals. Letting $F$ denote the first two principal components of $X$, the two columns of $F$ represent the two components of the FOMC's announcements that have had the greatest impact on the assets in $X$ over the period from July 1991 to December 2008.

Although the first two principal components of $X$ explain a maximal fraction of the variation in $X$, they are just a statistical decomposition and typically do not have a structural interpretation. In order to associate one column of $F$ with changes in the federal funds rate and the other column with changes in forward guidance—which is a structural interpretation—it's necessary to transform the factor matrix $F$ so that it fits this interpretation.

Keeping this goal in mind, note that if $F$ and $\Lambda$ characterize the data $X$ in equation (1), and $U$ is any $2 \times 2$ 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 $U$, in the sense that it produces exactly the same residuals $\varepsilon$ in equation (1).[6] Ideally, we would like the two columns of $F$

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correlated will tend to show up as a common factor, which would not be interesting if the correlation was generated by overlapping contracts rather than the way monetary policy is conducted. For example, FOMC announcements are generally spaced 6 to 8 weeks apart, so there is essentially no gain to including the second federal funds futures contract in addition to the first—the second contract is very highly correlated with the first fed funds futures contract, once the latter contract has been scaled to represent the outcome of the current FOMC meeting. Similarly, including the first Eurodollar futures contract would provide essentially no additional information beyond the first and third fed funds futures contracts. I follow GSS and switch from federal funds futures to Eurodollar futures contracts at a horizon of about 2 quarters because Eurodollar futures were much more liquid over this sample than longer-maturity fed funds futures, and are thus likely to provide a better measure of financial market expectations at those longer horizons (see Gürkaynak, Sack, and Swanson, 2007).

[6] The scale of $F$ and $\Lambda$ are also indeterminate: if $k$ is any scalar, then $kF$ and $\Lambda/k$ also fit the data $X$ exactly

to correspond to changes in the federal funds rate and changes in the FOMC's forward guidance, as mentioned above. Although the first two principal components of $X$ do not in general have this interpretation, we can choose a rotation matrix $U$ such that the rotated factors $\widetilde{F}$ do have such an interpretation. In particular, we can choose $U$ such that, if $\tilde{f}_1$ and $\tilde{f}_2$ are the two columns of $\widetilde{F}$, then $\tilde{f}_2$ has *no* effect on the current federal funds rate.[7] This implies that all of the variation in the current federal funds rate (up to the white noise residuals $\varepsilon$) in response to FOMC announcements is due to changes in the first factor, $\tilde{f}_1$. The factor $\tilde{f}_1$ can thus be interpreted as the surprise component of the FOMC's change in the federal funds rate target. The second factor, $\tilde{f}_2$, then corresponds to all of the *other* information in the FOMC's announcements, above and beyond the surprise change in the funds rate, that changed financial market expectations about the *future path* of the funds rate. Thus, $\tilde{f}_2$ can be thought of as "forward guidance" by the FOMC.[8] As GSS show, the second factor $\tilde{f}_2$, identified in this way, corresponds closely to important changes in the FOMC statement about the outlook for the future path of monetary policy between 1991 and 2008, supporting the interpretation of $\tilde{f}_2$ as the change in the FOMC's forward guidance.

I next adapt this methodology to the zero lower bound period in the U.S., from January 2009 to October 2015. As in GSS and discussed above, I create a data matrix $X$ with rows corresponding to FOMC announcements between January 2009 and October 2015, and columns corresponding to the responses of different futures rates and bond yields in a narrow, 30-minute window bracketing each announcement. However, I exclude the first and third federal funds futures contracts and the second Eurodollar futures contract from this analysis, because those contracts have such short maturities that they essentially do not respond to news during the ZLB period.[9] The matrix $X$ that I construct for the ZLB sample thus has dimensions $55 \times 5$, corresponding to the 55 FOMC announcements over this period, and 5 different asset price responses: the third and fourth Eurodollar futures contracts and the 2-, 5-, and 10-year Treasury yields.

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as well as $F$ and $\Lambda$. Traditionally, the scale of $F$ is normalized so that each column has unit variance.

[7] In other words, $\tilde{\lambda}_{21} = 0$, where $\tilde{\lambda}_{ij}$ denotes the $(i,j)$th element of $\widetilde{\Lambda}$, so the current-month federal funds futures contract is not affected by changes in the second factor.

[8] GSS called $\tilde{f}_1$ the "target factor" and $\tilde{f}_2$ the "path factor", because it relates to the future path of the federal funds rate, but the latter is now typically referred to as "forward guidance".

[9] The first and third federal funds futures contracts correspond to federal funds rate expectations over the next 1 and 3 months, respectively, and the second Eurodollar futures contract corresponds to funds rate expectations from about three to six months ahead. As shown and discussed by Swanson and Williams (2014), interest rates at these short maturities essentially stopped responding systematically to news from 2009 to 2012 (the end of their sample), and this remains true through about mid-2015.

As in GSS and discussed above, I extract the first two principal components from the matrix $X$. These are the two features of FOMC announcements between 2009 and late 2015 that moved the five yields listed above the most. As before, these two principal components do not have a structural interpretation in general. Let $F^{\text{zlb}}$ denote the $55 \times 2$ matrix of principal components, let $U$ be a $2 \times 2$ orthogonal matrix, let $\widetilde{F}^{\text{zlb}} \equiv F^{\text{zlb}}U$, and let $\tilde{f}_1^{\text{zlb}}$ and $\tilde{f}_2^{\text{zlb}}$ denote the first and second columns of $\widetilde{F}^{\text{zlb}}$. I search over all possible rotation matrices $U$ to find the one where the first rotated factor $\tilde{f}_1^{\text{zlb}}$ is as close as possible (in terms of its asset price effects) as the "forward guidance factor" $\tilde{f}_2$ estimated previously (over the 1991–2008 sample).[10] The identifying assumption is thus that the effect of forward guidance on medium- and longer-term interest rates during the ZLB period is about the same as it was during the pre-ZLB period from 1991–2008. The remaining factor, $\tilde{f}_2^{\text{zlb}}$, then corresponds to the component of FOMC announcements, above and beyond changes in forward guidance, that have the biggest effect on medium- and longer-term interest rates. It is natural to interpret this second factor as corresponding to the FOMC's large-scale asset purchases.

The crucial assumption underlying this identification is that forward guidance has essentially the same effects on medium- and longer-term interest rates before and after the ZLB. This assumption is subject to debate, but it provides a natural starting point for my analysis and in fact seems to work very well, as I show below. Thus, for every FOMC announcement from January 2009 through June 2015, I can separately identify the forward guidance component and the LSAP component of that announcement. Once I've separately identified the two components, it's straightforward to estimate the effects of each component on asset prices using ordinary least squares regressions.

## 3. The FOMC's Forward Guidance and LSAP Announcements

I now report the results of these methods applied to the pre-ZLB and ZLB periods.

### 3.1  Federal Funds Rate and Forward Guidance Factors before the ZLB

Table 2 reports the rotated loading matrices $\widetilde{\Lambda}$ from the estimation procedure described above. The first two rows report results for the pre-ZLB period, July 1991 to December 2008. Each factor,

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[10] In other words, I choose the rotation matrix $U$ that matches the factor loadings $\tilde{\lambda}_{11}^{\text{zlb}}, \tilde{\lambda}_{12}^{\text{zlb}}, \tilde{\lambda}_{13}^{\text{zlb}}, \tilde{\lambda}_{14}^{\text{zlb}},$ and $\tilde{\lambda}_{15}^{\text{zlb}}$ to $\tilde{\lambda}_{24}, \tilde{\lambda}_{25}, \tilde{\lambda}_{26}, \tilde{\lambda}_{27},$ and $\tilde{\lambda}_{28}$ as closely as possible, in the sense of minimum Euclidean distance.

TABLE 2: ESTIMATED EFFECTS OF CONVENTIONAL AND UNCONVENTIONAL MONETARY POLICY ANNOUNCEMENTS ON INTEREST RATES BEFORE AND AFTER DEC. 2008

| | MP1 | MP2 | ED2 | ED3 | ED4 | 2y Tr. | 5y Tr. | 10y Tr. |
|---|---|---|---|---|---|---|---|---|
| **July 1991–Dec. 2008:** | | | | | | | | |
| (1) change in federal funds rate | 8.58 | 6.26 | 5.90 | 5.61 | 4.82 | 3.81 | 1.93 | 0.68 |
| (2) change in forward guidance | 0.00 | 1.18 | 4.20 | 5.39 | 6.09 | 5.10 | 5.21 | 4.03 |
| **Jan. 2009–October 2015:** | | | | | | | | |
| (3) change in forward guidance | — | — | — | 3.53 | 4.46 | 3.78 | 4.59 | 2.62 |
| (4) change in LSAPs | — | — | — | −0.76 | −1.02 | −1.29 | −4.79 | −7.32 |
| **memo:** | | | | | | | | |
| (5) row 3, rescaled | — | — | — | 4.74 | 5.98 | 5.07 | 6.14 | 3.51 |

Coefficients in the table correspond to elements of the loading matrix $\Lambda$ from equation (1), in basis points per standard deviation change in the monetary policy instrument (except for row 5, which is rescaled). 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.

