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Brent Bundick, Trenton Herriford, and A. Lee Smith

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Forward Guidance, Monetary Policy Uncertainty, and the Term Premium*

Brent Bundick[†] Trenton Herriford[‡] A. Lee Smith[§]

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Abstract

When the Federal Reserve provides greater clarity about the path of future interest rates, term premia in longer-term bonds fall and economic activity increases. This interest rate uncertainty channel of forward guidance sheds light on three important issues in macroeconomics. First, this channel explains how forward guidance shapes term premia, both away from and at the zero lower bound. Second, our mechanism offers a novel explanation for the puzzling fact that monetary policy announcements affect distant real forward rates. Finally, we show that event studies overstate the effects of large-scale asset purchases when they fail to control for simultaneous forward guidance.

JEL Classification: E32, E52
Keywords: Forward Guidance, Policy Uncertainty, Term Premium

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[†] Federal Reserve Bank of Kansas City. Email: brent.bundick@kc.frb.org

[‡] University of Texas at Austin. Email: trenton.herriford@utexas.edu

[§] Federal Reserve Bank of Kansas City. Email: andrew.smith@kc.frb.org

1 Introduction

At its August 9, 2011 meeting, the Federal Open Market Committee (FOMC) profoundly shifted its forward guidance about the future path of its policy rate. Specifically, the Committee stated that it anticipated "exceptionally low levels for the federal funds rate at least through mid-2013." This announcement was the first FOMC statement to explicitly reference a calendar date for how long the funds rate would remain near zero. Following this announcement, term premia in longer-horizon Treasury bonds declined significantly. Figure 1 shows the one-day change in the Adrian, Crump and Moench (2013) and Kim and Wright (2005) measures of term premia following this announcement. Both measures show that the term premium on a 10-year Treasury note fell by over 15 basis points following this forward guidance announcement.

This episode challenges commonly-accepted intuition from policymakers and macro-finance models. For example, Bernanke (2013) states that, "Forward rate guidance affects longer-term interest rates primarily by influencing investors' expectations of future short-term interest rates. Large-scale asset purchases (LSAPs), in contrast, most directly affect term premiums." Under this view, the August 2011 forward guidance announcement should not affect term premia since the FOMC did not change its balance sheet policy nor provide information about possible future balance sheet actions at that meeting. Moreover, Rudebusch and Swanson (2012) and Andreasen (2012) show that changes in the stance of monetary policy have very little effect on longer-horizon term premia in estimated macro-finance models.

In this paper, we show that changes in the uncertainty about the future path of short-term interest rates explain much of the decline in term premia following the August 2011 forward guidance announcement. Moreover, we show that this connection between interest rate uncertainty and term premia in longer-horizon bonds extends beyond just this particular announcement. We present robust empirical evidence that forward guidance works, in part, by changing the uncertainty around the policy path. Lower uncertainty about future policy rates transmits to the broader macroeconomy by reducing term premia in longer-term bond markets. These results suggest a new and quantitatively important transmission mechanism of central bank forward guidance.

To illustrate this new transmission mechanism, we undertake three steps. First, we measure uncertainty about future short-term interest rates. Second, we isolate exogenous shifts in this measure of uncertainty around monetary policy announcements. Finally, we examine the effects of these exogenous changes in monetary policy uncertainty on term premia in bond markets and the broader macroeconomy. For the first task of measurement, we develop new, daily frequency measures of uncertainty about future short-term interest rates over multiple horizons. Specifically, we apply the CBOE Volatility Index (VIX) methodology to Eurodollar options with various expiration dates. Then, following the recent literature on identifying first-moment monetary policy shocks, we use the changes in our measures around regularly-scheduled FOMC meetings to isolate exogenous shifts in interest rate uncertainty attributable to monetary policy. Finally, we use event-study regressions and a vector autoregression (VAR) model to determine the effects of changes in monetary policy uncertainty on bond market term premia and measures of economic activity and prices.

We begin our analysis using the 1994–2008 sample period, which avoids the task of disentangling the effects of forward guidance from large-scale asset purchases. While the FOMC's most recent experience with forward guidance occurred at the zero lower bound, previous FOMC statements influenced perceptions about future policy rates. Many times, post-meeting communication explicitly referenced future policy rates. In other instances, the Committee's description of risks surrounding the outlook for growth and inflation implicitly shaped perceptions about future policy rates. For the purposes of this paper, we define all such forms of post-meeting communication as forward guidance since they all could affect the amount of uncertainty surrounding future policy rates.

During the pre-zero lower bound period, we find that forward guidance announcements that lower uncertainty about future short rates lead to statistically significant declines in term premia. We find that two principal components succinctly capture changes in the term structure of short-rate uncertainty around FOMC announcements. These two components can be interpreted as shocks to the level and slope of the term structure of implied short-rate uncertainty. Using an event-study approach around FOMC meetings, we find an unexpected decline in the slope of option-implied uncertainty leads to a significant decline in bond market term premia of all horizons. Quantitatively, a 5 basis point flattening in the slope of the term structure of interest rate uncertainty leads to about a 3 basis point reduction in the 10-year term premium. Importantly, these estimated effects remain when we include Gurkaynak, Sack and Swanson (2005)-type target and path factors in our model, which alternatively measure changes in the expected path of rates around policy announcements. Thus, our interest rate uncertainty factors measure a novel, distinct, and empirically-relevant channel through which forward guidance transmits to financial markets.

This uncertainty channel of forward guidance became more important during the zero lower bound. For a given movement in FOMC-induced interest rate uncertainty, we find that the transmission to longer-horizon term premia roughly triples during the zero lower bound period. Moreover, we show that our interest rate uncertainty factors explain a significant fraction of movements in longer-horizon term premia around FOMC announcements at the zero lower bound. This finding suggests that the FOMC's use of more explicit rate guidance, such as its use of date-based guidance in August 2011, likely amplified the transmission mechanism of interest rate uncertainty to bond market term premia.

In addition to explaining how the August 2011 FOMC statement lowered term-premia on longer-term bond yields, this interest rate uncertainty channel of forward guidance also sheds light on the puzzling response of distant forward real rates to FOMC statements and the efficacy of LSAPs. Building on the work of Hanson and Stein (2015), we show that forward guidance, operating through interest rate uncertainty, plays a quantitatively important role in explaining movements in distant real forward rates around policy announcements. In addition, we show that existing empirical work likely overstates the effect of large-scale asset purchases if event studies fail to control for contemporaneous changes in forward guidance operating through interest rate uncertainty. Using the Krishnamurthy and Vissing-Jorgensen (2011) event study as an example, we find that controlling for the simultaneous effects of interest rate uncertainty on term premia reduces the quantitative magnitude of the effects of LSAPs by roughly 25 percent. Taken together, our results suggest that the uncertainty around the future path of policy rates plays a more important role than previously thought in understanding the transmission mechanism of monetary policy.

Beyond these effects on financial markets, we show that changes in uncertainty surrounding the future path of policy rates also affect the broader macroeconomy. Using a vector autoregression, we show that a persistent decline in future short-rate uncertainty eases financial conditions and leads to increases in economic activity and prices. Following a one standard deviation reduction in the slope of implied short-rate uncertainty, industrial production rises by 0.50 percent, the unemployment rate declines by about 5 basis points, and prices increase by 0.25 percent after about one year. Importantly, these effects remain even after controlling for changes in the expected path of rates, suggesting a new and quantitatively important link between monetary policy communication, financial conditions, and the broader economy.

2 Simple Theoretical Model

We now describe a simple model which helps illustrate why changes in uncertainty about future interest rates can be a key determinant of term premia in longer-term bonds. While the model is quite stylized, we use it to guide our intuition and motivate our empirical specifications.

Our simple model features a representative household which maximizes lifetime expected utility over consumption C_t. The household receives endowment income e_t and can purchase nominal bonds with maturities of 1 to N periods. p_t^n denotes the price of an n-period bond, which pays one nominal dollar at maturity ($p_t^0 = 1$). We denote the aggregate price level using P_t. The household divides its income between consumption C_t and the amount of the bonds b_{t+1}^n for $n = 1, \ldots, N$ to carry into next period.

The representative household chooses C_{t+s}, and b_{t+s+1}^n for all bond maturities $n = 1, \ldots, N$ and all future periods $s = 0, 1, 2, \ldots$ by solving the following problem:

$$\max \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \log\left(C_{t+s}\right)$$

subject to the intertemporal household budget constraint each period,

$$C_t + \sum_{n=1}^{N} p_t^n \frac{b_{t+1}^n}{P_t} \leq e_t + \sum_{n=1}^{N} p_t^{n-1} \frac{b_t^n}{P_t}.$$

Using a Lagrangian approach, we can derive the following two optimality conditions for the 1- and n-period bonds.

$$p_t^1 = \mathbb{E}_t \left\{ \beta \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \right\} \tag{1}$$

$$p_t^n = \mathbb{E}_t \left\{ \beta \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} p_{t+1}^{n-1} \right\} \tag{2}$$

We assume that the central bank sets the one-period gross nominal interest rate R_t, which is equal to the inverse of the one-period bond price p_t^1. For analytical tractability, we also make two additional assumptions. First, we assume that all nominal bonds are in zero net supply. Second, we assume that prices are fixed $P_t = P$ for all t such that monetary policy can control the path of real interest rates. This second assumption is not crucial, however it allows us to derive clearer expressions for longer-term bond yields and the term premium.[1]

After some algebraic manipulation, we can use a second-order approximation of Equation (2) to derive the following expression:

$$c_t = \mathbb{E}_t\Big\{c_{t+n}\Big\} - \frac{1}{2}\,\mathbb{VAR}_t\Big\{c_{t+n}\Big\} - n\,\Big(y_t^n + \log\big(\beta\big)\Big). \tag{3}$$

In this equation, $c_t = \log(C_t)$, $\mathbb{VAR}_t$ denotes the conditional variance, and y_t^n is the yield to maturity on an n-period bond.[2] Consumption today depends on the expectation and uncertainty about consumption in period $t+n$ and on the longer-term yield bond. All else equal, Equation (3) shows that lower long-term bond yields induce higher household consumption.

Moreover, we can decompose the yield to maturity on the n-period bond into two components:

$$y_t^n \approx \frac{1}{n}\left[\sum_{i=0}^{n-1}\mathbb{E}_t\Big\{r_{t+i}\Big\} + \frac{1}{2}\mathbb{VAR}_t\left\{\sum_{i=0}^{n-1} r_{t+i}\right\}\right], \tag{4}$$

where $r_t = \log(R_t)$ is the net nominal interest rate controlled by the central bank. The first component depends on the expected path of short-term interest rates. The second term reflects the additional compensation the household requires to hold a longer-term security in the face of an uncertainty about future short-term interest rates.

Following Rudebusch and Swanson (2012), we can derive an expression for the term premium as the difference between the yield to maturity on the n-period bond y_t^n and the yield on a risk-neutral n-period bond $\hat{y}_t^n$:

$$TP_t^n \triangleq y_t^n - \hat{y}_t^n \approx \frac{1}{n}\,\mathbb{VAR}_t\left\{\sum_{i=0}^{n-1} r_{t+i}\right\}. \tag{5}$$

Equation (5) highlights the link between term premia and interest rate uncertainty. Households require higher compensation to hold a longer-term bond when they face higher uncertainty about future short-term interest rates. This model suggests that forward guidance announcements that provide greater clarity about future short-term interest rates should lower term premia in longer-term nominal bonds.

[1] If we don't assume fixed prices, we can derive Equation (5) under the assumption that households have linear utility. Using a simple two-period model with mean-variance investors, Hanson and Stein (2015) also show that the term premium depends on uncertainty about future short rates.

[2] The Appendix contains a detailed derivation of all of the equations in Section 2.

Our simple model provides two key testable predictions. Motivated by Equation (5), forward guidance announcements which change uncertainty about future short-term interest rates should also affect term premia in longer-term bond yields. Moreover, Equation (3) suggests that if forward guidance announcements lower term premia and bond yields, then all else equal, they should also increase broader economic activity. In this paper, we present robust empirical evidence that supports both of these model predictions.

