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

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Abstract

We examine the macroeconomic and term-premia implications of monetary policy uncertainty shocks. Using Eurodollar options, we employ the VIX methodology to measure implied volatility about future short-term interest rates at various horizons. We identify monetary policy uncertainty shocks using the unexpected changes in this term structure of implied volatility around monetary policy announcements. Two principal components succinctly characterize these changes around policy announcements, which have the interpretation as shocks to the level and slope of the term structure of implied interest rate volatility. We find that an unexpected decline in the slope of implied volatility lowers term premia in longer-term bond yields and leads to higher economic activity and inflation. Our results suggest that forward guidance about future monetary policy can materially affect bond market term premia, even without large-scale asset purchases.

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1 Introduction

With the federal funds rate near zero, the Federal Open Market Committee (FOMC) turned to forward guidance and large-scale asset purchases (LSAPs) to help stabilize the economy during and after the Great Recession. In explaining these policies, then Chair Bernanke stated:

> Both LSAPs and forward guidance for the federal funds rate support the economy by putting downward pressure on longer-term interest rates, but they affect longer-term rates through somewhat different channels. To understand the difference, it is useful to decompose longer-term interest rates into two components: One reflects the expected path of short-term interest rates, and the other is called a term premium. The term premium is the extra return that investors require to hold a longer-term security to maturity compared with the expected yield from rolling over short-term securities for the same period...
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> Forward rate guidance affects longer-term interest rates primarily by influencing investors' expectations of future short-term interest rates. LSAPs, in contrast, most directly affect term premiums. – Bernanke (2013)

However, Michael Woodford uses the following simple example to illustrate why this rigid dichotomy between these two policy tools and their effects may not be correct in general:

> Suppose that FOMC forward guidance were to convince market participants that there was no possibility of a funds rate above zero for the next ten years ... An absence of arbitrage opportunities would require the ten-year zero-coupon yield to fall to zero – meaning that both the expectations component and the term premium would be reduced to zero by such a change in expectations about the short-rate process ...
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> Term premia are affected by expectations about the short-rate process (in particular, the degree of uncertainty about future short rates). – Woodford (2012)

In this paper, we empirically test Woodford's claim: Do changes in forward guidance alone significantly affect term premia in bond markets? Specifically, if a forward guidance announcement causes a decline in uncertainty about future short-term interest rates, does it also reduce term premia on longer-term bonds?

To answer these questions, we undertake three steps. First, we measure uncertainty about future short-term interest rates. Second, we isolate exogenous shifts in this measure of uncertainty due to unexpected changes in monetary policy. Finally, we examine the effects of changes in monetary policy uncertainty on term premia in bond markets. 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 daily changes in our measures around regularly-scheduled FOMC meetings to isolate changes in interest rate uncertainty attributable to monetary policy. Finally, we use standard event-study regressions to determine the effects of changes in monetary policy uncertainty on two different measures of bond market term premia.

We focus our analysis on the 1994–2008 sample period, which avoids the task of disentangling the effects of forward guidance from large-scale asset purchases. While the quotes of Bernanke and Woodford reference the FOMC's most recent experience with forward rate guidance at the zero lower bound, the FOMC previously used its policy statements to influence expectations 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 expectations about future policy rates rate expectations. 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.

We find forward guidance announcements that lower uncertainty about future short rates lead to statistically significant declines in term premia. Building on the work of Gurkaynak, Sack and Swanson (2005), we find that two principal components can succinctly capture changes in the term structure of short-rate volatility around FOMC announcements. These two components can be interpreted as shocks to the level and slope of the term structure of implied short-rate volatility. Using an event-study approach around FOMC meetings, we find an unexpected decline in the slope of implied volatility leads to a significant decline in bond market term premia of all horizons. Quantitatively, a 5 basis point decline in our slope factor leads to about a 3 basis point reduction in the ten-year term premium.

Using these estimates from the pre-zero lower bound period, we provide additional evidence that the Committee's recent date-based guidance was especially effective at shaping longer-term yields by reducing interest rate uncertainty. At the August 2011 FOMC meeting, the Committee gave very explicit guidance that interest rates were likely to remain near zero "at least through mid-2013." While the Committee made no changes to the size or composition of its balance sheet at that meeting, term premia on Treasury securities declined meaningfully after that announcement. Using our regression model from the 1994–2008 sample, we show that the observed reduction in uncertainty surrounding future policy rates alone explains much of this decline in term premia. Thus, we believe our findings based on the 1994–2008 period remain informative about the effects of the FOMC's use of forward guidance after 2008.