$\tilde{f}_1$ and $\tilde{f}_2$, is normalized to have a unit standard deviation over this sample, so the coefficients in the table are in units of basis points (bp) per standard deviation change in the monetary policy instrument. A one-standard-deviation increase in the federal funds rate over this period is estimated to cause the current federal funds rate to rise by about 8.6bp, the expected federal funds rate at the next FOMC meeting to rise about 6.3bp, the second through fourth Eurodollar futures rates to rise by 5.9, 5.6, and 4.8bp, respectively, and the 2-, 5-, and 10-year Treasury yields to increase by 3.8, 1.9, and 0.7bp, 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.

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 then dying off slightly for longer horizons. For long-term yields, such as the 10-year yield, changes in forward guidance are a far more important source of variation in those yields than are changes in the federal funds rate, as originally emphasized by GSS.

## 3.2 Forward Guidance and LSAP Factors during the ZLB Period

The third and fourth rows of Table 2 report the loadings $\widetilde{\Lambda}$ for the ZLB period from January 2009 through October 2015. The third row reports the effects of a one-standard-deviation change in

forward guidance on the third and fourth Eurodollar futures contract and the 2-, 5-, and 10-year Treasury yields, respectively. By construction, these coefficients match those in the second row as closely as possible, up to a constant scale factor, so the effect of forward guidance is hump-shaped with a peak at a horizon of about 1 year. (For reference, the fifth row of Table 2 rescales the coefficients in row 3 so that their correspondence to the second row can be seen more easily.)

The fourth row reports the effects of a one-standard-deviation increase in the FOMC's asset purchases. I normalize the sign of this factor so that an increase in purchases causes interest rates to fall. The effect on yields is relatively small at short and medium horizons but increases steadily with maturity—exactly the opposite of changes in the current federal funds rate. At a horizon of one year, the effect of LSAPs is only about 1bp, but for the 10-year Treasury yield, the effect is more than seven times larger, about 7.5bp.

The very different patterns in the third and fourth rows of Table 2—hump-shaped vs. strongly sloping—provide evidence against the hypothesis that LSAPs only work through a "signalling channel" (e.g., Woodford, 2012; Bauer and Rudebusch, 2014). If that were the case, the third and fourth rows of Table 2 should be much more similar. In fact, if LSAPs only worked through signalling, then there should be only one dimension of monetary policy during the ZLB period, and the fourth row in Table 2 should be statistically insignificant. Some evidence that this is not the case is that the fourth row of Table 2 explains about 31% of the variation in the asset price responses $X$, compared to 65% for the forward guidance factor. Thus, quantitatively, the LSAP factor in Table 2 appears to be important.

In addition, Table 3 reports results from the Cragg and Donald (1997) rank test applied to the asset price response matrix $X$. The first row of Table 3 reports results for the baseline case where five asset price responses are included in $X$. For this case, the test overwhelmingly rejects the hypothesis that $X$ has 0 factors (i.e., that $X$ is just a matrix of white noise), and rejects the hypothesis that $X$ has just 1 factor at the 5% level. If the fourth row of Table 2 was statistically insignificant, then the matrix of asset price responses $X$ should be well explained by a single factor; the fact that it is not is evidence that LSAPs affect asset prices through more than just signalling alone.

Interestingly, the results for the Cragg-Donald (1997) test for the hypothesis that $X$ has 2 underlying factors is also borderline rejected at the 5% level, suggesting that a third factor could be required to explain the variation in $X$. The second and third rows of Table 2 expand the set of assets in $X$ and do not provide strong evidence for or against the presence of a third factor—in

TABLE 3: TESTS FOR THE NUMBER OF FACTORS UNDERLYING INTEREST RATE
RESPONSES TO FOMC ANNOUNCEMENTS, 2009–15

| | $p$-value for $H_0$ of: | | |
| --- | --- | --- | --- |
| Included assets | rank 0 | rank 1 | rank 2 |
| ED3, ED4, 2yT, 5yT, 10yT | .0001 | .0178 | .0440 |
| ED3, ED4, 6mT, 2yT, 5yT, 10yT | .0002 | .0136 | .1721 |
| ED3, ED4, 6mT, 2yT, 5yT, 10yT, 30yT | .0000 | .0026 | .0427 |

The table reports $p$-values from the Cragg-Donald (1997) Wald test for the number of factors underlying the matrix of asset price responses $X$. The first row considers the baseline case with five assets included in $X$; the second and third rows extend the set of included assets. Each column reports the $p$-value for $H_0$: rank$(X) = n$ vs. $H_1$: rank$(X) > n$. See text for details.

one case, the null of rank 2 is not rejected, while in the other it is borderline rejected. In the remainder of the paper, I abstract from the possibility of a third factor for several reasons: first, the evidence for a third factor in Table 3 is weak, much weaker than for the existence of two factors; second, the next principal component of $X$ explains only 2.5% of the variation in $X$, so little is lost by dropping that component; and third, restricting attention to the first two factors makes the analysis above and below much simpler and the results much clearer, so that case is preferred on pedagogical grounds.

## 3.3 Correspondence of Factors to Notable FOMC Announcements

In Figure 1, I plot the time series of estimated values of the forward guidance and LSAP factors for each FOMC announcement from January 2009 to June 2015. The dashed blue line depicts the forward guidance factor, and the solid orange line the LSAP factor. To make the interpretation of the LSAP factor more intuitive, I scale it by $-1$ in the figure, so that an increase in LSAPs appears as a *negative* value; this sign convention implies that positive values in the figure correspond to monetary policy tightenings and negative values to monetary policy easings. The figure also contains brief annotations that help to explain some of the larger observations in the figure.

The largest and most striking observation in Figure 1 is the negative 5.5-standard-deviation LSAP announcement on March 18, 2009, near the beginning of the ZLB sample. This observation corresponds to the announcement of the FOMC's first LSAP program, often referred to as "QE1" in the press.[11] The key elements of this program are listed in Table 1, and the announcement seems

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[11] The "QE1" program began on November 25, 2008, when the Federal Reserve Board 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.

FIGURE 1: ESTIMATED FORWARD GUIDANCE AND LSAP FACTORS, 2009–2015
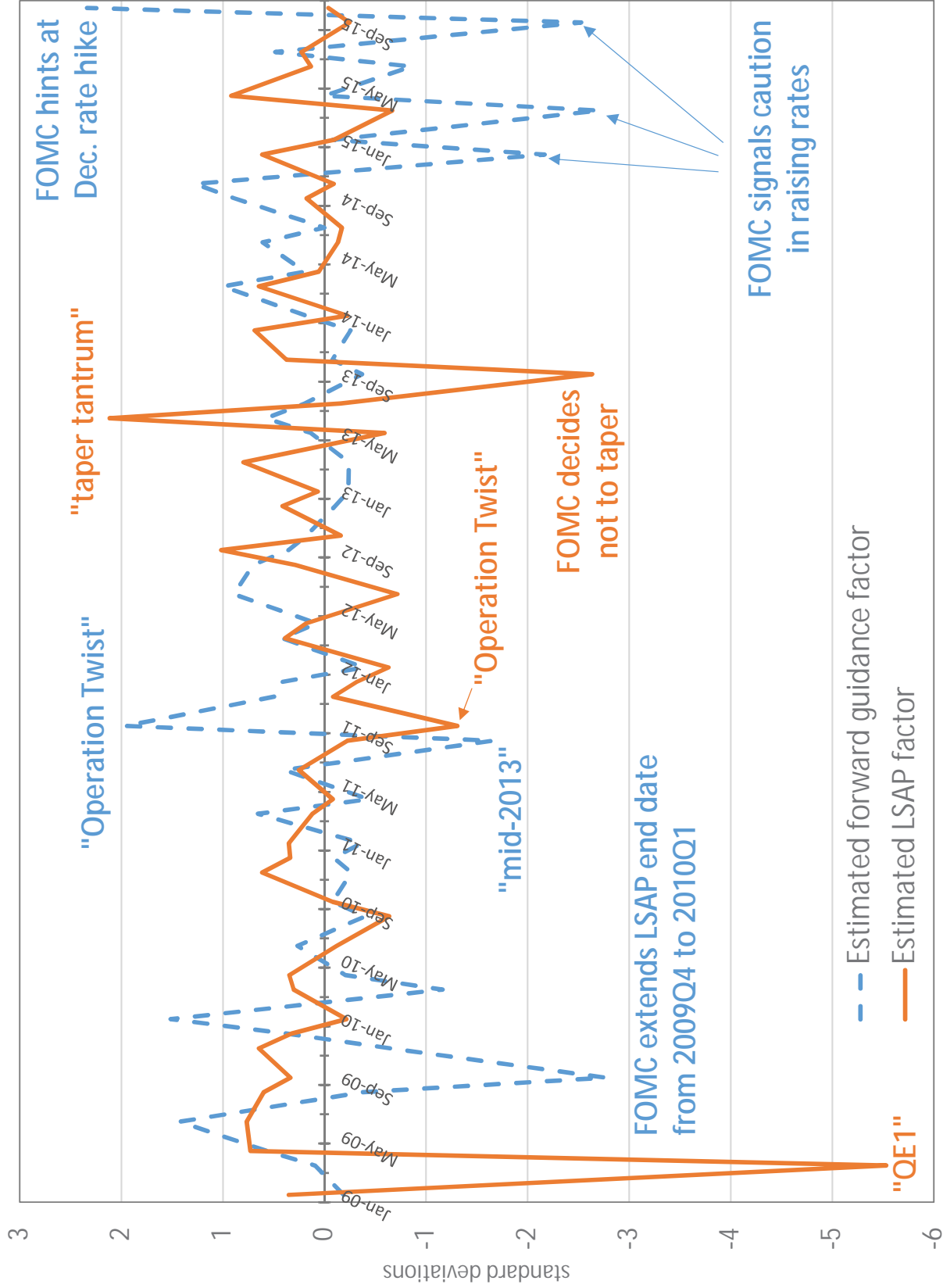
Plot of estimated forward guidance (dashed blue line) and LSAP (solid orange line) factors, $\tilde{f}_1^{zlb}$ and $\tilde{f}_2^{zlb}$, over time. Notable FOMC announcements are labeled in the figure for reference. The LSAP factor is multiplied by $-1$ in the figure so that positive values in the figure correspond to interest rate increases. See text for details.

to have been a major surprise to financial markets, given the huge estimated size of the factor on that date. Note that my identification procedure for forward guidance vs. LSAP announcements described above attributes the effects of this announcement to the LSAP factor. Given that this FOMC announcement placed such a large emphasis on asset purchases, my identification seems to be working well so far.