3 Measuring Interest Rate Volatility

To formally examine the link between changes in central bank forward guidance and term premia in longer-term bonds, we require measures of the uncertainty surrounding the future path of monetary policy. Furthermore, our econometric identification strategy calls for daily data. Therefore, while monthly measures of monetary policy uncertainty are available, we apply the VIX methodology to Eurodollar options to measure uncertainty about future short-term interest rates at a daily frequency. These interest rate derivatives settle based on the future value of the London Interbank Offer Rate (LIBOR), a benchmark short-term interest rate that is highly correlated with the federal funds rate. Using all out-of-the-money put and call options of a given expiration date, we calculate the option-implied volatility of short-term interest rates at a particular horizon. We then repeat this procedure for horizons between one- and five-quarters ahead. In practice, we find that options in these horizons have enough liquidity and available strike prices to reliably calculate implied interest rate volatility at a daily frequency.[3]

We denote our option-implied index of short-term rate uncertainty the EDX, short for Eurodollar Volatility Index. Figure 2 plots the one-quarter-ahead EDX (EDX 1Q) and the five-quarter-ahead EDX (EDX 5Q) for each day over the 1994–2015 period.[4]. On average,

[3]The Chicago Board Option Exchange details the VIX methodology at https://www.cboe.com/micro/vix/vixwhite.pdf. We purchased the Eurodollar options data from the CME Group.

[4]Eurodollar options most often trade for settlement in March, June, September, and December of a given year. For each month within a quarter, we assign the horizon based on the next available settlement date 1-5 quarters ahead. For example, for days in January, February, and March, we compute the 1-quarter ahead horizon using options with a June settlement of the same year. Thus, our 1-quarter ahead horizon actual refers to a 3-6 month horizon depending on the exact date within the quarter. Figure 2 shows that this method of assigning horizons leads to some predictable variation in interest rate uncertainty for our shortest 1-quarter ahead measure within each quarter. Alternatively, we could choose to average adjacent horizons in order to keep an exact horizon constant during the quarter. However, we prefer our method for two reasons.

the one-quarter-ahead uncertainty about future short-term interest rates is about 25-50 basis points. Over the five-quarter-ahead horizon, the market-implied uncertainty typically averages around 100-150 basis points, which illustrates an upward-sloping term structure of implied short-rate uncertainty. Both prior to and during the zero lower bound period, we observe significant fluctuations in our measures of interest rate uncertainty, especially at the longest five-quarter ahead horizon.

While we can construct our EDX measures for every trading day, we aim to identity fluctuations in uncertainty caused by changes in FOMC forward guidance. Therefore, our econometric identification follows the pioneering work of Kuttner (2001). He uses a one-day window around FOMC meetings to identify the effect of "unanticipated" changes in policy rates on Treasury yields. We make the same identifying assumption as Kuttner (2001): Prices in short-term financial markets reflect the expected distribution of future policy rates on the day before FOMC announcements. Then, we attribute the change in the price of short-term interest rate options on the day of a FOMC announcement to unanticipated monetary policy. For our baseline results, we use the change in our derived EDX measures around regularly-scheduled FOMC meetings over the 1994-2008 period to isolate monetary policy uncertainty shocks induced by changes in forward guidance.

We find that two principal components succinctly describe changes in our EDX measures of short-rate uncertainty around FOMC announcements. Table 1 shows the factor loadings and cumulative R^2 measures for the changes in our EDX measures. The first two principal components explain about 95% of the variation in interest rate uncertainty around FOMC announcements. Moreover, we see that the principal components have a distinctive loading pattern. Changes in uncertainty at all horizons are highly correlated with the first factor, which suggests that the first factor captures changes in the level of the term structure of short-rate uncertainty. The second factor, however, is negatively correlated with changes in short-term uncertainty but positively correlated with changes in longer-term uncertainty. Since our term structure of interest rate uncertainty features a positive slope on average, these factor loadings suggest that the second factor captures changes in the slope of the term structure of short-rate uncertainty.

We apply a simple scaling procedure to these level and slope factors to ease the interpre-

First, our primary interest is examining the *daily* changes in our EDX measure, which is not affected by this quarterly-frequency variation. Second, averaging between two adjacent horizons would shorten our longest maturity horizon, which we find is the most informative in explaining movements in term premia.

tation of our regression results. We scale our level factor such that a one standard deviation movement in the level factor moves our shortest-term uncertainty measure, EDX 1Q, by the same amount. Then, we scale the slope factor such that it moves the slope of the EDX term structure (EDX 5Q less the EDX 1Q) in a one-to-one fashion. Table 2 illustrates the results of these scaling procedures. These regressions reinforce our interpretation of the first and second principle component as the level and the slope factors, respectively. The level factor alone explains nearly 80% of the variation in EDX 1Q around FOMC meetings. Similarly, the slope factor explains almost 90% of the variation in the changes in the slope of interest rate uncertainty around policy announcements. Furthermore, the EDX level factor has virtually no effect on the slope of interest rate uncertainty.

In addition to measuring uncertainty about future interest rates, our event-study analysis also requires estimates of term premia in longer-term bond markets. To measure term premia, our baseline specification relies on the prior work of Adrian, Crump and Moench (2013). Academic economists and policymakers commonly use these well-cited term premia estimates, which are available at a daily frequency from the Federal Reserve Bank of New York for 1- to 10-year zero-coupon bonds. However, to ensure that our conclusions are not driven by a particular estimate of term premia, we also use the Kim and Wright (2005) measure of term premia as a robustness check in our empirical analysis.

4 Forward Guidance & Term Premia: Evidence

Using these measures of interest rate uncertainty and bond market term premia, we now return to our key empirical question: Do changes in forward guidance that offer greater clarity about the path of future policy rates lead to a reduction in term premia in longer-term bonds? To answer this question, we use an event-study approach by examining movements in term premia and our interest-rate uncertainty factors around FOMC announcements. For our baseline specification, we estimate the following regression using ordinary least squares for each horizon over the 1994-2008 period:

$$\Delta TP_t^n = \alpha + \beta^L L_t + \beta^S S_t + \varepsilon_t, \qquad (6)$$

where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC announcement. L_t denotes our level factor and S_t denotes our slope factor, which are derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings.

We find robust evidence that FOMC-induced declines in uncertainty about future interest rates lead to reductions in term premia. Specifically, our slope factor has significant effects on bond market term premia at all horizons. Table 3 shows the regression results for each horizon. On average, a 5 basis point decline in the difference between EDX 5Q and EDX 1Q leads to a statistically significant 2-3 basis point decline in term premia of all horizons. The coefficients on the level factor are all positive, but are imprecisely estimated. Around FOMC announcements, our interest rate uncertainty slope factor explains between 11 and 20 percent of the variation in term premia in bond yields with maturities of 5 years or less. While the explained variation falls for the 6-10 year maturity term premia, we still observe a positive and statistically significant coefficient on our slope factor that remains relatively constant across different maturities. These results suggest that forward guidance announcements that shape the uncertainty around the path of policy rates influences the compensation investors require to hold longer-term Treasury securities.

4.1 Alternative Specifications & Other Measures of Policy Shocks

The link between forward guidance and term premia remains if we instead use a different measure of term premia or compute interest rate uncertainty using an alternative method. Table 4 illustrates larger effects for the slope factor and some additional precision on the level factor coefficients relative to our baseline estimates if we instead use the Kim and Wright (2005) measure of term premia. In addition, Table 5 shows that we also find very similar results to our baseline specification if we compute uncertainty by constructing the complete probability density function from options prices rather using the VIX methodology.[5] This method has two differences relative to our baseline EDX construction. First, this method uses both in- and out-of-the-money options prices, while the EDX only relies on the out-of-the-money options. Second, the VIX methodology technically measures the implied volatility of returns while our constructed probability density function method gives implied volatility about the level of interest rates.[6] Despite these differences, these alternative PDF measures are highly correlated with our EDX measures, leading to similar regression coefficients.[7] These results illustrate that our findings are robust to alternative measures of term

[5]Specifically, we use the method outlined in the Technical Appendix of Bundick and Herriford (2017) to construct the probability density function using Eurodollar options. We measure uncertainty using the standard deviation of the market-implied probability density function.

[6]Recent work by Bauer, Lakdawala and Mueller (2019) uses an alternative method for calculating interest rate uncertainty and highlights a systematic pattern in monetary policy uncertainty over an FOMC meeting cycle. Around policy announcements, our measures are highly correlated with their measure.

[7]We thank Michael Bauer for feedback that helped clarify our thinking in this area. Since the EDX calculation uses the strike prices of the options, which tend to be near 100 (100 - strike price = implied

premia and interest rate uncertainty.

Moreover, our conclusions are robust to including Gurkaynak, Sack and Swanson (2005)-type target and path factors in our model, which measure changes in the expected path of interest rates around policy announcements. Using changes in federal funds and Eurodollar futures, Gurkaynak, Sack and Swanson (2005) construct orthogonal target and path factors that together summarize almost all of the variation in these futures rates around policy announcements. Table 6 shows the coefficient estimates if we add these measures of changes in the target rate and the expected path of rates to our baseline regression model. Across all horizons, we observe coefficients on our slope factor that are very similar to our baseline specification without the Gurkaynak, Sack and Swanson (2005) target and path factors. At some horizons, we find evidence that the Gurkaynak, Sack and Swanson (2005) path factor explains movements in term premia.[8] However, looking across all maturities, we do not find robust evidence that the coefficients on the Gurkaynak, Sack and Swanson (2005) factors are statistically different from zero. The lack of a robust relationship between the Gurkaynak, Sack and Swanson (2005) factors and term premia is consistent with the intuition from Equation (5), which shows that changes in the expected path of policy do not determine the term premium. Overall, our findings suggest that changes in interest rate uncertainty represent a distinct channel through which forward guidance affects longer-term bonds, which is not well captured by existing "first-moment" monetary policy shocks.

4.2 Alternative Uncertainty Measures

Our results suggest that changes in the uncertainty about future short-term interest rates have significant implications for term premia. However, one may be concerned that our new measures of short-rate uncertainty reflect either shifts in overall macroeconomic uncertainty or risk premia embedded in options prices more broadly. For example, Bloom (2009) finds that many measures of uncertainty move together over time, a finding which could reflect either of these dynamics. We illustrate that neither dynamic is driving our main results by adding the VIX and MOVE indices to our baseline regression model. The VIX index measures implied equity market volatility, while the Bank of America Merrill Lynch Option Volatility Estimate (MOVE) Index captures implied volatility in the prices of longer-term Treasury bonds. Together, these measures should proxy well for overall macroeconomic un-

LIBOR Rate), the volatility of returns and the volatility of the level of interest rates are quite similar.

[8] Recent work by Hansen, McMahon and Tong (2019) shows that changes in the narrative information from the Bank of England's Inflation Report, which likely captures inflation risk premia as opposed to forward guidance (which is the focus of our paper), also help explain movements in term premia in longer-term bonds.

certainty and both are exposed to risk premia in options prices.

The VIX and MOVE measures of uncertainty do not explain movements in term premia around FOMC announcements. Table 7 shows the results for this model. The coefficients on both the VIX and the MOVE are basically zero. Furthermore, the coefficients on our slope factor are essentially unchanged from our baseline regression results in Table 3. This finding suggests that our slope factor represents a distinct measure of uncertainty about future monetary policy and does not simply reflect overall macroeconomic uncertainty or risk premia reflected in equity or bond markets.

4.3 FOMC Communication and Interest Rate Volatility

Our results suggest that, on average, FOMC-induced reductions in interest rate uncertainty lower term premia in longer-term bonds. We now provide narrative evidence that highlights the role that FOMC forward guidance plays in driving these shifts in interest rate uncertainty and, ultimately, term premia. Specifically, we examine the FOMC statements associated with some of the largest movements in our slope factor during the pre-zero lower bound period. We find that increases in the slope factor typically correspond to FOMC statements which offered less clarity about the pace of future rate changes. In contrast, decreases in the slope factor tend to correspond to statements which offered more clarity about the pace of future rate changes.

4.3.1 February 1994: A Preemptive Strike on Inflation

At its February 1994 meeting, the FOMC announced an unexpected increase in the target federal funds rate. The day before the policy change, the federal funds futures market implied less than a 40% chance of a rate increase at that meeting. This increase in interest rates was the first rate hike since 1989, and its stated purpose was to preempt a rise in inflation. In addition to this policy action, then Chair Greenspan issued a statement, an unprecedented move at the time, signaling the Committee's intent to embark on a tightening cycle. However, the brief statement offered no clarity on the timing nor pace of future rate rate increases.[9]

These policy actions led markets to expect additional hikes over the next year, but views about the size and pace of increases became more diffuse. The top row of Figure 3 shows the prices for the out-of-the-money put and call options used to calculate the EDX measures

[9]See pages 28–40 of the transcript from this meeting for a discussion of the intent behind the statement.

the day before and the day of the FOMC announcement. In a risk-neutral setting, higher options prices indicate a higher probability that particular state of the world materializes. Near-term uncertainty about future short-term rates, as measured by the EDX 1Q, actually fell after the meeting as investors became more certain the rates would rise over the next quarter. However, we see a large increase in the EDX 5Q, primarily due to a widening of the right tail of the distribution of future policy rates. As a result, the EDX slope factor increased by 2.5 standard deviations following the policy announcement and, consistent with our regression results, term premiums increased.