Finally, we show that changes in uncertainty surrounding the future path of policy rates affects both financial markets and the broader macroeconomy. Using a vector autoregression, we show that declines in future short-rate volatility lead to persistent increases in economic activity and prices. Following a one standard deviation reduction in the slope of implied interest rate volatility, industrial production and prices both increase by about 0.30 percent and the unemployment rate declines by about 5 basis points after about one year. Even after controlling for surprises in the level of current and future expected interest rates, we find that changes in uncertainty around the future rate path can significantly impact economic activity.

2 Simple Theoretical Model

We now describe a simple model which helps guide our intuition and motivates our empirical specifications. While the model is quite stylized, it delivers two key analytical predictions. First, consistent with Bernanke's motivation for the use of unconventional monetary policy tools, the model predicts that lowering longer-term interest rates leads to higher household consumption. Second, the model highlights Woodford's conjecture that uncertainty about the future short-term interest rates is a key determinant of the term premium.

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.

Formally, 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. This second assumption is not crucial for our main intuition, however, it allows us to derive clear expressions for longer-term bond yields and the term premium.

Consistent with Bernanke's intuition, our simple model implies that lowering longer-term bond yields boost household consumption. After some algebraic manipulation, we can use a second-order approximation of Equation (2) to derive the following expression:

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

In this equation, $c_t = \log\left(C_t\right)$, $\mathbb{VAR}_t$ denotes the conditional variance, and y_t^n is the yield to maturity on an n-period bond.[1] 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.

[1] A Technical Appendix, available on the Federal Reserve Bank of Kansas City's webpage, contains a detailed derivation of all of the equations in Section 2.

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

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

where $r_t = \log(R_t)$ is the net nominal interest rate controlled by the central bank. The first component depends on both the expected path of short-term nominal 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 and the yield on a risk-neutral n-period bond, denoted $\hat{y}_t^n$:

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

Equation (5) rigorously formulates Woodford's simple example: Term premia in our simple model depend on the uncertainty about the future path of interest rates. Households will require higher compensation to hold a longer-term bond when they face higher uncertainty about future short-term interest rates. From a policy perspective, our simple model suggests that forward guidance announcements that change the uncertainty about future short-term interest rates should also affect term premia in longer-term nominal bonds.

Our simple model provides two key testable predictions. Motivated by Equation (5), monetary policy 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 they should also increase broader economic activity. In the following section, we present robust empirical evidence that supports both of these model predictions.

3 Measuring Interest Rate Volatility

Our primary interest in this paper is examining the effect of monetary policy uncertainty shocks on bond market term premia and the broader macroeconomy. Thus, beyond standard macroeconomic data series, we need measures of the uncertainty surrounding the future path of monetary policy. Furthermore, our econometric identification strategy requires daily data.

To measure uncertainty about future short-term interest rates at a daily frequency, we apply the VIX methodology to Eurodollar options. 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.[2]

We denote our option-implied index of short-term rate uncertainty the EDX, short for Eurodollar Volatility Index. Figure 1 plots the one-quarter-ahead EDX (EDX 1Q) and the five-quarter-ahead EDX (EDX 5Q) for each day over the 1994–2008 period. On average, the one-quarter-ahead uncertainty about future short-term interest rates is about 50 basis points. Over the five-quarter-ahead horizon, the average market-implied uncertainty rises to about 150 basis points, which illustrates an upward-sloping term structure of implied short-rate uncertainty.

Our main focus is identifying 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. We then attribute the change the price of short-term interest rate options on the day of a FOMC announcement to unanticipated monetary policy. In particular, we use the change in our derived EDX measures around regularly-scheduled FOMC meetings to isolate a monetary policy uncertainty shock.

We find that two principal components succinctly describe changes in our EDX measures of implied volatility around FOMC announcements. Table 1 shows the factor loadings

[2] 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 CME Group.

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 patten. Changes in volatility at all horizons are highly correlated with the first factor, which suggests that the first factor is very similar to a change in the level of the term structure of interest rate volatility. The second factor, however, is negatively correlated with changes in short-term volatility but positively correlated with changes in longer-term volatility. Since our term structure of interest rate volatility has a positive slope on average, these factor loadings suggest that the second factor can be interpreted as a change in the slope of the term structure of interest rate volatility.