It's also interesting that the FOMC's subsequent "QE2" program, described in Table 1, does not show up as a major event in Figure 1, perhaps becuase it was anticipated by financial markets in advance. Looking at Figure 1 around the November 3, 2010, announcement date of the program, there is essentially no estimated effect, because the interest rates included in the estimation 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.

The next major event in Figure 1 is the negative 3-standard-deviation forward guidance announcement on September 23, 2009. On this date, the FOMC stated it would extend its asset purchase program by an additional three months, through 2010Q1 rather than 2009Q4. From the text of the FOMC statement alone, it's unclear whether the announcement should be regarded as forward guidance or LSAPs, or both. However, my identification characterizes this announcement as forward guidance, based on the way financial markets responded (i.e., shorter-term interest rates responded more than longer-term interest rates). It's important to bear in mind that the U.S. economy was beginning to recover by late 2009 and financial markets expected the FOMC to begin raising the federal funds rate in just a few quarters (Swanson and Williams, 2014), but not until a few meetings after completing its asset purchase program. Thus, an extension of the end date of the LSAP program was taken by markets to imply a correspondingly later liftoff date for the federal funds rate.

August 9, 2011, is another interesting date in Figure 1. That announcement marked the first time the FOMC gave explicit (rather than implicit) forward guidance about the likely path of the federal funds rate over the next several quarters. In that announcement, described in Table 1, the FOMC stated that it expected the current (essentially zero) level of the federal funds rate would be appropriate "at least through mid-2013", a date almost two years in the future. Reassuringly, I estimate the announcement on this date as a negative 2-standard-deviation surprise in forward guidance, with essentially no LSAP component.

The next FOMC announcement, on September 21, 2011, corresponds to "Operation Twist",

described in Table 1, a program where the FOMC sold about $400 billion of short-term Treasury securities in its portfolio and used the proceeds to purchase a like quantity of long-term Treasuries. As can be seen in Figure 1, this announcement is estimated to have both LSAP and forward guidance components: a negative 1.3-standard-deviation LSAP effect (which is intuitive), and a *positive* 2-standard-deviation forward guidance effect, which is perhaps surprising. This latter effect is due to the fact that shorter-maturity interest rates rose in response to the FOMC announcement—presumably due to a change in risk premia on those securities resulting from the large increase in expected sales by the Fed. Although this is probably not an example of forward guidance by the FOMC per se, it nevertheless looks like forward guidance in the data because of the unusual implication of the announcement for short-term Treasury yields. Thus, even though my identification is arguably missing this subtle distinction on this particular date, the estimates coming out of the identification are intuitive and sensible.

On June 19, 2013, I estimate a substantial, 2-standard-deviation decrease in the LSAP factor (which is positive in Figure 1 becuase it represents a monetary policy tightening). There is little change in the FOMC statement on that date, but as reported by *The Wall Street Journal,* the FOMC released economic projections along with the statement that showed a substantial increase in the FOMC's economic outlook. Given earlier remarks by then-Chairman Ben Bernanke that the FOMC could begin tapering its asset purchases soon, markets interpreted this as a signal that a tapering was imminent: for example, *The Wall Street Journal* 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..." (*The Wall Street Journal*, 2013a). Thus, this episode fits into the "taper tantrum" period during the summer of 2013, and appears to be correctly identified by my procedure as an increase in interest rates due to the LSAP factor.

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. *The Wall Street Journal* reported that "No Taper Shocks Wall Street," and "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" (*The*

*Wall Street Journal*, 2013b,c).[12] The surprise decision by the FOMC not to taper its asset purchases seems to be correctly identified in my estimates as an increase in LSAPs (depicted as a negative value in Figure 1 since it is a monetary policy easing).

On three occasions near the end of my sample—December 17, 2014, March 18, 2015, and September 17, 2015—markets expected the FOMC to signal that a hike in the federal funds rate would be coming in the near future. In each of these cases, the FOMC surprised markets by signaling additional caution in raising the funds rate.[13] My identification attributes these announcements to changes in FOMC forward guidance, which is very much in line with the market commentary after each of these announcements.

Finally, on October 28, 2015, the FOMC kept the federal funds rate at zero, but explicitly stated that a rate hike in December was being considered—an unusually explicit signal that significantly altered market's expectations of a rate hike at the upcoming meeting.[14] The Fed's statement caused short- and medium-term interest-rate futures and Treasury yields to jump, and is thus identified by my estimation as a significant increase in forward guidance.

## 3.4 Scale of Forward Guidance and LSAP Factors

The forward guidance and LSAP factors estimated above and plotted in Figure 1 have been normalized to have a unit standard deviation over the sample. Similarly, the loadings in Table 2 are for these normalized factors and thus represent a basis points per standard deviation effect. For practical policy applications, however, it's more useful to convert these factors to a scale that is tangible and observable.

For forward guidance, it's natural to think of the factor in terms of a 25bp effect on the Eurodollar future rate one year ahead, ED4. Note that a forward guidance announcement of this

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[12] *The Wall Street Journal* also reported that "'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 Wall Street Journal,* 2013b,c).

[13] 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 financial markets had expected (see, e.g., "U.S. stocks surged... after the Federal Reserve issued an especially dovish policy statement at the conclusion of the FOMC meetings," *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 downward, significantly 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 borrowing costs for the economy..." (*The Wall Street Journal*, 2015a,b). And on Sep. 17, 2015, the FOMC declined to raise the federal funds rates, issued a statement that was widely regarded as more dovish than expected, and released interest rate forecasts that were substantially lower than before (see, e.g., *The Wall Street Journal*, 2015c,d,e).

[14] See *The Wall Street Journal* (2015f,g).

size would be very large by historical standards, equal to about a 6-standard-deviation surprise during the ZLB period, or a 4-standard-deviation surprise in the pre-ZLB period.[15] To estimate the effects of a forward guidance announcement of this magnitude, we can multiply the coefficients in the third row of Table 2 by a factor of about 6, which implies that the effects on the 5- and 10-year Treasury yields would be about 25.5 and 14.2bp, respectively. The interpretation is that, if the FOMC gave forward guidance for the federal funds rate that was about 25bp lower one year ahead than financial markets expected, then the 5- and 10-year Treasury yields would decline by about 25.5 and 14.2bp on average.

For LSAPs, we would like the units to be in billions of dollars of purchases, which is a more difficult transformation than a simple renormalization of the coefficients in Table 2. 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., Swanson, 2011, and Table 1 of Williams, 2013). Using this estimate as a benchmark implies that the coefficients in the fourth row of Table 2 correspond to a roughly $300 billion surprise LSAP announcement. Thus, it seems reasonable to interpret the coefficients in that row of Table 2 as corresponding to a $300 billion change in purchases. The interpretation is thus that, if the FOMC announced a new LSAP program that was about $300 billion larger than markets expected, the effects would be about as large those provided in the fourth row of Table 2.

## 4. The Effects of Forward Guidance and LSAPs on Asset Prices

Once I've identified the forward guidance and LSAP components of the FOMC's announcements from 2009 through 2015, it's relatively straightforward to estimate the effects of those announcements on asset prices, using ordinary least squares regressions.

### 4.1 Treasury Yields

Table 4 reports the responses of 6-month and 2-, 5-, 10-, and 30-year Treasury yields to the forward guidance and LSAP components of the FOMC's announcements. As in previous tables

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[15] Interestingly, I estimate that the FOMC's forward guidance announcements were larger on average before the ZLB than during the ZLB, as can be seen in Table 2. One explanation for why this may be is that, once the FOMC issued its "mid-2013" forward guidance, there were essentially no updates or news about that guidance for many meetings. Similarly, after the FOMC revised the guidance to "late 2014", there were again no updates or news about that guidance for many more meetings, and so on.