4.3.2 May 2003: Uncertainty in the Run Up to the Iraq War

Uncertainty over the economic outlook swelled in the run up to the Iraq War. The minutes from the March 2003 FOMC meeting revealed that the Committee had difficulty gaging whether recent economic weakness was due "to underlying economic conditions" or uncertainty about the effects of the impending war. Thus, the March 2003 FOMC statement omitted a description of the balance of risks, instead opting to acknowledge the sizable geopolitical uncertainties clouding the outlook. While the initial invasion proceeded smoothly, incoming data on core inflation remained weak. In its May 2003 statement, the Committee therefore indicated that while the risks to the growth forecast were now roughly balanced, the probability of a "substantial fall in inflation, though minor, exceeds that of a pickup in inflation from its already low level. The Committee believes that, taken together, the balance of risks to achieving its goals is weighted toward weakness over the foreseeable future."

Following this easing bias, options prices implied a significant decrease in the probability of policy rate increases over the next year. The second row of Figure 3 illustrates the resulting shift in rate expectations. The market's view about how much and how quickly rates might fall over the next year became more concentrated, causing the EDX 5Q to fall by more than the EDX 1Q. As a result, the EDX slope factor declined by more than 4 standard deviations following the release of the May 2003 statement. Term premia also declined, which is consistent with the predictions of our regression model.

4.3.3 June 2004: Measured Pace Language

At its June 2004 meeting, the FOMC embarked on its first tightening cycle since the 2001 recession. Past tightening cycles, such as in 1994–1995 and 1999–2000, featured rate increases of 25-75 basis points at each meeting. However, the Committee indicated in its June 2004 statement that "policy accommodation can be removed at a pace that is likely to be measured." Financial markets interpreted this language as the Committee planning to steadily tighten policy but at a restrained pace. The third row of Figure 3 shows that the EDX 5Q decreased as the prospect for larger 50-75 basis point policy actions had diminished, making expectations for one-year-ahead policy rates more concentrated. The EDX 1Q decreased for similar reasons. However, the upward-sloping nature of the term structure of option-implied rate volatility led the EDX slope factor to decline by 4 standard deviations. Greater clarity over how the Committee was likely to proceed with rate increases resulted in lower term premiums, as predicted by our regression results.

5 Empirical Evidence During the Zero Lower Bound

Our results thus far suggest that, during the 1994-2008 period, forward guidance announcements that offered more clarity about the path of interest rates led to a decline in term premia in longer-term bonds. After hitting the zero lower bound in December 2008, the Committee provided more explicit guidance about the likely evolution of future policy rates, such as its dated-based guidance in August 2011. In addition, the FOMC also implemented several rounds of asset purchases during the zero lower bound period, which often coincided with changes in the Committee's forward guidance.

Bernanke (2013)'s intuition we discuss in the Introduction, combined with our results presented thus far, suggest that *both* forward guidance and asset purchases can affect term premia in longer-term bonds. As a result, disentangling the separate effects of forward guidance and simultaneous asset purchases presents a nontrivial identification problem during the zero lower bound. In our baseline analysis in Section 4, we avoid this issue by estimating our event-study regressions using the pre-zero lower bound, prior to use of asset purchase programs. In the following two sections, we attack this identification problem more directly. Specifically, we estimate the effects of central bank forward guidance on term premia during the zero lower bound period, using two different approaches to control for the simultaneous asset purchase programs.

5.1 Out-Of-Sample Prediction for August 2011 Announcement

First, we focus on the August 2011 FOMC announcement, which provides a unique opportunity to examine the term-premium implications of explicit, date-based interest rate guidance during the zero lower bound without the need to account for any effects of asset purchases. This forward guidance announcement did not coincide with any change in actual or expected balance sheet policy. Thus, we can easily isolate the term premia effects of explicit forward guidance following this policy announcement.

Both term premia in bond markets and our measures of interest rate uncertainty declined significantly following the August 2011 FOMC announcement. As we discuss in the Introduction, Figure 1 shows that term premia, as measured using either the Adrian, Crump and Moench (2013) and Kim and Wright (2005) estimates, fell significantly for all horizons following the adoption of date-based guidance. Both measures show that the term premium on a 10-year Treasury bond fell by over 15 basis points. Following the announcement, we also observe a 7 basis point decline in our level factor and a 3 basis point decline in our slope factor. While the magnitude of these declines in term premia and interest rate uncertainty measures in August 2011 are larger than typical observations during the pre-zero lower bound period, these responses continue to suggest an important link between interest rate uncertainty and term premia.

Using our regression model estimated over the pre-zero lower bound period, we conduct an out-of-sample prediction to quantify how much of the observed decline in term premia following the August 2011 announcement can be explained by the decline in policy rate uncertainty alone. Figure 1 uses the empirical model in Equation 6, estimated over the 1994–2008 period, to predict the change in the term premium as a function of our EDX factors.[10] Using the Kim and Wright (2005) term premium, our simple empirical model can explain nearly all of its decline on August 9, 2011. Our regression model explains less of the decline in the Adrian, Crump and Moench (2013) term premium. However, based on either term premium model, the results of this exercise suggest that a forward guidance announcement which reduces interest rate uncertainty over the next two years is capable of generating a meaningful decline in longer-term term premia.

5.2 Controlling for the Effects of Asset Purchases

Our out-of-sample exercise for the August 2011 announcement suggests that FOMC-induced changes in interest rate uncertainty likely remain important at the zero lower bound. However, the slight under-prediction of the actual movements in the Adrian, Crump and Moench (2013) term premia we observe in Figure 1 suggest that the recent more explicit guidance may have strengthened our interest rate uncertainty mechanism. Indeed, we find evidence

[10]For this exercise, we generate the EDX level and slope factors for the August 2011 observation using the factor loadings from the 1994–2008 sample period.

supporting this idea when we examine scatter plots of the Adrian, Crump and Moench (2013) term premia measure and our EDX factors. Figure 4 shows that the relationship between our interest rate uncertainty factors and term premia becomes much steeper and displays less dispersion if we re-estimate our factors during the December 2008–November 2015 zero lower bound period.

To formally compare whether the Committee's use of more explicit guidance altered the transmission mechanism of forward guidance operating through changes in interest rate uncertainty, we now re-estimate our baseline regression model in Equation 6 using data from the zero lower bound period. In an attempt to account for the simultaneous effects of asset purchases, we omit 4 observations that coincided with the announcement of a new asset purchase program.[11] Given that many of these LSAP announcement dates also contained significant shifts in forward guidance, this approach is fairly conservative in estimating the effects our interest rate uncertainty mechanism during the zero lower bound.

Even under this conservative approach, we find that the FOMC's use of more explicit forward guidance strengthened the transmission mechanism of changes in interest rate uncertainty to longer-term bond yields. Table 8 illustrates the coefficient estimates for our level and slope factors during the zero lower bound period, dropping the dates associated with new asset purchase announcements. Compared with our pre-zero lower bound estimates from Table 3, we observe larger regression coefficients on the slope factor. On average, a 5 basis point decline in the difference between EDX 5Q and EDX 1Q leads to about a 9 basis point decline in term premia in 6-10 year maturity Treasury bonds, which is over three times the magnitude of our pre-zero lower bound results. Moreover, we now estimate a statistically significant and much larger coefficient on our EDX level factor.[12] These in-sample results, as well as the out-of-sample predictions around the August 2011 announcement, suggest that changes in uncertainty around the policy path are a key mechanism through which forward guidance transmits to longer-term bond yields, especially at the zero lower bound.

[11]Specifically, we drop March 18, 2009, November 3, 2010, September 21, 2011, and September 13, 2012, which correspond to the expansion of QE1 and beginning of QE2, QE3, and the MEP.

[12]Unlike the medium- and longer-term bond yields, we fail to find any statistically significant relationship for our shortest-term 1-year term premium estimates. However, previous work by Swanson and Williams (2014) suggests that this result likely comes from the reduced variation in 1-year bond yields during the later half of the zero lower bound period.

6 Implications for the Forward Real Rate Puzzle

While we document a link between FOMC announcements and term premia in longer-horizon zero coupon bond yields, Hanson and Stein (2015) show that FOMC announcements also affect very distant real forward rates. They note that, in standard macroeconomic models, monetary policy only affects real variables due to sticky prices. Thus, after ten to twenty years, one would expect all prices in the economy to adjust and therefore monetary policy should not affect real forward rates far in the future. Nevertheless, Hanson and Stein (2015) document the surprising result that FOMC announcements which shift the expected path of the funds rate affect forward real rates up to ten and even twenty years ahead.

Hanson and Stein (2015) explain this puzzling sensitivity of distant forward real rates through changes in term premia driven by yield-oriented investors. Specifically, they develop a supply and demand model with investors who reach-for-yield in long-term bonds when the central bank reduces the expected short-term policy rate. They show that term premia in long-term real rates in their model depend on two factors: (1) the uncertainty about short-term future policy rate, which is the traditional term premium we highlight in Section 2, and (2) a reach-for-yield term premium, which is affected by the expected path, or first-moment, of future short rates. They focus on the latter reach-for-yield premium, whereas our EDX measures provide a novel angle to explore the quantitative significance of the former short-rate uncertainty channel.

To illustrate the quantitative importance of interest rate uncertainty in explaining far forward real rates, we build on the baseline results from Hanson and Stein (2015). Specifically, they estimate regressions of the form:

$$\Delta f_t^{X(n)} = a_X(n) + b_X(n)\Delta y_t^{\$(2)} + \Delta\varepsilon_t^{X(n)}, \tag{7}$$

where $\Delta f_t^{X(n)}$ is the change in the forward nominal rate of security X with maturity n. We consider the change in the nominal forward rate ($X(n) = \$(n)$), the forward real rate ($X(n) = TIPS(n)$), and the forward break-even inflation rate ($X(n) = \pi(n)$). $\Delta y_t^{\$(2)}$ is the change in the two-year zero-coupon nominal yield. Hanson and Stein (2015) calculate these changes in a two-day window around FOMC meetings and estimate the regression from January 1999 through February 2012.[13] To examine the quantitative importance of both interest rate uncertainty channel and the reach-for-yield premium, we augment their

[13]They exclude five FOMC meetings associated with significant LSAP announcements.

regression model with our level and slope factors:

$$\Delta f_t^{X(n)} = a_X(n) + b_X(n)\Delta y_t^{\$(2)} + \beta_X^L(n)L_t + \beta_X^S(n)S_t + \Delta\varepsilon_t^{X(n)}, \tag{8}$$

where L_t is our level factor and S_t is our slope factor constructed as before but now over the Hanson and Stein (2015) event window and event dates. Table 9 illustrates the regression results for Equations 7 and 8 for forward nominal, real, and break-even inflation rates.[14]

We find that the uncertainty of future short-term policy rates plays a significant role in driving far forward interest rates around FOMC announcements. The first row of each maturity replicates the point estimates from Table 1 of Hanson and Stein (2015). They document that forward interest rates, in particular real forward rates, respond in a positive and statistically significant manner to an FOMC-induced increase in two-year Treasury yields. The second row for each maturity shows the coefficients from Equation 8, which includes our interest rate uncertainty factors. Focusing first on the results for forward nominal rates in the left panel of Table 9, we find that the coefficient estimates on Hanson and Stein's two-year yield measure fall by roughly 35-55 percent when we add our EDX factors to the regression. Moreover, we estimate a positive, statistically and economically meaningful coefficient on our EDX slope factor at all maturities, even at the 20 year horizon. We also find that our EDX level factor is positive and significant out to the 10-year horizon. Taken together, the coefficients on both the EDX level the EDX slope factors in the 10-year nominal forward regression imply that a 100 basis point upward shift or steepening of the term structure of interest rate uncertainty increases 10-year ahead nominal forward rates by 67 basis points. These coefficients are not only economically significant, but they also add greatly to the statistical power of the regression model. The adjusted r-squared measures of fit increase significantly across all horizons when we include our interest rate uncertainty factors, suggesting that the uncertainty channel plays a quantitatively meaningful role in explaining movements in nominal forward rates around policy announcements.