We apply a simple scaling procedure to the level and slope factors to ease the interpretation of our regression results. We scale our EDX level factor such that a one standard deviation movement in the EDX level factor moves our shortest-term volatility measure, EDX 1Q, by the same amount. Then, we scale the EDX slope factor such that it moves the slope of the EDX term structure (Δ EDX 5Q less the Δ 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 components as the level and the slope factor, respectively. The level factor alone explains nearly 80% of the variation in Δ EDX 1Q around FOMC meetings. Similarly, the slope component explains almost 90% of the variation in the changes in the slope of interest rate uncertainty around policy announcements. Furthermore, changes in the level factor have virtually no effect on the slope of interest rate uncertainty.

In addition to measuring uncertainty about future interest rates, our analysis also requires estimates of term premia in longer-term bond markets. To measure term premia, we use the rely on the prior work of Adrian, Crump and Moench (2013) and Kim and Wright (2005). These well-cited term premia estimates are commonly used by academic economists and policymakers. Data on the term premia for one- to ten-year zero-coupon bonds and are available at a daily frequency from the Federal Reserve Bank of New York or the Federal Reserve Board. Using two independent measures of the term premia ensures that our conclusions are not driven by a particular estimate of the term premia.

4 EDX & Term Premia: High-Frequency Evidence

Using these measures of interest-rate uncertainty and bond market term premia, we now return to our key empirical question: Do changes in uncertainty about future interest-rates lead to significant changes in term premia? To answer this question, we use an event-study type approach by examining movements in term premium and our interest-rate uncertainty factors around FOMC announcements over the 1994-2008 period. Using either the Adrian, Crump and Moench (2013) and Kim and Wright (2005) term premium measures, we estimate the following regression using ordinary least squares for each horizon:

$$\Delta TP_t^n = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \varepsilon_t, \tag{6}$$

where ΔTP_t^n is the daily change in the term premium of maturity n around an FOMC annoucement. ΔL_t denotes our level factor and ΔS_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 changes in uncertainty about future interest rates lead to changes in term premia. Specifically, changes in our EDX slope factor have significant effects on bond market term premia at all horizons. Table 3 shows the regression results for each horizon using the Adrian, Crump and Moench (2013) term premia measures. On average, a 10 basis point decline in the difference between EDX 5Q and EDX 1Q leads to a statistically significant 4-6 basis point decline in term premia of all horizons. The coefficients on the level factors are all positive, but are imprecisely estimated. Using the Kim and Wright (2005) measure of term premia, Table 4 shows significantly larger effects for the slope factor and some additional precision on the level factor coefficients. Using either term premia measure, our results suggest that interest rate uncertainty has a significant effect on bond market term premia.

4.1 Controlling for the VIX and MOVE Indices

Our results suggest that changes in the uncertainty about future short-term interest rates have significant implications for the term premium. However, one may be concerned that our new measure of uncertainty simply reflects uncertainty more broadly, rather than uncertainty specific to monetary policy. For example, Bloom (2009) finds that many measures of uncertainty move together over time. To illustrate that this conjecture is not driving our main results, we now include the VIX and MOVE indices in our previous regression model:

$$\Delta TP_t^n = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \beta^V \Delta VIX_t + \beta^M \Delta MOVE_t + \varepsilon_t \tag{7}$$

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.

The inclusion of these additional measures of uncertainty have no effect on our findings. Tables 5 and 6 show the results for this model. The coefficients on both alternative measures of uncertainty are basically zero. Furthermore, the coefficients on our EDX slope factors are essentially indistinguishable from the regression results shown in Tables 3 and 4. On further investigation, we also find that our EDX level factor has a high positive correlation (0.50) with changes in the MOVE, but the slope factor is essentially uncorrelated (0.02) with MOVE fluctuations around FOMC announcements. Our baseline regression model found the level factor to have little explanatory power for movements in the term premium around FOMC meetings. Unlike the slope factor, this level factor is not robustly significant across different measures of the term premium. This finding suggests that our EDX slope factor of implied short-rate volatility represents a distinct measure of uncertainty about future monetary policy and does not simply reflect aggregate uncertainty as measured in equity or bond markets.