TABLE 4: ESTIMATED EFFECTS OF FORWARD GUIDANCE AND LSAPS ON U.S. TREASURY YIELDS, 2009–2015

| | 6-month | 2-year | 5-year | 10-year | 30-year |
|---|---|---|---|---|---|
| change in forward guidance | 0.96*** | 3.78*** | 4.59*** | 2.62*** | 0.55 |
| (std. err.) | (.276) | (.203) | (.224) | (.205) | (.617) |
| [t-stat.] | [3.46] | [18.66] | [20.47] | [12.80] | [0.90] |
| change in LSAPs | −0.11 | −1.29*** | −4.79*** | −7.32*** | −5.68*** |
| (std. err.) | (.082) | (.076) | (.537) | (.406) | (.473) |
| [t-stat.] | [−1.37] | [−16.83] | [−8.92] | [−18.06] | [−12.00] |
| Regression $R^2$ | .49 | .94 | .95 | .97 | .78 |
| # Observations | 55 | 55 | 55 | 55 | 55 |

Coefficients $\beta$ from regressions $\Delta y_t = \alpha + \widetilde{F}_t^{\text{zlb}}\beta + \varepsilon_t$, where $t$ indexes FOMC announcements between Jan. 2009 and June 2015, $y$ denotes a given Treasury yield, $\widetilde{F}$ denotes the forward guidance and LSAP factors estimated previously, and $\Delta$ 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. Huber-White heteroskedasticity-consistent standard errors in parentheses; $t$-statistics in square brackets; *** denotes statistical significance at the 1% level. See text for details.

and figures, the coefficients here are in untis of basis points per standard deviation surprise in the announcement. Each column of the table reports estimates from an OLS regressions of the form

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

where $t$ indexes FOMC announcements between January 2009 and October 2015, as before, $y$ denotes the corresponding Treasury yield, $\Delta$ denotes the change in a 30-minute window bracketing each FOMC announcement, $\widetilde{F}^{\text{zlb}}$ denotes the forward guidance and LSAP factors as estimated above, $\varepsilon$ is a regression residual, and $\alpha$ and $\beta$ are parameters.

The point estimates for the 2-, 5-, and 10-year Treasury yields in Table 4 are the same as those in Table 2. However, Table 4 also reports Huber-White heteroskedasticity-consistent standard errors and $t$-statistics for each coefficient, from which we can see that the responses of these yields to both forward guidance and LSAPs are extraordinarily statistically significant, with $t$-statistics ranging from about 9 to more than 20. The regression $R^2$ values are also quite high, over 94 percent, so these two factors explain a very large share of the variation in these Treasury yields around FOMC announcements.

Table 4 also reports results for the 6-month and 30-year Treasury yields, which were not included in the estimation of the factors themselves.[16] LSAPs do not have a statistically significant

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[16] Results for the 3-month Treasury yield are not reported, since the 3-month Treasury yield generally did not respond to news over this period—see Swanson and Williams (2014).

effect on the 6-month Treasury yield, and the effect of forward guidance is statistically significant but small, amounting to only about 1bp per standard deviation surprise over this period, about one-fourth the size of the 2-year Treasury yield response. This is likely due to the fact that the 6-month Treasury yield was very close to zero and largely unresponsive to news over much of this period (see Swanson and Williams, 2014). To the extent that the 6-month Treasury yield was pinned to zero for a significant part of the sample, we wouldn't expect to see much of a response to any type of announcement.

The effect of forward guidance on the 30-year Treasury yield is also quantitatively small and, in this case, statistically insignificant. In contrast to the 6-month Treasury, the 30-year Treasury yield was not pinned to zero for any length of time during this period, so the small coefficient reflects the fact that forward guidance apparently has little effect on very long-maturity Treasuries. The effect of LSAPs on the 30-year Treasury yield, however, are large and very highly statistically significant, with a $t$-statistic of 12. Interestingly, the effects of LSAPs on the 30-year yield are not quite as large as their effects on the 10-year yield, presumably because the FOMC's LSAP operations were typically concentrated at maturities closer to 10 years.

## 4.2  Stock Prices and Exchange Rates

Table 5 reports regression 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 in equation (2), except the dependent variable in each regression is now 100 times the log change in the asset price in each column.

As can be seen in Table 5, both forward guidance and LSAPs have statistically significant effects on stock prices and exchange rates. For stocks, a one-standard-deviation increase in forward guidance causes prices to fall by about 0.2 percent, while a one-standard-deviation increase in LSAPs causes stock prices to rise by a similar amount. Both of these coefficients are highly statistically significant, with $t$-statistics of about 2.8 and 3.6, respectively, and both effects are in the direction one would expect from a dividend-discount model, given the interest rate responses in the previous table. That is, an increase in interest rates reduces the present value of a stock's dividends (and may reduce the size of the dividends themselves, if the economy contracts), which we would expect to cause stock prices to fall. Finally, it's interesting that the $R^2$ for this regression is much lower than those for Treasury yields, due to the high and idiosyncratic volatility of stock prices after FOMC announcements.

The effects of forward guidance and LSAPs on the dollar are more precisely estimated. Both

Table 5: Estimated Effects of Forward Guidance and LSAPs on Stock Prices and Exchange Rates, 2009–2015

|  | S&P500 | $/euro | $/yen |
|---|---|---|---|
| change in forward guidance | −0.19*** | −0.28*** | −0.19*** |
| (std. err.) | (.069) | (.040) | (.036) |
| [t-stat.] | [−2.82] | [−6.96] | [−5.43] |
| change in LSAPs | 0.19*** | 0.32*** | 0.36*** |
| (std. err.) | (.054) | (.049) | (.047) |
| [t-stat.] | [3.55] | [6.60] | [7.59] |
| Regression $R^2$ | .27 | .68 | .79 |
| # Observations | 55 | 55 | 55 |

Coefficients $\beta$ from regressions $\Delta \log x_t = \alpha + \widetilde{F}_t^{\mathrm{zlb}} \beta + \varepsilon_t$, where $t$ indexes FOMC announcements between Jan. 2009 and June 2015, $x$ is the asset price, $\widetilde{F}$ denotes the forward guidance and LSAP factors estimated previously, and $\Delta$ 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. Huber-White heteroskedasticity-consistent standard errors in parentheses; $t$-statistics in square brackets; *** denotes statistical significance at the 1% level. See text for details.

the dollar-euro and dollar-yen exchange rates are expressed as the dollar price per unit of foreign currency. In response to a one-standard-deviation increase in forward guidance, the U.S. dollar appreciates by about 0.2 to 0.3 percent, and the effect is highly statistically significant, with $t$-statistics of about 7 for the euro and 5.4 for the yen. A one-standard-deviation increase in LSAPs causes the dollar to depreciate about 0.35 percent, and the effect is again highly statistically significant with $t$-statistics of 6.6 and 7.6. Again, the effects have the signs one would expect from uncovered interest parity, given the response of interest rates in Table 4. That is, an increase in U.S. interest rates makes U.S. dollar investments more attractive relative to foreign investments, and tends to drive the value of the dollar up.

## 4.3 Corporate Bond Yields and Spreads

Table 6 reports results for corporate bond yields and spreads. Corporate bonds are less frequently traded than U.S. Treasuries, stocks, and foreign exchange, so only daily frequency corporate bond yield data are available. Thus, the regressions in Table 6 use the one-day change in corporate bond yields or spreads around each FOMC announcement as the dependent variable. To measure corporate yields, I consider both the Aaa and Baa indexes of long-term seasoned corporate bond yields from Moody's.

As can be seen in the first row of the table, I estimate that changes in the FOMC's forward

Table 6: Estimated Effects of Forward Guidance and LSAPs on
Corporate Bond Yields and Spreads, 2009–2015

| | Corporate Yields | | Spreads | |
|---|---|---|---|---|
| | Aaa | Baa | Aaa−10-yr. | Baa−10-yr. |
| change in forward guidance | 0.71 | −0.06 | −1.16** | −1.93** |
| (std. err.) | (.564) | (.669) | (.536) | (.658) |
| [t-stat.] | [1.26] | [−0.09] | [−2.17] | [−2.93] |
| change in LSAPs | −4.57*** | −5.05*** | 4.12*** | 3.64*** |
| (std. err.) | (.365) | (.598) | (.539) | (.901) |
| [t-stat.] | [−12.55] | [−8.45] | [7.64] | [4.04] |
| Regression $R^2$ | .44 | .49 | .54 | .55 |
| # Observations | 55 | 55 | 55 | 55 |

Coefficients $\beta$ from regressions $\Delta y_t = \alpha + \widetilde{F}_t^{\text{zlb}}\beta + \varepsilon_t$, where $t$ indexes FOMC announcements between Jan. 2009 and June 2015, $y$ denotes the corporate bond yield or spread, $\widetilde{F}$ denotes the forward guidance and LSAP factors estimated previously, and $\Delta$ 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. Huber-White heteroskedasticity-consistent standard errors in parentheses; $t$-statistics in square brackets; ** and *** denote statistical significance at the 5% and 1% levels, respectively. See text for details.

guidance have essentially no effect on corporate bond yields. The point estimates for both Aaa and Baa yields are small (less than one basis point per standard deviation change in forward guidance) and statistically insignificant. Because 10-year Treasury yields rise modestly in response to a change in forward guidance, the effect on the corporate-Treasury yield spread is thus modestly negative, falling about 1 to 2bp in response to an increase in guidance, and this effect is fairly statistically significant, with $t$-statistics of 2.2 and 2.9.