The economic significance and increased explanatory power of nominal forward rates from our measures of interest rate uncertainty emanate from their effects on forward real rates, not break-even inflation rates. In the middle and right panels of Table 9, we decompose the nominal forward regression coefficients into their additive real and break-even inflation components. These results show that the decline in the 2-year yield's coefficient on nominal forward rates reflects a reduction in the coefficient on the real component of forward rates

[14] For brevity, we focus on maturities of $n = 5, 10, 15, 20$ in Table 9. Estimates for all maturities from $n = 5, ..., 20$ are available upon request.

explains. For example, focusing on the 10-year forward rate, the coefficient on the 2-year yield falls from 0.45 to 0.23 when we add our EDX factors in the model. Of this 0.22 reduction in sensitivity, 0.15 — or about 70 percent of the reduction — comes from a decline in the sensitivity of real forward rates. Moreover, for the slope factor, the 0.67 coefficient on nominal forward rates can be decomposed into a statistically significant 0.50 coefficient on real forward rates and a noisily estimated 0.17 coefficient on break-even inflation. Finally, we observe that the increase in adjusted R-squared measures when we incorporate our EDX factors are concentrated on the real forwards much more than on the modest increases in the break-even inflation regressions.

Our augmented Hanson and Stein (2015) regressions suggest that the term structure of short-rate uncertainty propagates in a quantitatively meaningful way to term premia on long-horizon forward real rates. Focusing again on the 10-year real forward rate, the adjusted r-squared increases from 0.18 to 0.31 when we introduce our EDX factors. In other words, incorporating our EDX factors nearly doubles the share of the explained variation in distant real rates around FOMC announcements. We observe similar increases in explained variation across all horizons. Moreover, the coefficient on the EDX slope factor in the 10-year real forward rate regression is 0.50, very similar to the 0.51 coefficient we estimate on the slope factor in the baseline 10-year term premium regression in Table 3. This finding suggests that the effects we estimate on nominal term premia in Section 4 are likely driven by the effects of interest rate uncertainty on forward real term premia.

The results in this section extend our previous analysis to shed light on why distant real forward rates systematically vary around FOMC announcements. Changes in interest rate uncertainty, manifesting from FOMC forward guidance, appear to be a primary driver of changes in forward real rates around policy announcements. From a quantitative standpoint, the effects of forward guidance are equally, or perhaps even more important, than the reach-for-yield mechanism put forward by Hanson and Stein (2015). While we reach different conclusions about the underlying mechanism that explains movements in term premia relative to Hanson and Stein (2015), our results are consistent with one of the broader conclusions of their work. Namely, movements in term premia drive changes in real forward rates around policy announcements. This finding contrasts with the explanation of Nakamura and Steinsson (2018) in which monetary policy announcements drive the *expected path* of distant real rates through the revelation of central bank information. However, it remains an open question how forward guidance over the path of rates in the next several quarters transmits to distant forward rates. One possible explanation is the term-structure of interest rate uncertainty we measure over the next 5 quarters actually permeates to much longer horizons than we are able to measure using Eurodollar options.

7 Implications for the Effects of Quantitative Easing

Event studies analyses, like those we use to establish the transmission of forward guidance to longer-horizon term premia, are also a commonly-accepted approach for estimating the effects of the Federal Reserve's unconventional large-scale asset purchases (LSAPs) on longer-term rates. For example, Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), Abrahams et al. (2016), and many others examine the change in 10-year Treasury yields in the one or two days following an LSAP announcement.

However, several key LSAP announcements also contain pronounced shifts in forward guidance, which our results show also transmit to long-term interest rates. For instance, on December 16, 2008, the FOMC announced that it "will purchase large quantities of agency debt and mortgage-backed securities... is also evaluating the potential benefits of purchasing longer-term Treasury securities... [and] will continue to consider ways of using its balance sheet to further support credit markets and economic activity." In addition to this unprecedented announcement regarding its asset purchase program, the FOMC also offered forward guidance that the federal funds rate would remain exceptionally low "for some time."

The simultaneity of such LSAP and forward guidance announcements pose a challenge to event studies trying to isolate the effects of any one of these policy tools on long-term rates. For example, Krishnamurthy and Vissing-Jorgensen (2011) observe that the 10-year constant maturity Treasury yield declined by 33 basis points from December 15 to December 17, the two-day window around the aforementioned December 2008 announcement. They, like many others, implicitly attribute this large decline in the 10-year rate solely to the LSAP component of the announcement. However, from December 15 to December 17, our 5-quarter ahead EDX measure of interest rate uncertainty also declined by nearly 25 basis points; likely reflecting the shift in forward guidance. Thus, the 33 basis point decline in the 10-year Treasury rate likely reflects *both* the effects of the asset purchase announcement and changes in forward guidance.

Thus, LSAP event studies which omit controls for simultaneous forward guidance announcements are likely to be biased in the direction of overstating the effects of LSAPs. In particular, failing to account for changes in forward guidance improperly attributes the effects of guidance to the efficacy of LSAPs. As an illustration, we first replicate the Krishnamurthy and Vissing-Jorgensen (2011) LSAP event study. Specifically, they estimate a regression of the following form:

$$\Delta y_t^{10} = \beta^{QE} QE_t + \varepsilon_t, \tag{9}$$

where Δy_t^{10} is the two-day change in the 10-year constant maturity Treasury yield and QE_t is a dummy variable which takes a value of 1/9 on each of the 9 LSAP dates in Krishnamurthy and Vissing-Jorgensen (2011). The coefficient on this dummy variable reflects the cumulative effects of the 9 LSAP announcements on the 10-year Treasury yield. After reproducing the key Krishnamurthy and Vissing-Jorgensen (2011) results, we augment their event-study regressions with our measures of short-term interest rate uncertainty to control for the simultaneous effects of forward guidance:

$$\Delta y_t^{10} = \beta^{QE} QE_t + \beta^L L_t + \beta^S S_t + \varepsilon_t, \tag{10}$$

where L_t is a daily measure of our level factor, and S_t is a daily measure of our slope factor.[15] Table 10 displays the ordinary least squares estimates of Equations 9 and 10 where the first column shows the coefficient on the LSAP dummy variable. Examining this coefficient with and without the interest rate uncertainty controls allows us examine any upward bias in the efficacy LSAPs if we do not account for changes in forward guidance.

We find that accounting for forward guidance induced changes in short-rate uncertainty dampens the estimated efficacy of LSAPs. Absent any controls for interest rate uncertainty, Krishnamurthy and Vissing-Jorgensen (2011) find that the cumulative effects of QE1, QE2, and the Maturity Extension Program (MEP) reduced the 10-year Treasury yield by 170 basis points. When we include our controls for interest rate uncertainty in the second row of Table 10, we find that the total effects of LSAPs were, on average, overstated by about 25 percent as the cumulative effect of LSAPs falls to 135 basis points. The effects of LSAPs remain statistically significant, but we also observe statistically significant coefficients on our level and slope factors, suggesting that both policy tools play an important role in explaining movements in long-term rates.

[15] We construct daily measures of L_t and S_t using the factor loadings from our pre-zero lower bound event study. Given the larger effects of the level and slope factors on term premia during the zero lower bound period that we document in Section 5.2, this approach offers a conservative estimate of the effects of forward guidance on long-term yields. Thus, the estimates of the effects of LSAPs on 10-year Treasury yields in the second row of Table 10 should be considered an *upper bound* of the effects of LSAPs.

However, not all rounds of LSAPs were equally exposed to concurrent forward guidance announcements. For example, the five dates that Krishnamurthy and Vissing-Jorgensen (2011) include in their QE1 analysis also contain two prominent shifts in forward guidance: the previously discussed December 16, 2008 announcement and the March 18, 2009 guidance that replaced "some time" with "an extended period." Similarly, the first of the three QE2 events that Krishnamurthy and Vissing-Jorgensen (2011) study is the August 10, 2010 meeting at which the FOMC announced that it would begin reinvesting principal payments from its MBS portfolio into longer-term Treasury securities. However, within the same statement, the Committee also explicitly indicated it would "employ its policy tools as necessary," which one may interpret as some combination of forward guidance and asset purchases. In contrast, the announcement of the maturity extension program (MEP) on September 21, 2011, which increased the duration of the Federal Reserve's balance sheet, included very little change in the Committee's guidance over future policy actions. To examine how the presence of simultaneous forward guidance might affect the estimated efficacy of each individual asset purchase program, we re-estimate Equations 9 and 10 using separate dummy variables for QE1, QE2, and the Maturity Extension Program.

We find that the presence of concurrent forward guidance announcements likely induce upward bias in the estimated effects of QE1 and QE2 while the estimates of the MEP remain more accurate. Table 11 illustrates the estimated effects using a separate dummy variable for each asset purchase program both with and without our interest rate uncertainty factors. The first row of Table 11 decomposes the cumulative 170 basis point decline across all nine of Krishnamurthy and Vissing-Jorgensen (2011) LSAP announcements between QE1, QE2, and the MEP. The 170 basis point cumulative decline in the 10-year yield is comprised of a 107 basis point decline around QE1 announcements, a 40 basis decline around QE2 announcements, and a 23 basis point decline around the MEP announcement. However, once we include the EDX level and slope factors in these event study regressions, the estimated potency of QE1 and QE2 is reduced by 24 basis points and 14 basis points, respectively. Moreover, the estimated effects of QE1 are now only significant at the 10 percent level whereas, before, they were significant at the 1 percent level. We also find that the estimated potency of the MEP remains unchanged whether or not we include our interest rate uncertainty factors. Since no meaningful change in guidance occurred at the same time, the MEP announcement acts as a important placebo test which supports our interpretation of the omitted-variable bias in the estimated effects of LSAPs.

Examining the behavior of our interest rate uncertainty factors around the MEP announcement also provides some evidence about the importance of the signaling channel of LSAPs. Theoretical work, such as Bhattarai, Eggertsson and Gafarov (2015), argues that LSAPs operate as a mechanism through which the central bank increases the interest rate risk of its balance sheet to commit to a low path of future policy rates. Under this mechanism, an increase in the duration of the central bank's balance sheet should, all else equal, lower uncertainty about future short-term interest rates. However, we find that our 5-quarter EDX measure of interest rate uncertainty was little changed following the MEP announcement. This finding suggests that, at least for the MEP, the signaling channel does not appear to be the main mechanism through which LSAPs transmit to longer-term bond yields.

Taken together, the results in this section imply that both forward guidance and asset purchases can ease broader financial conditions. These results also call for caution when interpreting estimates of the efficacy of LSAPs which fail to control for simultaneous forward guidance announcements.

8 Macroeconomic Effects of Policy Uncertainty Shocks

Even prior to the use of large scale asset purchases, which were directly aimed at reducing term premia and stimulating the economy, policymakers asserted that lower term premia ease financial conditions, flatten the slope of the yield curve, and stimulate aggregate demand (Bernanke, 2006). While our simple theoretical model in Section 2 supports this view, little empirical evidence exists that support this link between term premia and economic activity. One difficulty in estimating this relationship empirically is the feedback effects that inherently exist between the bond market and the broader economy. However, our EDX measures, combined with our high-frequency event study approach, capture unexpected changes in Fed-induced interest rate uncertainty, likely limiting such endogeneity concerns. Moreover, in Section 4, we demonstrated a robust link between the EDX measures and term premia on longer-term bonds. Therefore, our EDX measures enable us to more directly inspect the linkages between monetary policy communication which shapes term premia, financial conditions, and the broader economy. Specifically, in this section we show that a persistent decline the EDX slope factor eases financial conditions by flattening the Treasury yield curve which fosters increases in economic activity and prices. However, we find no significant evidence of a similar channel for the EDX level factor.

8.1 Baseline VAR Model

Our aim in this section is to empirically examine the transmission of lower interest rate uncertainty to financial conditions and, ultimately, macroeconomic aggregates. To trace out these linkages, we embed our high-frequency measures of FOMC-induced interest rate uncertainty into a monthly vector autoregression (VAR) model. Since our measures capture the unexpected change in the level and slope of the term structure of short rate uncertainty around regularly-scheduled FOMC meetings, we follow Romer and Romer (2004) and Barakchian and Crowe (2013) and assign a value of zero to months in which there is no FOMC meeting and cumulatively sum the resulting EDX measures to generate a monthly series for the implied levels of monetary policy uncertainty. Building on the work of Bloom (2009), which uses the *level* of the VIX, this approach is akin to putting the EDX measures in the VAR in levels as opposed to first differences.

To examine the possible links between interest rate uncertainty, financial conditions, and the macroeconomy, we include financial, real, and nominal variables in our VAR model. Building on the premise set out in Bernanke (2006), we include the 10-year less 2-year yield spread to capture the slope of the Treasury yield curve as a key measure of financial conditions. Following Romer and Romer (2004), Coibion (2012), and Gertler and Karadi (2015), among others, we measure real economic activity at a monthly frequency using the natural log of industrial production. We also include the unemployment rate in our VAR model, which helps to measure US economic activity beyond factory output.[16] Finally, we include the natural log of the CPI to measure aggregate prices.