5 FOMC Communication and Interest Rate Volatility

In addition to explaining movements in term premia around policy announcements, our new measures of interest rate volatility also align with changes in the FOMC communication regarding the likely path of future rates. Increases in the EDX 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 correspond to statements which offered more clarity about the pace of future rate changes. Given the novelty of our uncertainty measure, we briefly detail some of the most prominent shifts in policy and how they affected the term structure of option-implied volatility and bond markets.

5.1 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 rake 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 to signal the Committee's intent to embark on a tightening cycle, an unprecedented move at the time, but the brief statement offered no clarity on the timing nor pace of future rate rate increases.[3]

[3] See pages 28–40 of the Transcript from the February 3–4, 1994 FOMC meeting for a discussion of the intent behind the statement.

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 2 shows the prices for the out-of-the-money put and call options used to calculate the EDX measures the day before and day of the policy change. In a risk-neutral setting, higher options prices indicates a higher probability for that particular state of the world. Uncertainty about future short-term rates in the near term, 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 annoucement and, consistent with our regression results, term premiums increased.

5.2 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 risk assessment, options prices implied a significant decrease in the probability of policy rate increases over the next year. The second row of Figure 2 illustrates the resulting shift in rate expectations. The market's view about how much and how quickly rates would rise 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.

5.3 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 2 shows that the EDX 5Q decreased as the prospect for larger 50-75 basis point rate increases 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.

6 Recent Experiences with Forward Guidance

These narratives, as well as the prior work of Gurkaynak, Sack and Swanson (2005), clearly show that the FOMC implicitly and explicitly conveyed information that shaped the future distribution of expected policy rates prior to 2009. After hitting the zero lower bound in December 2008, the Committee provided much more explicit information about the likely evolution of future policy rates, but our analysis omits these observations because most of these announcements contain information about both rates and large-scale asset purchases.

However, the August 2011 FOMC statement provides a unique opportunity to examine the term-premium implications of explicit, date-based interest rate guidance. At this meeting, 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 that explicitly referred to a future date for how long it anticipated that the funds rate would remain near zero. Importantly, there was no corresponding change in balance sheet policy or explicit guidance provided about possible future balance sheet policy at that meeting.

Both term premia in bond markets and our measures of interest rate uncertainty declined significantly following the August 2011 FOMC statement. Figures 3 and 4 illustrate how these declines compare with the observed variation in term premia and our EDX factors over the 1994–2008 sample period. Each blue dot represents an observed change in the term premia-EDX factor pair over the 1994–2008 period, while the red dot illustrates the daily changes following the August 2011 policy announcement. According to the Kim and Wright (2005) measure, the one-year term premium fell by more than 5 basis points while the ten-year term premium fell by more than 15 basis points. Similarly, the Adrian, Crump and Moench (2013) measure suggests that the ten-year term premium declined by more than 15 basis points. In addition, both the EDX level and slope factors significantly declined.[4] While the magnitude of these declines in term premia and interest rate uncertainty measures in August 2011 are outsized compared to a typical past observation, they generally share the same relationship as the pre-zero lower bound period.

Using our regression model, we can quantify how much of the decline in term premia can be explained by the observed reduction in policy rate uncertainty. Figure 5 uses the empirical model in Equation 6, estimated over the 1994–2008 period, to predict the term premia as a function of our EDX factors. Using the Kim and Wright (2005) term premia, our simple empirical model can explain nearly all of the decline in term premia on August 9, 2011. Our regression model is a bit less successful in explaining the decline in the Adrian, Crump and Moench (2013) term premia. However, the model qualitatively captures the idea that a large reduction in interest rate uncertainty should generate a meaningful decline in longer-term term premia. Interestingly, both measures of the term premium suggest that explicit announcements about the short-term rate in two years are capable of affecting yields on Treasury securities maturing as far as five to even ten years in the future.

7 Macroeconomic Effects of Policy Uncertainty Shocks

Our event-study results suggest that changes in uncertainty about future short-term interest rates can affect term premia in bond markets, but do these FOMC-induced changes in interest rate uncertainty also affect real economic outcomes? Bloom (2009) and Basu and Bundick (2017) show that increases in uncertainty about future equity prices lead to economic contractions. More related to our paper, Baker, Bloom and Davis (2016) show that increases in uncertainty about general economic policy foreshadow persistent declines in real economic activity. But our measure of interest rate uncertainty and our high-frequency identification strategy narrowly focuses on the effects of monetary policy uncertainty emanating from the future path of interest rates. Thus, we want to know whether monetary policy induced changes in option-implied uncertainty about future short-term interest rates have

[4] To generate the level and slope factors for the August 2011 observation, we use the factor loadings from the 1994–2008 sample period.

meaningful macroeconomic effects.