The effect of LSAPs on corporate bond yields is much larger and more significant. A one-standard-deviation increase in LSAPs causes the Aaa and Baa yields both to fall about 5bp, and the effect is very highly statistically significant. However, the effect of LSAPs on the 10-year Treasury yield is larger than the effect on corporate bond yields, so the spread between corporate bonds and Treasuries actually *increases* in response to the LSAP program.[17] This result echoes findings in Krishnamurthy and Vissing-Jorgensen (2012) and Swanson (2011) that the Fed's LSAP programs—which tend to be concentrated in U.S. Treasury securities—push down Treasury yields

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[17] The 10-year yield response in Table 2 is estimated to be about −7.3bp, while the effect implied in Table 6 is a bit larger, about −8.7bp. There are two reasons for this difference: first, the responses in Table 2 are 30-minute responses, while those in Table 6 are one-day responses. Second, Table 2 uses the on-the-run coupon-bearing 10-year Treasury bond, while in Table 6 I use the 10-year zero-coupon yield estimate by Gürkaynak, Sack, and Wright (2007). The latter yield has a longer duration than the coupon-bearing 10-year security, which should be a better match to the long-term corporate bonds in the Moody's indexes.

more than they do private-sector yields. Nevertheless, the effect on corporate bond yields that I estimate here is a bit bigger than those authors found in their studies. For example, Swanson (2011) estimated corporate bond yields fall by about 4–5bp in response to a \$600 billion Treasury LSAP, while the estimates in Table 6 are closer to 9–10bp for the same size operation (assuming this is a roughly two-standard-deviation announcement, as discussed earlier). One reason for the larger estimates here may be because the FOMC's LSAP programs often included a substantial quantity of mortgage-backed securities as well as Treasuries. Those MBS are likely to be closer substitutes for corporate bonds than are Treasuries, so we should expect purchases of MBS to have a relatively larger effect on corporate bond yields than purchases of Treasuries alone. The earlier estimates in Krishnamurthy and Vissing-Jorgensen (2012) and Swanson (2011) were for the case of a Treasury-only LSAP, and thus could be expected to have smaller effects than the MBS-and-Treasury LSAPs conducted by the FOMC between 2009 and 2015.

## 5. Are the Effects of Forward Guidance and LSAPs Persistent?

The regressions above measure the 30-minute or one-day responses of different yields and asset prices to FOMC announcements. If yields and asset prices are martingales or near-martingales, as is typically assumed in the event-study literature, then these very short-term responses are representative of the response of those assets over longer windows as well.

However, there are empirical and theoretical studies that suggest the effects of unconventional monetary policy—particularly LSAPs—may not be persistent. For example, Duffie (2010) cites several examples from finance that large movements of captial (e.g., due to stocks entering or leaving the S&P500, or sizes of Treasury security auctions) can have transitory effects on asset prices that only dissipate over a period of time, up to several months in length. The idea is that arbitrage capital is "slow-moving" and cannot be reallocated instantaneously to take advantage of the asset price distortions caused by the change in idiosyncratic demand or supply for the asset in question. Fleckenstein, Longstaff, and Lustig (2014) find substantial support for this theory in the mispricing of TIPS securities that they document during the 2007–09 global financial crisis.

Turning to unconventional monetary policy, Taylor (2012) and Woodford (2012) argue against the effectiveness of LSAPs for essentially the same reasons. Although the FOMC's announcement of an LSAP operation causes high-frequency movements in yields or asset prices around the time of the announcement, the argument goes, these changes in risk premia will be

arbitraged away eventually as arbitrageurs react to the announcement and adjust their positions. But since the Fed's expected asset purchases are so large in magnitude, it may take some time for private-sector arbitrageurs to reallocate hundreds of billions of dollars of assets in their portfolios away from longer-term Treasury bonds and into alternative assets such as short-term Treasuries and corporate bonds.

The empirical evidence in Wright (2012) provides support for this "slow-moving capital" view. Wright (2012) estimates the effects of the FOMC's unconventional monetary policy on U.S. long-term bond yields between November 2008 and September 2011 using a daily-frequency VAR. Even after correcting the roots of the VAR for downward bias, he estimates the effects of the FOMC's unconventional monetary policy over this period had a half-life of about 2–3 months. However, Wright does not distinguish between forward guidance and LSAPs in his analysis, so it's unclear whether his results apply to both types of unconventional policy, and whether they are representative of the entire U.S. zero lower bound period from 2009–2015.

To get a first look at the persistence of the effects of the FOMC's forward guidance and LSAP announcements, I run a series of daily regressions at multiple horizons, of the form:

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

where each forecast horizon $h$ is associated with a different regression, $y$ denotes a given bond yield or log asset price, $t$ indexes days from January 2009 through October 2015, $\widetilde{F}$ denotes the forward guidance and LSAP components of FOMC announcements as estimated above (and is set equal to zero on non-FOMC announcement days), $\varepsilon_t^{(h)}$ is a residual, and $\alpha_h$, $\beta_h$, and $\gamma_h$ are parameters that may vary across regressions $h$. This is essentially Jordà's (2005) "local projection" method of estimating impulse response functions, with a lag length of zero for the lagged endogenous variable $y$ on the right-hand side, since I find that additional lags aren't needed. As discussed by Jordà (2005), the local projections in (3) have several advantages over extrapolating the results of a daily-frequency AR(1) or VAR(1) as in Wright (2012). In particular, the results of extrapolation compound any errors in the parameter estimates as the horizon $h$ increases, while the local projections method avoids extrapolation and compounding altogether and is thus more robust to model misspecification.

I estimate that the coefficients $\alpha_h$ and $\beta_h$ are essentially always close to zero and one, respectively, so I impose those restrictions in the analysis. Then (3) is just a regression of the $h$-day difference, $y_{t+h} - y_t$, on the factors $\widetilde{F}_t$. The estimated coefficients $\hat{\gamma}_h$ vary across forecast

**Figure 2.** Estimated effects of forward guidance and LSAPs on 2- and 10-year zero-coupon Treasury yields, for different horizons $h$ ranging from 1 to 120 days. Estimated coefficients $\hat{\gamma}_h$ (solid bue line) and heteroskedasticity-consistent $\pm 1.96$-standard-error bands (dashed red lines) are from regressions $\Delta y_{t+h} = \gamma_h \widetilde{F}_t + \varepsilon_t^{(h)}$. See text for details.

horizons $h$, so we can plot those coefficients as a function of the horizon $h$ to see whether those coefficients tend to diminish as the horizon length 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 $\varepsilon_t^{(h)}$ will tend to be larger, and the standard errors surrounding the coefficient estimates $\hat{\gamma}_h$ will tend to be larger as well.

Figure 2 plots the results of these regressions for the 2-year and 10-year Treasury yields. The solid blue line in each panel plots the point estimates of $\hat{\gamma}_h$ as a function of horizon $h$, and dotted red lines plot Huber-White heteroskedasticity-consistent $\pm 1.96$-standard-error bands

around those point estimates. The estimated effect of a one-standard-deviation change in forward guidance on the 2-year Treasury yield is about 2.9bp on impact ($h = 1$ in the top-left panel of Figure 2), slightly less than the estimated effect in Table 4 that used intradaily data. The standard errors around the point estimate show that this one-day response is highly statistically significant. For horizons $h$ out to about 50 days, the point estimates remain between about 2–5bp, and are statistically significant out to horizons of about 35 days. At horizons beyond about 50 days, the point estimates are a bit smaller, but the standard errors are wide.

The effect of forward guidance on the 10-year Treasury yield, reported in the bottom-left panel of Figure 2, is about 1.9bp on impact, and is highly statistically significant. For horizons out to about 30 days, the effect is actually somewhat larger, around 5bp, and is typically highly statistically significant. (Thus, the effects of forward guidance on the 10-year Treasury yield exhibit a hump-shaped pattern over the first 30 days during this sample.) After about 30 to 40 days, the effects of forward guidance on the 10-year yield seem to be close to zero, although the standard errors are large.

For LSAPs, there is stronger evidence that the effects die out over longer horizons $h$. The effect of a one-standard-deviation increase in LSAPs causes the 2-year Treasury yield to fall about 3.6bp on impact in the top-right panel of Figure 2, and this effect is very highly statistically significant.[18] However, the effect seems to decrease almost monotonically with the horizon $h$, falling gradually to about 2bp in size after 50 days, and then fluctuating around 0 after that point. The standard error bands are somewhat narrower than for forward guidance. For the 10-year Treasury yield, the estimated effect is nearly 9bp on impact in the bottom-right panel, and again the effect diminishes almost monotonically over time, reaching 3bp after about 40 days, and then fluctuating around 0 at horizons of 50 days or more.