Given the differences observed in Table 3 in how the level and slope factors transmit to term premia, we estimate two separate VAR models using the level and slope factors. In both VAR models, we follow much of the monetary policy shock literature and use a recursive identification scheme. We order our EDX factors after real variables and prices, which maintains the common assumption that output and prices respond to changes in monetary policy with a lag. However, to be consistent with our event-study evidence, we order the slope of the yield curve after our EDX factors. However, we show that this ordering is not material for our main results. In our baseline specification, we estimate our VAR model over the 1994–2008 sample period, the same period for our baseline event-study regressions. We also show results below for an extended sample which includes the zero lower bound period.

[16] Coibion (2012) also includes the unemployment rate when measuring the real effects of monetary policy shocks.

Our VAR evidence reveals that declines in the slope factor flatten the yield curve and lead to an increase in economic activity and prices whereas declines in the level factor have little effect on financial conditions and the broader economy. Figure 5 plots the impulse responses to a one-standard deviation level and slope shock. Focusing first on the level shock in the left column of Figure 5, a persistent decline in the level factor has no statistically significant effect on the slope of the yield curve. This monthly impulse response corroborates the high-frequency evidence shown in Table 3 that demonstrates no relationship between the level of interest rate volatility and longer-term term premia. Given that the level factor fails to gain traction in altering financing conditions, it comes as little surprise that declines in the level of interest rate uncertainty also fail to influence real economic activity. In contrast, and again consistent with the high-frequency evidence in Table 3, a persistent decrease in the slope factor significantly flattens the slope of the Treasury yield curve, both on impact and over time. Consistent with the mechanism described in Bernanke (2006), the flatter yield curve eases financial conditions which helps to stimulate production and employment. After 12-18 months, industrial production increases by 50 basis points and the unemployment rate falls by over 5 basis points.[17] The persistent expansion in economic activity drives consumer prices higher as well.

8.2 Robustness Regarding the Real Effects of Policy Uncertainty

Our finding that a persistent flattening in the term structure of interest rate uncertainty — as measured by a decline in our slope factor — leads to a flatter yield curve and foreshadows increases in economic activity and prices is robust to a number of material changes to the VAR model. Figure 6 shows the impulse responses from a number of alternative VAR specifications. To ease comparison, the solid blue line in Figure 6 reproduces our point estimates to a slope factor shock from our baseline VAR model. For brevity, we omit error bands on each of these robustness checks; however, full results with error bands are available in the online appendix.

Our VAR results are not materially different when we order our high-frequency slope factor surprises first in the VAR, increase the number of lags in the VAR model, or consider

[17] Our estimated point estimate for the unemployment rate is broadly similar to the findings of Creal and Wu (2017), who use a macro-finance term structure model to estimate the effects of interest rate uncertainty on the macroeconomy. However, their identifying assumptions require that changes in interest-rate uncertainty do not affect bond yields at impact, which runs counter to our high-frequency empirical evidence in Section 4.

broader measures of real economic activity. Our daily event-window approach identifies unexpected movements in interest rate volatility. If these surprises are uncorrelated with other shocks buffeting the economy, the VAR results will be largely invariant to alternative orderings. Indeed, we find that the correlations between the residuals on our slope factor equation and the residuals from the other equations in our baseline VAR are low. As a result of these low correlations, Figure 6 shows that when we order our slope factor first, the impulse response functions are similar to those from our baseline VAR model. In addition, increasing the number of lags in the VAR to 12, a common rule-of-thumb selection for monthly data, leads to the same qualitative relationship found in the baseline VAR model. However, the persistence of the decline in the EDX slope factor is reduced with more lags, leading to similarly less persistent effects on financial conditions and the economy. Replacing industrial production with a broader measures of real economic activity reinforces our findings regarding the real effects of a decline in the EDX slope factor. In the "Real GDP" robustness exercise in Figure 6, we replace industrial production with a monthly measure of real GDP. These responses show that the estimated effects on factory output and labor markets extend more broadly to consumption and investment.

Importantly, our conclusions regarding the real effects of declines in the EDX slope factor are also robust to explicitly controlling for changes in the expected path of rates. Monetary policy communication that influences the uncertainty around future rates also likely contains information about the expected path of future rates. Thus, unexpected changes in monetary policy uncertainty are likely correlated with changes to expected future rates. In other words, one may be concerned that our VAR results could be driven by the macroeconomic effects of changes in the first moment of the future policy rate distribution.[18] To address this concern, we include Gurkaynak, Sack and Swanson (2005)-type target and path factor surprises as controls in our VAR.[19] Figure 6 shows that the estimates from the VAR model with these additional controls closely mirror those from our baseline model. This confirms that our

[18]Our term premium regressions in Section 4 are immune to this concern since the term premium reflects the portion of Treasury yields orthogonal to the expected path of future interest rates. Moreover, we show that our baseline results are robust to including changes in the expected path of rates in our event-study regressions.

[19]This approach is similar to the orthogonalizing regression Husted, Rogers and Sun (2019) use in which they regress the high-frequency change in option-implied interest rate uncertainty on the target, path, and QE factors. While related, our VAR results offer a more nuanced view of how FOMC forward guidance shifts the term structure of interest rate volatility and these different shifts (level vs slope) affect financial conditions and the real economy that has not been previously highlighted by the existing literature on monetary policy uncertainty.

identified macroeconomic effects are emanating from changes in the perceived uncertainty around policy rates and not just shifts in the expected rate path.

In our final VAR robustness check, we extend the estimation sample to include the zero lower bound period. We choose our baseline sample of January 1994-November 2008 to avoid the need to disentangle simultaneous LSAP announcements and forward guidance announcements. However, given that the use of longer horizon and more explicit guidance since December 2008 was aimed at ultimately stimulating the economy, it is of interest to study the transmission mechanism between forward guidance, financial conditions, and the macroeconomy during this more recent period. Therefore, in the "Full Sample" specification in Figure 6, we extend the sample through December 2015. In a coarse approach to accounting for simultaneous LSAP announcements, we simply set the change in the EDX slope factor to zero on days that the FOMC announced a fresh round of large-scale asset purchases.[20] Given that many of these LSAP announcement dates also contained significant shifts in forward guidance, this approach is fairly conservative. Nonetheless, the responses in Figure 6 show that the relationship between the EDX slope factor, the slope of the Treasury yield curve, and the economy remains in the more recent period. Quantitatively, we find that the effects of FOMC-induced declines in the slope of interest-rate uncertainty lead to larger declines in the unemployment rate and still smaller inflationary effects than we found over the baseline sample. Thus, these impulse responses seem to confirm the apparent flattening of the price-Phillips curve in recent years.

9 Conclusions

The possibility of more frequent encounters with the zero lower bound in the future underscores the importance of better understanding the transmission channels and efficacy of unconventional monetary policy tools. In this paper, we help contribute to this understanding by putting forth a new and empirically-relevant channel through which forward guidance transmits to financial markets and the macroeconomy. We show that forward guidance announcements have significant effects on bond term premia — even at longer horizons — through an interest rate uncertainty channel. We also propose forward guidance — as transmitted through interest rate uncertainty — as a novel explanation for Hanson and Stein's (2015) real forward rate puzzle. Moreover, these findings have implications for properly mea-

[20]Specifically, we omit March 18, 2009, November 3, 2010, September 21, 2011, and September 13, 2012 observations, which correspond to the expansion of QE1 and beginning of QE2, QE3, and the MEP, respectively.

suring the term-premia effects of the FOMC's recent large-scale asset purchases. We show empirically that both forward guidance and asset purchases have significant effects on term premia. Therefore, LSAP event studies which fail to control for concurrent forward guidance announcements will tend to overstate the efficacy of asset purchases. Finally, we present VAR evidence that persistent, FOMC-induced reductions in interest rate uncertainty transmit to the broader economy by flattening the slope of the Treasury yield curve, apparently easing financial conditions, and fostering increases in production, employment, and prices.

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Table 1: EDX Factor Loadings

	EDX Level Factor	EDX Slope Factor
ΔEDX 1Q	0.87	−0.44
ΔEDX 2Q	0.95	−0.21
ΔEDX 3Q	0.95	0.10
ΔEDX 4Q	0.95	0.22
ΔEDX 5Q	0.94	0.31
Cumulative R^2	0.86	0.94

The first column reports the factor loadings on the first principle component while the second column reports the factor loadings on the second principle component. ΔEDX 1Q denotes the daily change in the one-quarter-ahead Eurodollar option-implied volatility around an FOMC announcement and similarly for ΔEDX 2Q through ΔEDX 5Q. Number of observations: 119. The sample period is January 1994 through November 2008. See Section 3 for additional details.

Table 2: Scaling Regressions of EDX Components on EDX Factors

Dependent Variable	EDX Level Factor	EDX Slope Factor	R^2	Slope Only R^2
EDX 1Q	1.00***	−0.60***	0.97	0.20
	(0.02)	(0.03)		
EDX 5Q – EDX 1Q	0.00	1.00***	0.91	0.91
	(0.02)	(0.03)		

The first row reports coefficients β from the regression: $\Delta EDX1Q_t = \alpha + \beta^L L_t + \beta^S S_t + \varepsilon_t$ where $\Delta EDX1Q_t$ is the daily change in the one-quarter-ahead Eurodollar option-implied volatility around an FOMC announcement, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings). The second row replaces the dependent variable in the previous regression with $\Delta(EDX5Q_t - EDX1Q_t)$. Eicker-White standard errors are reported in parenthesis. Number of observations: 119. The sample period is January 1994 – November 2008. See Section 3 for additional details.

Table 3: Baseline Term-Premium Regressions

Dependent Variable	EDX Level Factor	EDX Slope Factor	R^2	Slope Only R^2
1-Year Term Premium	0.07	0.43***	0.18	0.17
	(0.09)	(0.08)		
2-Year Term Premium	0.11	0.59***	0.20	0.19
	(0.13)	(0.10)		
3-Year Term Premium	0.12	0.61***	0.18	0.17
	(0.15)	(0.12)		
4-Year Term Premium	0.13	0.59***	0.15	0.14
	(0.16)	(0.14)		
5-Year Term Premium	0.13	0.56***	0.11	0.11
	(0.18)	(0.16)		
6-Year Term Premium	0.13	0.54***	0.09	0.08
	(0.20)	(0.18)		
7-Year Term Premium	0.12	0.53***	0.07	0.07
	(0.21)	(0.19)		
8-Year Term Premium	0.12	0.52**	0.06	0.06
	(0.23)	(0.21)		
9-Year Term Premium	0.12	0.52**	0.06	0.05
	(0.24)	(0.22)		
10-Year Term Premium	0.11	0.51**	0.05	0.05
	(0.25)	(0.24)		

Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L L_t + \beta^S S_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC announcement, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings). Eicker-White standard errors are reported in parenthesis. Number of observations: 118 due to the closing of the U.S. bond market on Veterans Day 1997 which was the day before the November 1997 FOMC meeting. The sample period is January 1994 – November 2008. See Section 4 for additional details.

Table 4: Term-Premium Regressions Using Kim and Wright (2005) Measure

Dependent Variable	EDX Level Factor	EDX Slope Factor	R^2	Slope Only R^2
1-Year Term Premium	0.19	0.43***	0.18	0.14
	(0.12)	(0.12)		
2-Year Term Premium	0.29*	0.61***	0.19	0.14
	(0.17)	(0.17)		
3-Year Term Premium	0.34*	0.70***	0.19	0.15
	(0.19)	(0.18)		
4-Year Term Premium	0.36*	0.74***	0.20	0.15
	(0.20)	(0.19)		
5-Year Term Premium	0.36*	0.76***	0.20	0.15
	(0.20)	(0.18)		
6-Year Term Premium	0.36*	0.76***	0.20	0.15
	(0.20)	(0.18)		
7-Year Term Premium	0.36*	0.75***	0.20	0.15
	(0.20)	(0.17)		
8-Year Term Premium	0.36*	0.74***	0.20	0.15
	(0.19)	(0.17)		
9-Year Term Premium	0.35*	0.73***	0.20	0.15
	(0.19)	(0.16)		
10-Year Term Premium	0.34*	0.71***	0.19	0.15
	(0.19)	(0.16)		

Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L L_t + \beta^S S_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Kim and Wright (2005) term premium of maturity n around an FOMC announcement, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings). Eicker-White standard errors are reported in parenthesis. Number of observations: 118 due to the closing of the U.S. bond market on Veterans Day 1997, which was the day before the November 1997 FOMC meeting. The sample period is January 1994 – November 2008. See Section 4.1 for additional details.