In the following sections, we use a structural vector autoregression (VAR) to examine the macroeconomic effects of monetary policy induced changes in interest rate uncertainty. Following FOMC communication that reduces the slope of the term structure of interest rate uncertainty, we find that financial conditions ease and the economy expands. Moreover, we find that our estimated elasticity of output with respect to the term premium is consistent with other researchers' findings. Overall, our VAR results suggest that monetary policy makers may have the ability to influence economic and financial conditions through the amount of clarity they offer about the future path of short-term interest rates.

7.1 Baseline VAR Model

To trace out the macroeconomic response to changes in interest rate uncertainty, we embed our high-frequency slope factor into a monthly vector autoregression. To generate a monthly series for the implied level of policy uncertainty, 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 slope factor series. Building on the work of Bloom (2009), this approach is akin to putting the VIX in the VAR in levels as opposed to first differences.

Following Romer and Romer (2004), we measure real economic activity and prices at a monthly frequency using the natural log of both industrial production and the producer price index for finished goods. We also include the unemployment rate in our VAR model, which helps measure U.S. economic activity beyond factory output.[5] However, our results are unchanged if we exclude the unemployment rate from our model. Finally, we include two financial variables: the federal funds rate and the slope of the yield curve. Including the funds rate in our model helps control for the level of short-term interest rates at the time of the monetary policy uncertainty shock. The slope of the yield curve is defined as the ten-year less the one-year nominal average Treasury yield.

Following the monetary policy shock literature, we use a recursive identification scheme. We order our policy uncertainty measure after production and prices, which maintains the common assumption that output and prices respond to changes in monetary policy with a

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

lag. However, to be consistent with our event-study evidence, we order the federal funds rate and bond market variables after our slope factor. In Section 7.3, however, we show that this ordering is not material for our main results. We estimate our baseline VAR model over the 1994–2008 sample period.

A decline in uncertainty about future monetary policy flattens the yield curve and leads to a significant expansion of economic activity and prices. Figure 6 plots the impulse responses to a one standard deviation shock to our identified slope factor along with their 90% probability intervals calculated using a (normal) diffuse prior over the VAR parameters. Following a typical shock, uncertainty about future short-term interest rates falls sharply at impact and remains lower for about a year. As a result, the slope of the yield curve declines, which is consistent with our high-frequency empirical evidence from Section 4. In addition, the yield curve slope remains depressed for a significant period after the shock. The flatter yield curve, a hallmark of easier financial conditions, helps stimulate production and employment. After about one year, industrial production is about 30 basis points higher and the unemployment rate falls over 5 basis points.[6] Higher levels of output lead producers to raise prices over the next few years. The central bank endogenously responds to the increase in output and prices by raising the federal funds rate by about 15 basis points over the next year.

7.2 A Quantitative Comparison to Other VAR Estimates

To offer a comparison of our estimated quantitative effects with the previous literature, we now estimate a second VAR which replaces industrial production with real GDP and replaces the producer price index for finished goods with the consumer price index. Weale and Wieladek (2016) use these measures of real activity and prices in their the VAR study on the macroeconomic effects of large-scale asset purchases.[7] They find that an asset purchase announcement equal to one-percent-of-GDP has a peak effect of increasing real GDP by 0.58% and the CPI price level by 0.62%.

[6]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.

[7]We obtain a measure of monthly real GDP from Macroeconomic Advisers, the same source used by Weale and Wieladek (2016).

Using these estimates, along with the findings of Gagnon et al. (2011), we can compute an implied elasticity of output with respect to the ten-year term premium. Gagnon et al. (2011) find that a one-percent-of-GDP asset purchase announcement depresses the Kim and Wright (2005) ten-year term premium by 4.4 basis points. Translating the Weale and Wieladek (2016) estimates into an elasticity of the 10-year term premium: an asset purchase announcement which depresses the ten-year term premium by 1 basis point leads to an increase in real GDP of 0.13% and the CPI price level of 0.14%.