To estimate the degree of attenuation in these sensitivity coefficients over time, and the statistical significance of that attenuation, I fit an exponential function to the coefficients $\gamma_h$,

$$\gamma_h = a + be^{ch}, \tag{4}$$

where $a$, $b$, and $c$ are parameters. I stack the regressions in (3) into a single system, impose the

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[18] The estimated effect in Table 4 is smaller, only about $-1.3$bp for the intraday window, but that estimate is for an on-the-run (i.e., most recently issued, most liquid, and most heavily traded) coupon-bearing 2-year Treasury, while the estimates in Figure 2 are for a zero-coupon 2-year Treasury, which has a longer Macauley duration. Since the effects of LSAPs generally increase with duration, we should expect the effect on the zero-coupon 2-year Treasury to be larger. Zero-coupon yields are from the Gürkaynak et al. (2007) database and keep the maturity constant even as the horizon $h$ and time $t$ change. In contrast, a coupon-bearing Treasury's maturity could vary by up to 6 months, which can be problematic.
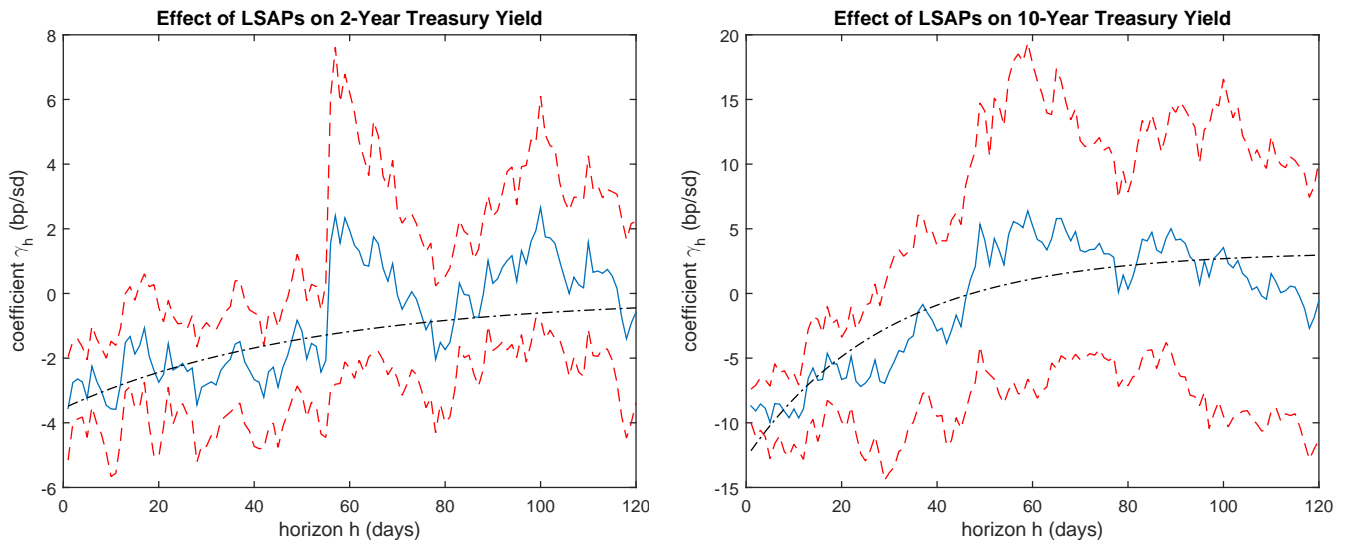
**Figure 3.** Estimated effects of LSAPs on 2- and 10-year zero-coupon Treasury yields for different horizons $h$. Unrestricted coefficient estimates $\hat{\gamma}_h$ (solid bue lines) and heteroskedasticity-consistent $\pm 1.96$-standard-error bands (dashed red lines) are from regressions $\Delta y_{t+h} = \gamma_h \widetilde{F}_t + \varepsilon_t^{(h)}$. Restricted coefficient estimates $\gamma_h = a + b e^{ch}$ (dot-dashed black lines) are from the same set of regressions estimated jointly via nonlinear least squares. See text for details.

restriction (4) on the coefficients $\gamma_h$, and estimate the parameters $a$, $b$, and $c$ in a single step via nonlinear least squares. The dashed black lines in Figure 3 depict the results of this restricted specification for the effect of LSAPs on the 2-year and 10-year Treasury yields (the right-hand panels of Figure 2).

Table 7 reports the estimated values of $a$, $b$, and $c$ for the effects of forward guidance and LSAPs on the 2- and 10-year Treasury yields. For forward guidance, the negative point estimates for the parameter $c$ are consistent with the attenuation in $\gamma_h$ that was visible in the left-hand panels of Figure 2. However, that attenuation is not statistically significant, with very small $t$-statistics for $c$. Small changes in $c$ do not lead to an appreciable change in fit in the regressions (4), given the large standard errors in the left-hand panels of Figure 2.

For LSAPs, however, the attenuation is more significant, economically and statistically, and particularly so for the 10-year Treasury yield. The estimated decay rate, $c$, is about 3.4 percent per (business) day, implying a half-life of about 20 business days, and is highly statistically significant, with a $t$-statistic of 2.8. (The estimated decay rate for the 2-year Treasury yield is smaller, about 2 percent per day, and is not statistically significant.) According to the point estimates for $a$, $b$, and $c$, the coefficient $\gamma_h$ falls to roughly zero after 45 days, consistent with the unrestricted estimates (the blue line) in the bottom-right panel of Figure 2 and right-hand panel of Figure 3.

However, these estimates are sensitive to whether the very large and influential March 18,

TABLE 7: ESTIMATED PERSISTENCE COEFFICIENTS

| | Forward Guidance | | | LSAPs | | |
|---|---|---|---|---|---|---|
| | $a$ | $b$ | $c$ | $a$ | $b$ | $c$ |
| 2-year Treasury yield | −18.7 | 21.7 | −0.0004 | −0.12 | −3.43*** | −0.0196 |
| (std. err.) | (2071) | (2071) | (.043) | (1.147) | (0.965) | (0.018) |
| [$t$-stat.] | [−0.01] | [.011] | [−.010] | [−0.10] | [−3.56] | [−1.11] |
| 10-year Treasury yield | −21.4 | 28.2 | −0.0048 | 3.24 | −15.93*** | −0.0337*** |
| (std. err.) | (45.43) | (44.20) | (.010) | (1.344) | (2.281) | (0.012) |
| [$t$-stat.] | [−0.47] | [0.64] | [−0.47] | [2.41] | [−6.98] | [−2.80] |

Coefficients $a$, $b$, and $c$ for restriction $\gamma_h = a + be^{ch}$ in regressions (3), estimated via nonlinear least squares. Standard errors in parentheses; $t$-statistics in square brackets; *** denotes statistical significance at the 1% level. See text for details.

2009, FOMC announcement is included or excluded from the analysis. Recall that the March 2009 announcement was both very large (over $1.1 trillion of new long-term bond purchases were announced) and very informative, being the first LSAP announcement by the FOMC and one that suggested they would begin to conduct such LSAP operations on a more regular basis. In fact, the March 18 announcement's effects were so large that it appears as a 5.5-standard-deviation surprise in the LSAP factor in Figure 1.

Having influential observations is good for econometric power, but can be a problem if the behavior around that observation is unusual or nonrepresentative. Figure 4 examines the behavior of long-term interest rates around the March 18, 2009, announcement in more detail. Treasury yields across the curve fell dramatically on the day of the announcement, but 5- and 10-year yields began to creep back up over the ensuing weeks, erasing all of the decline in long-term yields by about the 30th business day after the announcement. In contrast, 1- and 2-year Treasury yields remained at their lower levels essentially indefinitely.

In Figure 5, I check whether this behavior was unusual by excluding the March 18 observation from the analysis and re-running the regressions (3) and (4) underlying Figures 2 and 3. The results for forward guidance are essentially unchanged from Figure 2 and are not reported, but the results for LSAPs are significantly different. For both the 2- and 10-year Treasury yields, the impact effects of LSAPs are essentially just as large (albeit a touch smaller for the 2-year yield), and these effects are highly statistically significant, as before. However, there is much less evidence that these effects die out over time, especially for the 10-year yield.

Thus, the lack of persistence that I estimated above for LSAPs seems to be driven almost entirely by the behavior of long-term bond yields after the March 18, 2009, FOMC announcement.
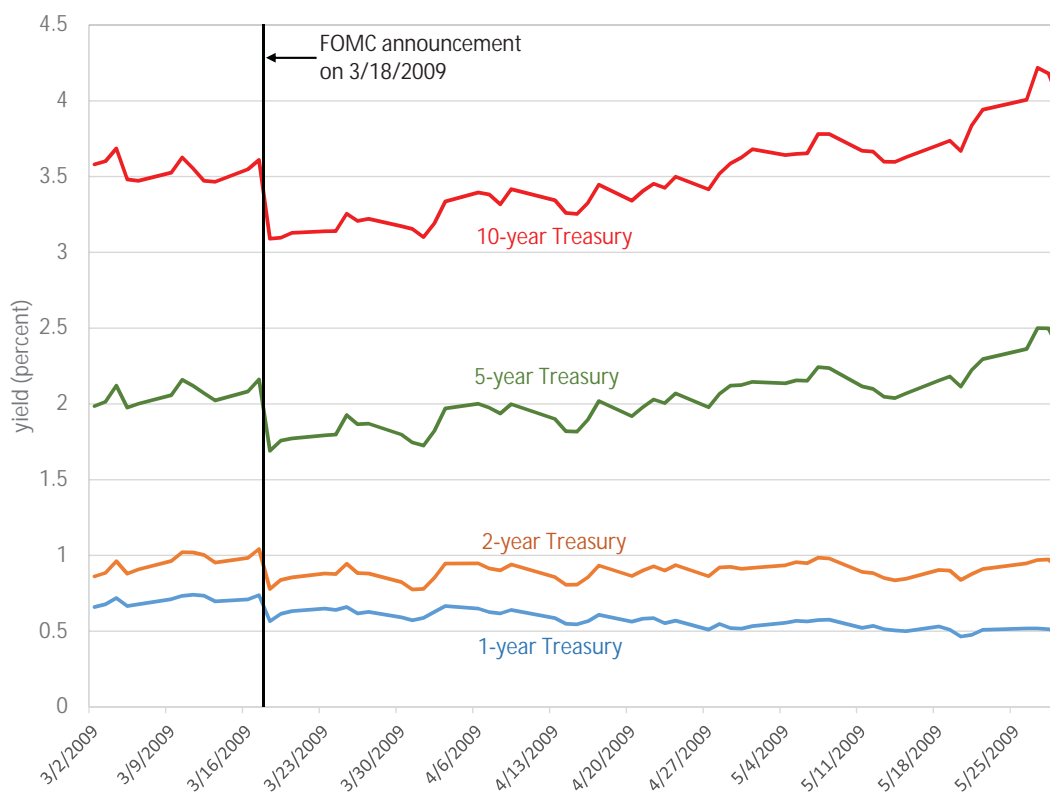
**Figure 4.** 1-, 2-, 5-, and 10-year zero-coupon Treasury yields from March 1 to May 31, 2009. See text for details.