Table 5: Term-Premium Regressions Measuring Uncertainty Using Market-Implied PDF

Dependent Variable	PDF Level Factor	PDF Slope Factor	R^2	Slope Only R^2
1-Year Term Premium	0.07	0.44^{***}	0.17	0.16
	(0.10)	(0.09)		
2-Year Term Premium	0.09	0.58^{***}	0.17	0.17
	(0.14)	(0.11)		
3-Year Term Premium	0.11	0.58^{***}	0.15	0.14
	(0.16)	(0.13)		
4-Year Term Premium	0.12	0.54^{***}	0.11	0.10
	(0.18)	(0.15)		
5-Year Term Premium	0.13	0.51^{***}	0.08	0.08
	(0.20)	(0.17)		
6-Year Term Premium	0.13	0.49^{***}	0.06	0.06
	(0.22)	(0.19)		
7-Year Term Premium	0.13	0.48^{**}	0.05	0.05
	(0.23)	(0.21)		
8-Year Term Premium	0.13	0.47^{**}	0.05	0.04
	(0.25)	(0.23)		
9-Year Term Premium	0.13	0.47^{*}	0.04	0.04
	(0.26)	(0.24)		
10-Year Term Premium	0.13	0.47^{*}	0.04	0.04
	(0.27)	(0.25)		

Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L L_t^{PDF} + \beta^S S_t^{PDF} + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC announcement. For these results only, we compute our level factor L_t^{PDF} and slope factor S_t^{PDF} using PDF-implied measures of interest rate uncertainty rather than our EDX measures constructed using the VIX methodology. See Bundick and Herriford (2017) for additional details on estimating market-implied densities. We use the same principal components method as in our baseline results to generate the implied level and slope factors. Eicker-White standard errors are reported in parenthesis. Number of observations: 118 due to the closing of the U.S. bond market on Veterans Day 1997 which was the day before the November 1997 FOMC meeting. The sample period is January 1994 through November 2008. See Section 4.1 for additional details.

Table 6: Controlling for Gurkaynak, Sack and Swanson (2005) Target & Path Factors

Dependent Variable	EDX Level Factor	EDX Slope Factor	Target Factor	Path Factor	R^2
1-Year Term Premium	0.28	0.55^{**}	-0.21^{*}	-0.02	0.15
	(0.24)	(0.27)	(0.11)	(0.07)	
2-Year Term Premium	-0.03	0.42^{***}	-0.05	0.15^{***}	0.31
	(0.13)	(0.13)	(0.06)	(0.03)	
3-Year Term Premium	0.02	0.44^{***}	-0.08	0.11^{***}	0.31
	(0.14)	(0.15)	(0.07)	(0.04)	
4-Year Term Premium	0.07	0.45^{***}	-0.12	0.14^{***}	0.27
	(0.15)	(0.17)	(0.08)	(0.04)	
5-Year Term Premium	0.12	0.46^{***}	-0.14^{*}	0.12^{***}	0.23
	(0.17)	(0.19)	(0.08)	(0.04)	
6-Year Term Premium	0.17	0.48^{**}	-0.16^{*}	0.10^{**}	0.20
	(0.18)	(0.21)	(0.09)	(0.05)	
7-Year Term Premium	0.20	0.50^{**}	-0.17^{*}	0.09^{*}	0.18
	(0.20)	(0.22)	(0.10)	(0.05)	
8-Year Term Premium	0.23	0.52^{**}	-0.18^{*}	0.07	0.17
	(0.22)	(0.24)	(0.10)	(0.06)	
9-Year Term Premium	0.26	0.54^{**}	-0.19^{*}	0.06	0.16
	(0.23)	(0.25)	(0.11)	(0.06)	
10-Year Term Premium	0.28	0.55^{**}	-0.19^{*}	0.05	0.15
	(0.24)	(0.27)	(0.11)	(0.06)	

Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L L_t + \beta^S S_t + \beta^{target} target_t + \beta^{path} path_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC announcement, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings), and $target_t$ and $path_t$ denote the Gurkaynak, Sack and Swanson (2005) target and path factors, respectively. Eicker-White standard errors are reported in parenthesis. Number of observations: 118 due to the closing of the U.S. bond market on Veterans Day 1997 which was the day before the November 1997 FOMC meeting. The sample period is January 1994 – November 2008. See Section 4.1 for additional details.

Table 7: Term-Premium Regressions Controlling for the VIX & MOVE

Dependent Variable	EDX Level Factor	EDX Slope Factor	VIX Index	MOVE Index	R^2
1-Year Term Premium	0.09	0.43***	0.001	−0.03	0.20
	(0.09)	(0.08)	(0.001)	(0.05)	
2-Year Term Premium	0.14	0.59***	0.001	−0.04	0.22
	(0.12)	(0.10)	(0.002)	(0.06)	
3-Year Term Premium	0.17	0.60***	0.001	−0.05	0.20
	(0.14)	(0.12)	(0.003)	(0.07)	
4-Year Term Premium	0.17	0.58***	0.001	−0.05	0.15
	(0.16)	(0.14)	(0.003)	(0.08)	
5-Year Term Premium	0.17	0.55***	0.001	−0.05	0.12
	(0.17)	(0.16)	(0.004)	(0.09)	
6-Year Term Premium	0.16	0.53***	0.001	−0.05	0.10
	(0.19)	(0.18)	(0.004)	(0.10)	
7-Year Term Premium	0.15	0.52***	0.002	−0.05	0.08
	(0.21)	(0.19)	(0.005)	(0.11)	
8-Year Term Premium	0.14	0.50**	0.002	−0.04	0.07
	(0.22)	(0.21)	(0.005)	(0.11)	
9-Year Term Premium	0.13	0.51**	0.003	−0.04	0.07
	(0.23)	(0.22)	(0.005)	(0.12)	
10-Year Term Premium	0.12	0.50**	0.003	−0.04	0.06
	(0.24)	(0.24)	(0.005)	(0.12)	

Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L L_t + \beta^S S_t + \beta^{VIX} \Delta VIX_t + \beta^{MOVE} \Delta MOVE_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC announcement, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings), ΔVIX_t is the daily change in the CBOE Volatility Index, and $\Delta MOVE_t$ is the daily change in the 1-month Bank of America Merrill Lynch Option Volatility Estimate Index. Eicker-White standard errors are reported in parenthesis. Number of observations: 118 due to the closing of the U.S. bond market on Veterans Day 1997 which was the day before the November 1997 FOMC meeting. The sample period is January 1994 – November 2008. See Section 4.2 for additional details.

Table 8: Term-Premium Regressions During Zero Lower Bound Without LSAP Observations

Dependent Variable	EDX Level Factor	EDX Slope Factor	R^2
1-Year Term Premium	-0.02	-0.01	0.00
	(0.16)	(0.29)	
2-Year Term Premium	0.39^{**}	0.54^{*}	0.14
	(0.16)	(0.28)	
3-Year Term Premium	0.80^{***}	1.13^{***}	0.39
	(0.16)	(0.23)	
4-Year Term Premium	1.08^{***}	1.54^{***}	0.47
	(0.19)	(0.23)	
5-Year Term Premium	1.23^{***}	1.79^{***}	0.45
	(0.22)	(0.26)	
6-Year Term Premium	1.29^{***}	1.92^{***}	0.45
	(0.24)	(0.29)	
7-Year Term Premium	1.31^{***}	1.98^{***}	0.42
	(0.26)	(0.30)	
8-Year Term Premium	1.30^{***}	2.00^{***}	0.40
	(0.28)	(0.32)	
9-Year Term Premium	1.27^{***}	2.00^{***}	0.37
	(0.30)	(0.33)	
10-Year Term Premium	1.25^{***}	1.99^{***}	0.35
	(0.33)	(0.35)	

Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L L_t + \beta^S S_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC announcement, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings). Eicker-White standard errors are reported in parenthesis. Number of observations: 53. The sample period is December 2008 – December 2015, omitting observations that coincided with the announcement of a new asset purchase program. Specifically, we drop March 18, 2009, November 3, 2010, September 21, 2011, and September 13, 2012, which correspond to the expansion of QE1 and beginning of QE2, QE3, and the MEP. See Section 5.2 for additional details.

Table 9: The Response of US Treasury Forwards Around FOMC Announcements

	Nominal Forward Rates				Real Forward Rates				Inflation Forward Rates			
Maturity	2-Year Yield	EDX Level	EDX Slope	R^2	2-Year Yield	EDX Level	EDX Slope	R^2	2-Year Yield	EDX Level	EDX Slope	R^2
5-Year	0.84***			0.30	0.65***			0.24	0.19**			0.05
	(0.14)				(0.11)				(0.08)			
	0.54***	0.86***	0.93***	0.55	0.43***	0.76***	0.61***	0.46	0.11	0.10	0.32**	0.10
	(0.11)	(0.23)	(0.18)		(0.10)	(0.27)	(0.21)		(0.09)	(0.13)	(0.16)	
10-Year	0.45***			0.09	0.42***			0.18	0.03			0.001
	(0.13)				(0.09)				(0.11)			
	0.23*	0.67***	0.67***	0.26	0.27***	0.38**	0.50***	0.31	−0.05	0.29**	0.17	0.06
	(0.13)	(0.24)	(0.22)		(0.08)	(0.16)	(0.18)		(0.12)	(0.13)	(0.16)	
15-Year	0.29***			0.07	0.35***			0.15	−0.06			0.004
	(0.11)				(0.09)							
	0.18	0.12	0.46**	0.11	0.25***	0.26**	0.35*	0.23	−0.07	−0.14	0.11	0.02
	(0.12)	(0.15)	(0.20)		(0.08)	(0.13)	(0.18)		(0.10)	(0.18)	(0.16)	
20-Year	0.18			0.03	0.30***			0.10	−0.12			0.01
	(0.13)				(0.09)				(0.15)			
	0.08	−0.11	0.51***	0.10	0.20**	0.30**	0.31*	0.17	−0.12	−0.40	0.20	0.11
	(0.13)	(0.16)	(0.18)		(0.09)	(0.15)	(0.18)		(0.14)	(0.25)	(0.22)	

In each of the three panels, each row reports coefficients from the following regression both with and without our EDX factors: $\Delta f_t^{X(n)} = a_X(n) + b_X(n)\Delta y_t^{\$(2)} + \beta_X^L(n)L_t + \beta_X^S(n)S_t + \Delta\varepsilon_t^{X(n)}$, where $\Delta f_t^{X(n)}$ is the change in the forward nominal rate ($X(n) = \$(n)$), the forward real rate ($X(n) = TIPS(n)$), or the forward break-even inflation rate ($X(n) = \pi(n)$) at maturity n, $\Delta y_t^{\$(2)}$ is the change in the two-year zero-coupon nominal yield, L_t is our level factor, and S_t is our slope factor (derived from two-day changes in EDX 1Q through EDX 5Q around FOMC meetings). Eicker-White standard errors are reported in parenthesis. The sample period is January 1999 through February 2012, dropping 5 LSAP dates. See Section 6 for details.