A priori, there is no reason to exclude that announcement—in fact, it is arguably one of the best observations in my data, due to its size and the fact that it was largely unexpected. Nevertheless, the fact that the persistence estimates are not robust to its inclusion or exclusion does make those results somewhat suspect.

Finally, it is natural to compare my persistence estimates above to those of Wright (2012). Wright (2012) estimates a half-life of about 2–3 months for the effects of unconventional monetary policy on long-term bond yields, over a sample that includes the influential March 2009 observation and ends in late 2011. My persistence estimates differ from Wright's (2012) in two main respects: First, I distinguish between the persistence of the effects of LSAPs and those of forward guidance. I find that LSAPs are even less persistent over the full ZLB sample than Wright's estimate, with a half-life of only about 1 month rather than 2–3. Because Wright does not distinguish between LSAPs and forward guidance, his persistence estimates are effectively for an average of the two types of policies, and I find that the effects of forward guidance are more persistent than those of LSAPs, which would explain the difference. Second, I show the importance of the March 2009 FOMC announcement for the persistence results. Dropping that one observation, I estimate the
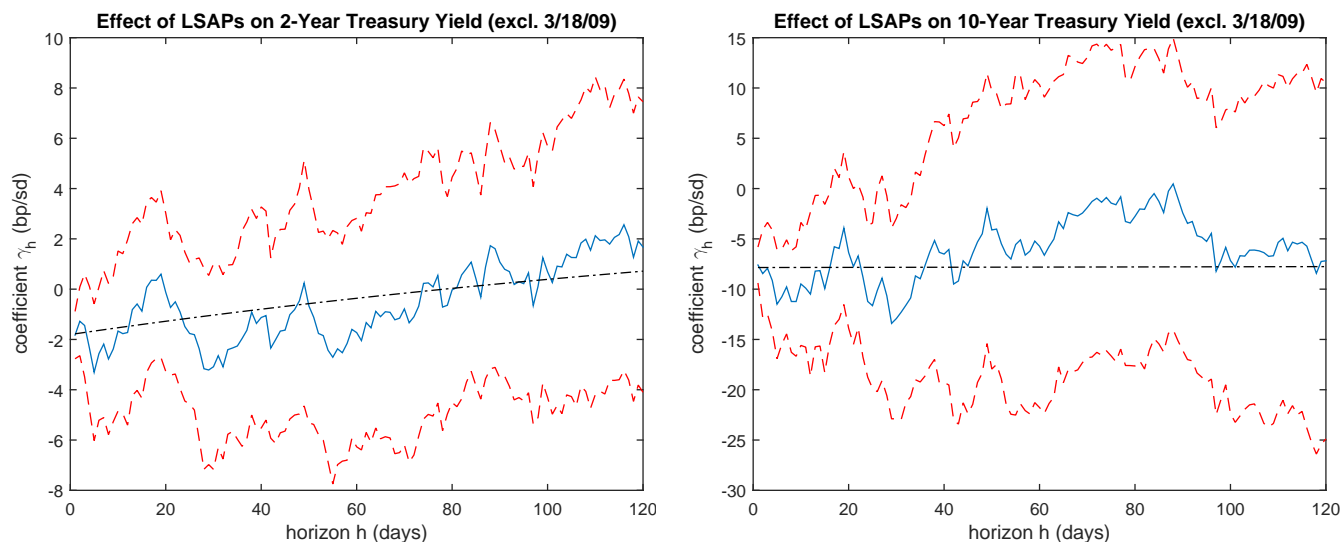
**Figure 5.** Estimated effects of LSAPs on 2- and 10-year zero-coupon Treasury yields for different horizons $h$, excluding the large and influential March 18, 2009, FOMC announcement. See notes to Figures 2 and 3 and text for details.

effects of LSAPs and forward guidance to be much more persistent than Wright's (2012) estimate.

## 6. Effects of Forward Guidance and LSAPs on Interest Rate Uncertainty

Unconventional monetary policy could also have substantial effects on interest rate uncertainty. For example, one goal of forward guidance is to reduce financial market uncertainty about the path of the federal funds rate, as well as financial market expectations about the level of that path (see, e.g., Bernanke, 2013). It is thus interesting to assess whether the FOMC's forward guidance announcements over this period achieved this former goal as well as the latter. For LSAPs, one can imagine that uncertainty about long-term bond yields could either rise or fall: on one hand, if LSAPs are a new source of variation and shocks to long-term bond yields, that could increase the volatility of these yield and increase uncertainty; on the other hand, however, LSAPs could reduce volatility and uncertainty if they were often implemented in response to increases in long-term yields, because then LSAPs would be a stabilizing force.

To measure uncertainty about the path of the federal funds rate over the next several months or quarters, I use data on Eurodollar options with five quarters to expiration, as in Swanson and Williams (2014). These data are available at daily frequency with a range of strike prices, which can be used to estimate the entire implied distribution of the federal funds rate in five quarters' time.[19] Following Swanson and Williams (2014), I use the distance between the $80^{\text{th}}$ and $20^{\text{th}}$

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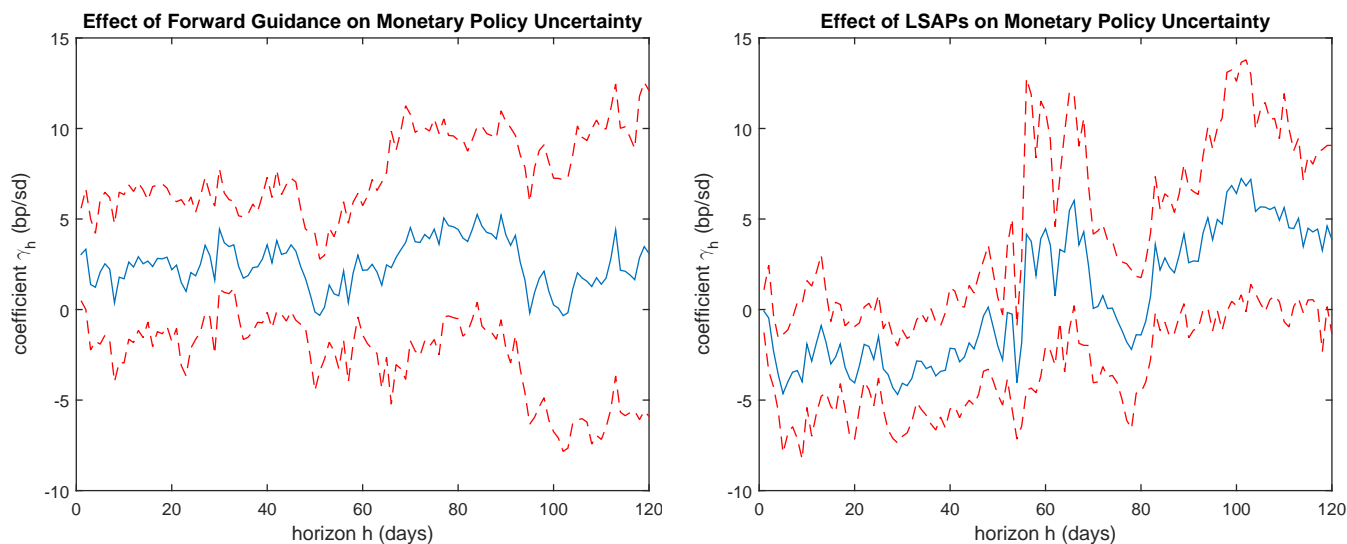[19] I do not need to assume normality for these distributions because we observe option prices for multiple different

**Figure 6.** Estimated effects of forward guidance and LSAPs on monetary policy uncertainty, measured as the distance (in bp) between the $80^{\text{th}}$ and $20^{\text{th}}$ percentiles of the PDF for the federal funds rate 5 quarters ahead, implied by Eurodollar options. See notes to Figure 2 and text for details.

percentiles of that distribution on any given day as a measure of uncertainty on that day about the path of the federal funds rate over the next 4 to 5 quarters.