Table 10: Effects of Large-Scale Asset Purchases With Forward Guidance Controls

Dependent Variable	QE Dummy	EDX Level Factor	EDX Slope Factor	R^2
10-Year Yield	-1.70^{***}			0.03
	(0.58)			
10-Year Yield	-1.35^{***}	0.58^{***}	1.01^{***}	0.26
	(0.51)	(0.07)	(0.09)	

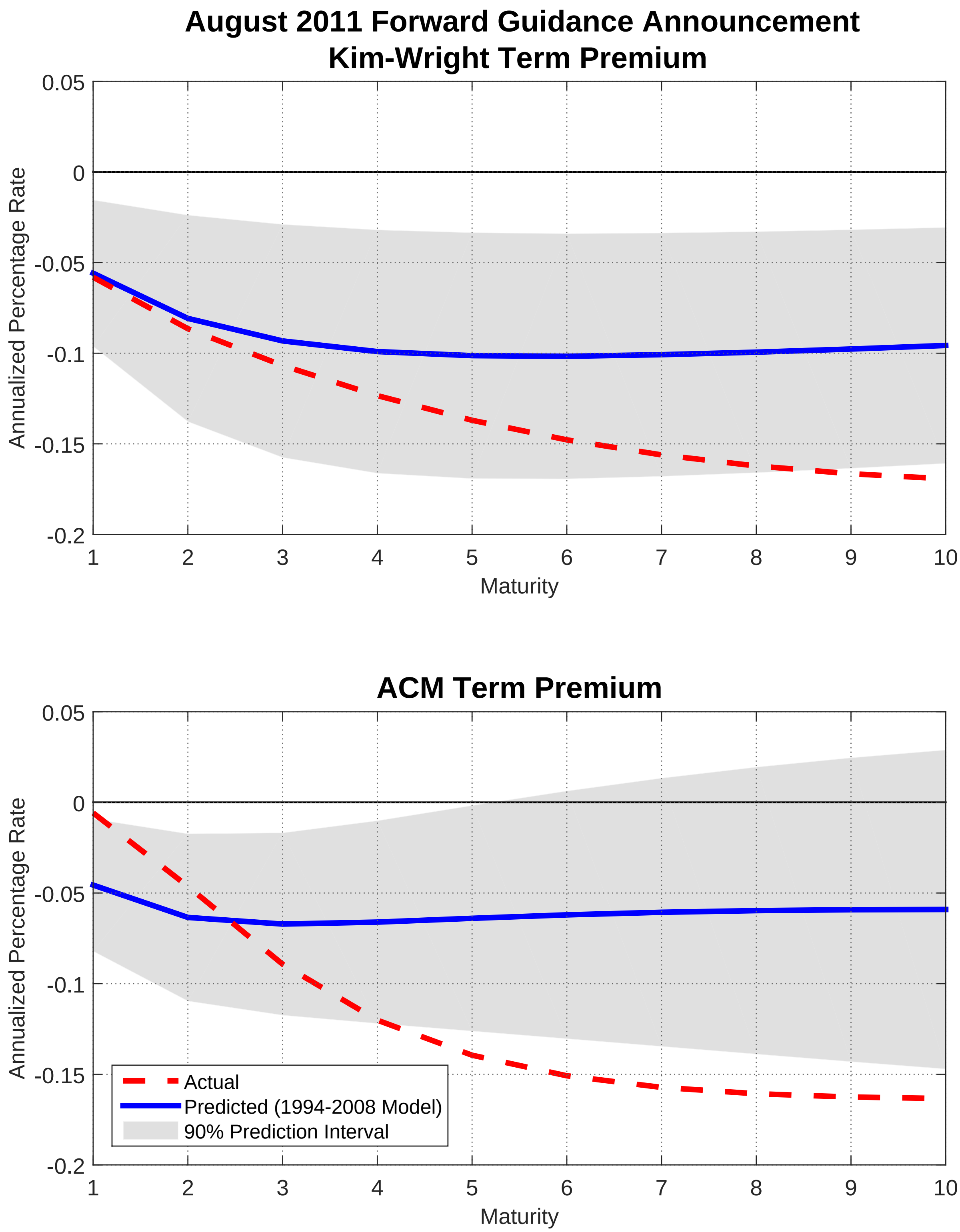
Each row reports coefficients from the following regression both with and without our EDX factors: $\Delta y_t^{10} = \beta^{QE} QE_t + \beta^L L_t + \beta^S S_t + \varepsilon_t$, where Δy_t^{10} is the two-day change in the 10-year constant maturity Treasury yield, QE_t is a dummy variable which takes a value of 1/9 on the 9 LSAP announcement dates, L_t is our EDX level factor and S_t is our EDX slope factor. Eicker-White standard errors are reported in parenthesis. Number of observations: 1366 and 1361, respectively. The sample period is January 2008 through September 2011. See Section 7 for additional details.

Table 11: Effects of Individual Asset Purchases With Forward Guidance Controls

Dependent Variable	QE1	QE2	MEP	EDX Level	EDX Slope	R^2
10-Year Yield	-1.07^{***}	-0.40^{***}	-0.23^{***}			0.03
	(0.56)	(0.04)	(0.00)			
10-Year Yield	-0.83^{*}	-0.26^{***}	-0.25^{***}	0.59^{***}	-1.02^{***}	0.27
	(0.48)	(0.04)	(0.00)	(0.07)	(0.09)	

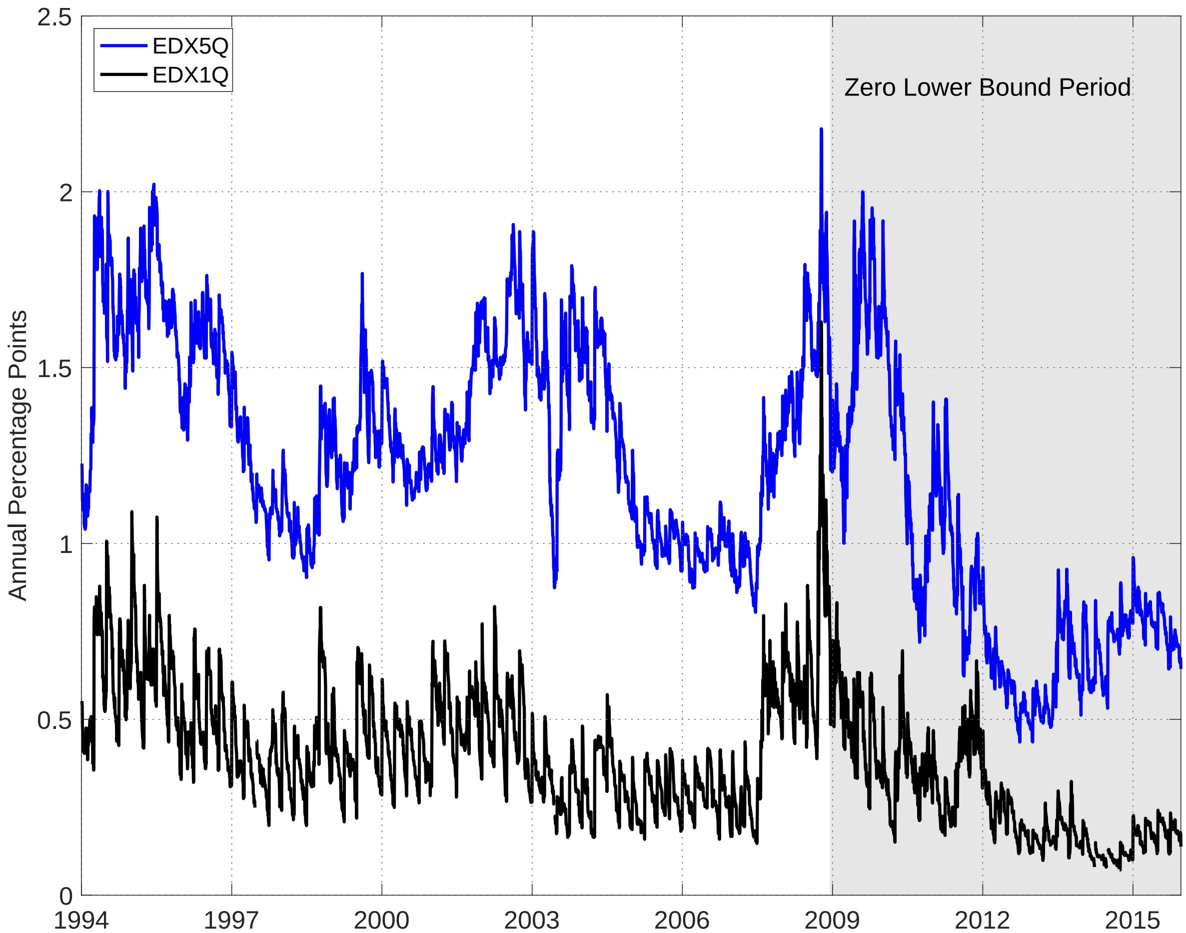
Each row reports coefficients from the following regression both with and without our EDX factors: $\Delta y_t^{10} = \beta^{QE1} QE1_t + \beta^{QE2} QE2_t + \beta^{MEP} MEP_t + \beta^L L_t + \beta^S S_t + \varepsilon_t$, where Δy_t^{10} is the two-day change in the 10-year constant maturity Treasury yield, $QE1_t$ is a dummy variable which takes a value of 1/5 on the 5 QE1 announcement dates, $QE2_t$ is a dummy variable which takes a value of 1/3 on the 3 QE2 announcement dates, MEP_t is a dummy variable which takes a value of 1 on the 1 MEP announcement date, L_t is our level factor, and S_t is our slope factor (derived from daily changes in EDX 1Q through EDX 5Q around FOMC meetings). Eicker-White standard errors are reported in parenthesis. Number of observations: 1366 and 1361, respectively. The sample period is January 2008 through September 2011. See Section 7 for additional details.

Figure 1: Actual & Predicted Changes in Term Premia Following August 9, 2011 Meeting



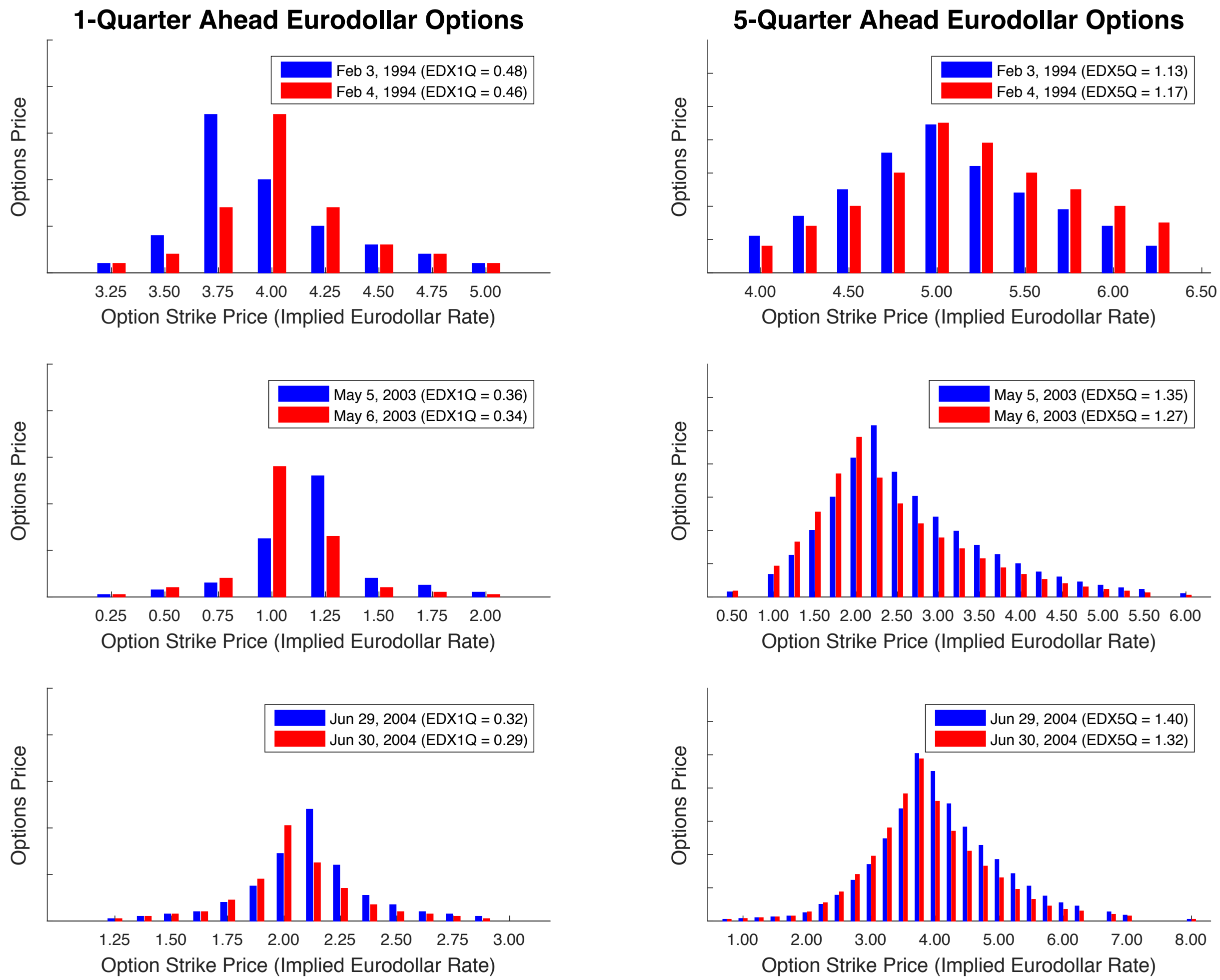
Note: This Figure plots the one-day change in the Adrian, Crump and Moench (2013) and Kim and Wright (2005) measures of term premia on August 9, 2011. The prediction emerges from our regression model in Equation 6 evaluated at $T_t^{10} = \hat{\alpha} + \hat{\beta}^L L_t + \hat{\beta}^S S_t$ on August 9, 2011. See Section 5 for additional details.