Figure 6 reports results from regression (3), with monetary policy uncertainty as the dependent variable $y$. In response to a one-standard-deviation increase in forward guidance, monetary policy uncertainty increases by about 3bp (as measured by the interquintile range in the implied PDF from Eurodollar options described above), and this change is statistically significant with a $t$-statistic of about 2.3. Thus, the data support Bernanke's (2013) stated goal that reductions in forward guidance by the FOMC should reduced financial market uncertainty about the future path of the federal funds rate. However, as can be seen in Figure 6, this effect is not statistically significant after about 2 days.

The right-hand panel of Figure 6 reports the effects of LSAPs on monetary policy uncertainty. Although the effects of LSAPs on that uncertainty are essentially 0 on impact, the effect becomes significantly negative over the course of the next three days, and remains at about $-2$ to $-5$bp for most of the next 50 days, often statistically significantly so. Thus, the FOMC's asset

strikes. On each day from January 2008 through December 2012, I use the range of available Eurodollar option put and call prices with five quarters to expiration to estimate the implied distribution of the spot 3-month Eurodollar rate in five quarters' time, using a flexible functional form. Eurodollar options are the most liquid options on a short-term interest rate and thus provide the best measure of the distribution of possible short-term interest rate outcomes. I use the spread between overlapping federal funds futures and Eurodollar futures rates at a one-year horizon to convert these implied distributions for the 3-month Eurodollar rate into an implied distribution for the federal funds rate. These probability estimates ignore risk premia and thus represent implied risk-neutral probabilities.
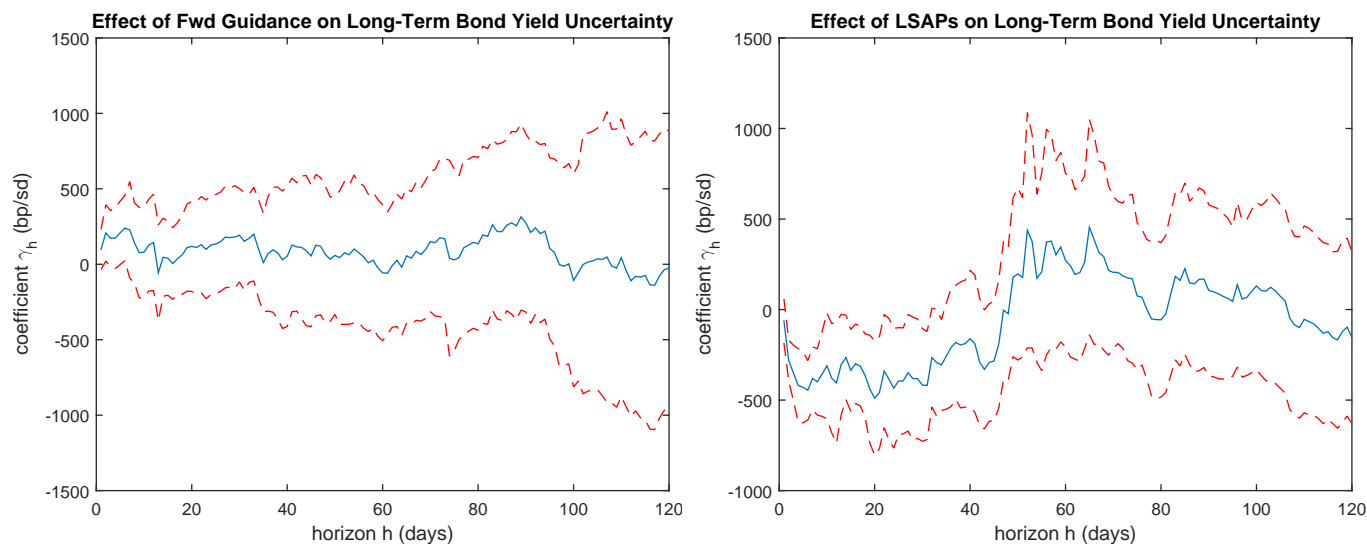
**Figure 7.** Estimated effects of forward guidance and LSAPs on long-term bond yield uncertainty, as measured by the Bank of America/Merrill Lynch MOVE index of implied volatility (in bp/year) from options on Treasury securities. See notes to Figure 2 and text for details.

purchases seem to have spoken more loudly than their words as far as convincing markets about their commitment to a future path for the federal funds rate. This finding seems very much in line with the discussion in Woodford (2012) and Bauer and Rudebusch (2014), that one channel through which LSAPs affected financial markets was by signalling the FOMC's commitment to keep the federal funds rate low for an extended period. Thus, even though my results in Tables 2 and 3 reject the hypothesis that LSAPs work *entirely* through the signalling channel, my results here do suggest that LSAPs have significant signalling effects.

In Figure 7, I plot similar results using the Bank of America/Merrill Lynch MOVE index of long-term bond yield uncertainty. The MOVE index is a composite of implied volatility on U.S. Treasury bonds with 2, 5, 10, and 30 years to maturity, measured using options on these securities, with most of the weight on the 5- and 10-year maturities. Overall, the results in Figure 7 look very similar to those in Figure 6 for shorter-term interest rate uncertainty: An increase in forward guidance raises longer-term bond yield uncertainty by a small amount, but the effect is not statistically significant and declines to zero after a few days. An increase in LSAPs, on the other hand, has essentially no effect on longer-term bond yield uncertainty on impact, but then leads to statistically significant declines in that uncertainty by about 4bp over the next few days, and this effect persists for about 45 days.

Far from increasing longer-term bond yield uncertainty, an increase in LSAPs by the FOMC seems to have had a stabilizing effect on longer-term bond yields. This would be the case, for

example, if the FOMC's LSAP operations were conducted in such a way as to "push back" against movements in long-term interest rates.

# 7. Conclusions

In this paper, I show how to identify and estimate the forward guidance and large-scale asset purchase component of every FOMC announcement between January 2009 and October 2015, the zero lower bound period in the U.S. Building on earlier work by Gürkaynak, Sack, and Swanson (2005), I estimate a time series for each type of unconventional monetary policy announcement, and show that these series correspond to identifiable characteristics of important FOMC statements during this period.

I use these identified forward guidance and LSAP announcements to estimate the effects of both types of policy on a wide variety of financial market instruments, including Treasuries, stock prices, exchange rates, and corporate bond yields and spreads. I find that forward guidance affects Treasury yields at all but the very longest maturities, with a peak effect at a maturity of about 5 years. In contrast, the effect of LSAPs generally increases with maturity, with a peak effect around 10 years. LSAPs have essentially no effect on the shortest-maturity Treasuries.

For corporate bond yields, I estimate that forward guidance has essentially no effect, while LSAPs have substantial and highly significant effects on those yields. The effects of LSAPs on corporate debt is smaller than their effects on Treasuries, however, so corporate bond spreads actually widen after an increase in the FOMC's asset purchases. This finding is consistent with others in the literature, and probably reflects the fact that the Fed's LSAP programs focused on purchasing Treasury and Agency securities.

I find that forward guidance and LSAPs were about equally important for stock prices and exchange rates. The effect on stock prices is perhaps surprising, given that forward guidance seems to have been relatively unimportant for other long-duration assets (long-term Treasuries and corporate bonds). For exchange rates, the effects of unconvetional monetary policy are consistent with a standard uncovered interest parity explanation: increases in U.S. interest rates due to either forward guidance or LSAPs cause the U.S. dollar to appreciate.

There is some evidence that the effects of LSAPs on Treasury yields are not very persistent, particularly for the longest-maturity yields. On its face, this is consistent with the "slow-moving capital" view of Duffie (2012), Fleckenstein, Longstaff, and Lustig (2014), and others, in which

financial markets may take a few weeks or even months to bring expected returns on assets back to their fundamental risk-adjusted values. However, I find that this persistence result for LSAPs is almost entirely driven by a single, very influential FOMC announcement on March 18, 2009, that essentially kicked off the FOMC's "QE" programs. Although there is no a priori reason to exclude this announcement from the sample, whether one finds LSAPs to have persistent effects or not is heavily dependent upon its exclusion or inclusion, respectively.

Finally, I find that the FOMC's forward guidance had only a small effect on financial market uncertainty during the zero lower bound period. On the other hand, LSAPs appear to have had a much greater effect, with increases in LSAPs reducing interest rate uncertainty for both short-term and long-term interest rates.

Looking forward, it's natural to ask which policy is more effective. First, it's difficult to compare the scale of these two different types of policies—for example, is a $100 billion LSAP operation large or small, and is it larger or smaller than a 25bp change in forward guidance about the federal funds rate one year ahead? One natural way of comparing magnitudes across the two types of policies is in terms of their historical importance: over the 2009–2015 period, a one-standard-deviation change in forward guidance by the FOMC corresponded to a change of about 4.5bp in federal funds rate expectations one year ahead, while a one-standard-deviation change in LSAPs corresponded to a roughly $300 billion change in bond purchases. Using these estimates as a basis for comparison, a one-standard-deviation (4.5bp) change in forward guidance appears to have been about as effective at changing medium-term Treasury yields, stock prices, and exchange rates as a one-standard-deviation ($300B) change in LSAPs, at least in the short run. As noted above, LSAPs were more effective at changing long-term Treasury and corporate bond yields, while forward guidance was more effective at moving shorter-term Treasury yields.

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