Figure 2: Eurodollar Option-Implied Volatility Index (EDX)



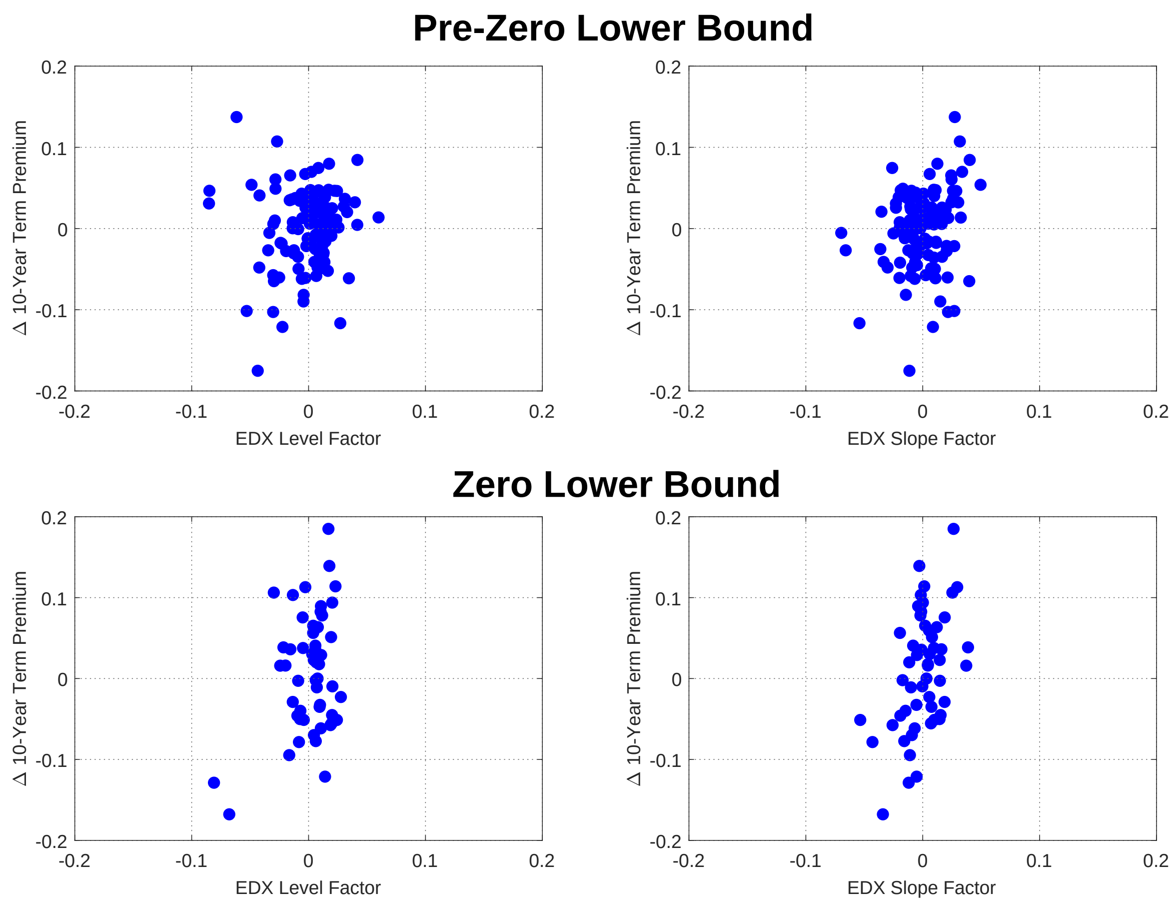
Note: This figure shows the one-quarter-ahead and five-quarter-ahead option-implied volatility calculated from out-of-the-money Eurodollar options. Daily Eurodollar options data are obtained from CME Group. See Section 3 for additional details.

Figure 3: Eurodollar Options Around Select FOMC Announcements



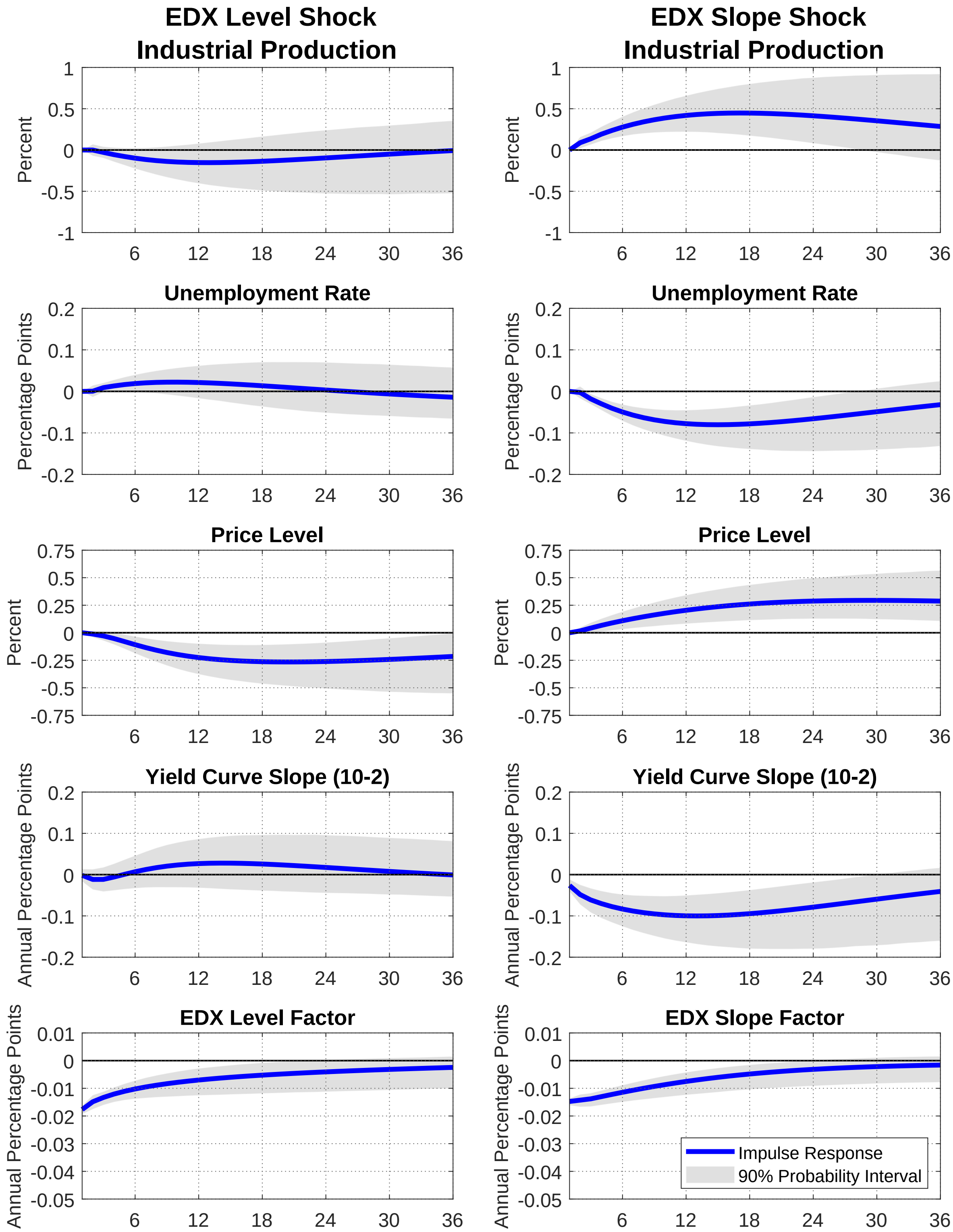
Note: This figure shows the prices of the Eurodollar options at all strikes used to calculate option-implied volatility. Since the options data was purchased from CME Group, we cannot release the raw options prices and leave the vertical axes unlabeled. The blue bars represent the prices on the day before an FOMC statement is released while the red bars show the prices on the day an FOMC statement is released. The top row corresponds to the February 4, 1994 statement; the second row corresponds to the May 6, 2003 statement; and the third row corresponds to the June 30, 2004 statement. See Section 4.3 for more discussion of these events.

Figure 4: EDX Volatility Factors vs Adrian, Crump and Moench (2013) Term Premium



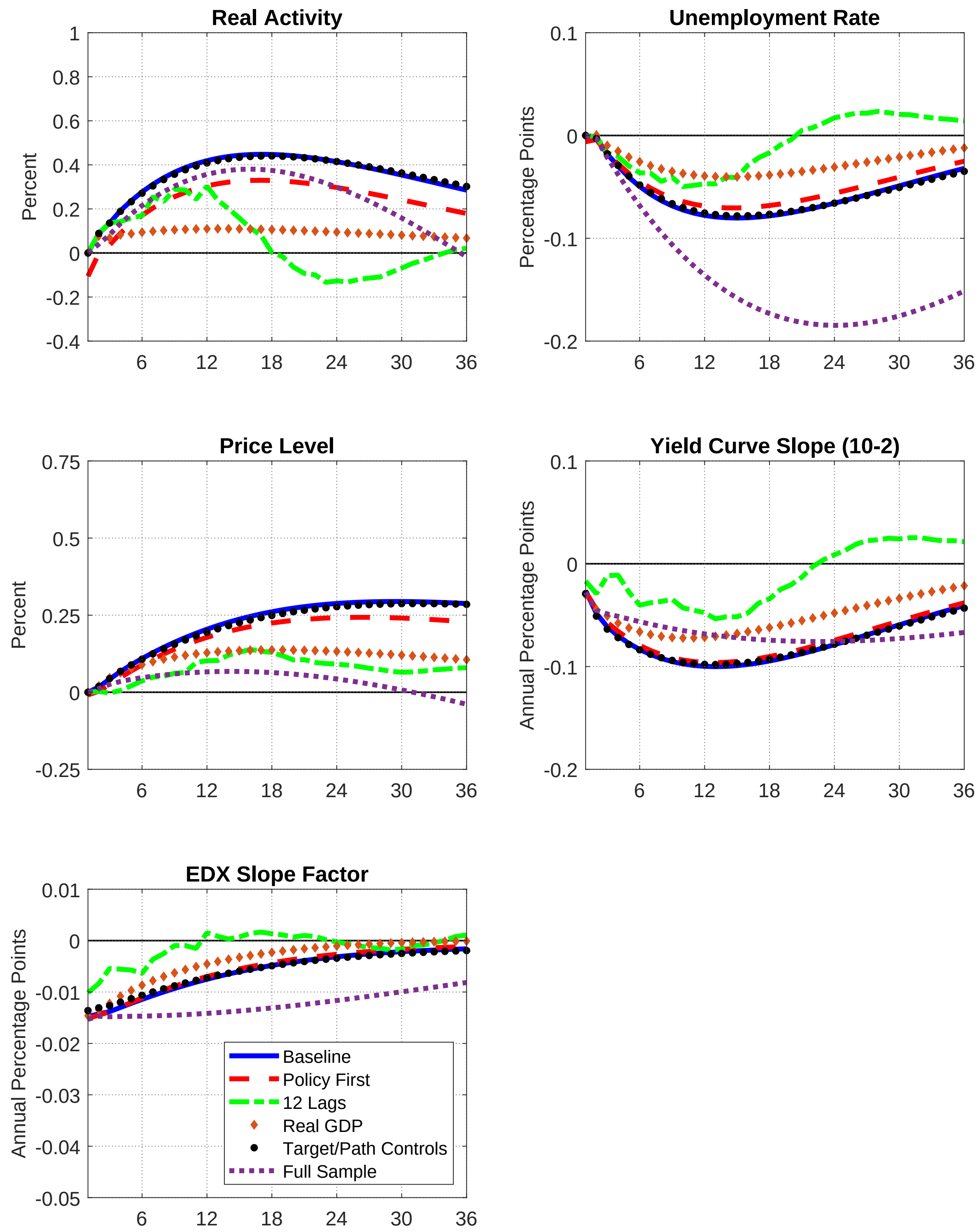
Note: The top and bottom panels scatter our EDX level and slope series against the one-day change in the 10-year Adrian, Crump and Moench (2013) term premium. The sample for the top panel is January 1994-November 2008 (Pre-Zero Lower Bound) and the sample for the bottom panel is December 2008-December 2015 (Zero Lower Bound). See Section 5 for additional details.

Figure 5: Impulse Responses to Monetary Policy Uncertainty Shocks



Note: The left column plots the impulse responses to an EDX Level shock while the right column plots the impulse responses to an EDX Slope shock. The solid blue line denotes the point estimate to a one standard deviation shock and the shaded regions denote the 90% probability interval of the posterior distribution. The sample period is January 1994 through November 2008. See Section 8.1 for additional details.

Figure 6: Impulse Responses to an EDX Slope Shock: Robustness



Note: Each line denotes the point estimate to a one standard deviation monetary policy uncertainty shock from a different VAR specification. See Section 8.2 for additional details.