We find very similar real GDP effects compared to Weale and Wieladek (2016), but smaller, albeit still significant, effects on the CPI price level. Figure 7 shows the impulse responses of this alternative VAR model. A one standard deviation shock decreases the slope factor of interest rate uncertainty by 1.4 basis points. At their peak response, real GDP and the CPI increase by a statistically significant 0.12% and 0.05%, respectively. Using these estimates, we can use our previous event-study results to translate our findings into an elasticity in terms of the 10-year term premium. Table 4 shows that a 1.4 basis point decrease in the EDX slope factor lowers the Kim and Wright (2005) 10-year term premium by almost exactly 1 basis point. Thus, our VAR implies that a decrease in interest rate uncertainty which depresses the ten-year term premium by 1 basis point leads to an increase in real GDP of 0.12% and the CPI price level of 0.05%. This elasticity for real GDP is very close the estimate of Weale and Wieladek (2016), whereas the elasticity of CPI prices is only one third of the size of their estimate. Though taking into account the precision of the two CPI responses, the estimates do not appear to be statistically different.

7.3 Further VAR Robustness Checks

Our VAR results are not materially changed when we order our high-frequency slope factor surprises first in the VAR. Our daily event-window approach identifies unexpected movements in interest rate volatility. To the extent that 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 largest correlation between the residuals on our policy uncertainty shock equation and the residuals from equations in our baseline VAR is 0.17. To illustrate the implications of this low correlation, we re-estimate our baseline model with monetary policy uncertainty ordered first.

Figure 8 shows that the magnitude and statistical significance of the impulse response functions are similar to our previous results. In our previous baseline model, we ordered monetary policy uncertainty last, which restricts the initial response of economic activity and prices to be zero. Importantly, Figure 8 shows that allowing industrial production and the unemployment rate to respond on impact still results in a persistent and significant expansion in industrial production and tighter labor market conditions. This exercise addresses Uhlig (2005)'s concern that the real effects of a monetary policy shock may hinge on the short-run restrictions placed on these variables.

Our VAR results are also invariant to explicitly controlling for changes in the expected path of rates. Monetary policy communication that influences the uncertainty around future rates 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.[8]

To guard against this concern, we construct Gurkaynak, Sack and Swanson (2005)-type "target" and "path" surprises from daily data on federal funds futures and Eurodollar futures and include them as controls in our VAR. Figure 9 shows the estimates from the VAR with these additional controls mirror those in our baseline model in Figure 6. While the probability intervals are slightly wider in Figure 9 (due to the increase in the number of estimated parameters), our main findings remain unchanged. This confirms that our identified macroeconomic effects are emanating from changes in the term structure of option-implied volatility, not the expected path of rates.[9]

8 Conclusions

Our results suggest a new and empirically-relevant channel through which forward guidance affects the macroeconomy. Consistent with the intuition laid out in Woodford (2012), we show that forward guidance announcements alone can have significant effects on term premia in bond yields–even those with longer maturities. Moreover, we show that changes in uncertainty about future monetary policy also have implications for the broader macroeconomy.

[8] 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.

[9] One may be concerned that the options-market-implied path of rates differs from that in the futures market. In our analysis of the data, we found the two markets to have incredibly similar predictions for the expected path of rates. This finding suggests sufficient liquidity for arbitrage between the two markets to regularly occur.

Our results also have implications for properly measuring the term-premia effects of the FOMC's recent large-scale asset purchases. Both forward guidance and asset purchases can have significant effects on the term premia. During the zero lower bound period, many FOMC announcements regarding large-scale asset purchases also contained clear communication about the future policy rates. Our results suggest that empirical models may overstate the actual effects of asset purchases if researchers do not control for the observed changes in interest rate uncertainty around such policy announcements. As more frequent encounters with the zero lower bound are perhaps more likely in the future, we believe that a better understanding the individual implications for both policies remains a key focus for policymakers.

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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 annoucement 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: $\Delta EDX1Q_t = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \varepsilon_t$ where $\Delta EDX1Q_t$ is the daily change in the one-quarter-ahead Eurodollar option-implied volatility around an FOMC annoucement, ΔL_t is our level factor, and ΔS_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: Adrian, Crump and Moench (2013) 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: $\Delta TP_t^n = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC annoucement, ΔL_t is our level factor, and ΔS_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: Kim and Wright (2005) Term-Premium Regressions

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: $\Delta TP_t^n = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Kim and Wright (2005) term premium of maturity n around an FOMC annoucement, ΔL_t is our level factor, and ΔS_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 5: Adrian, Crump and Moench (2013) Term-Premium Regressions with 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)	

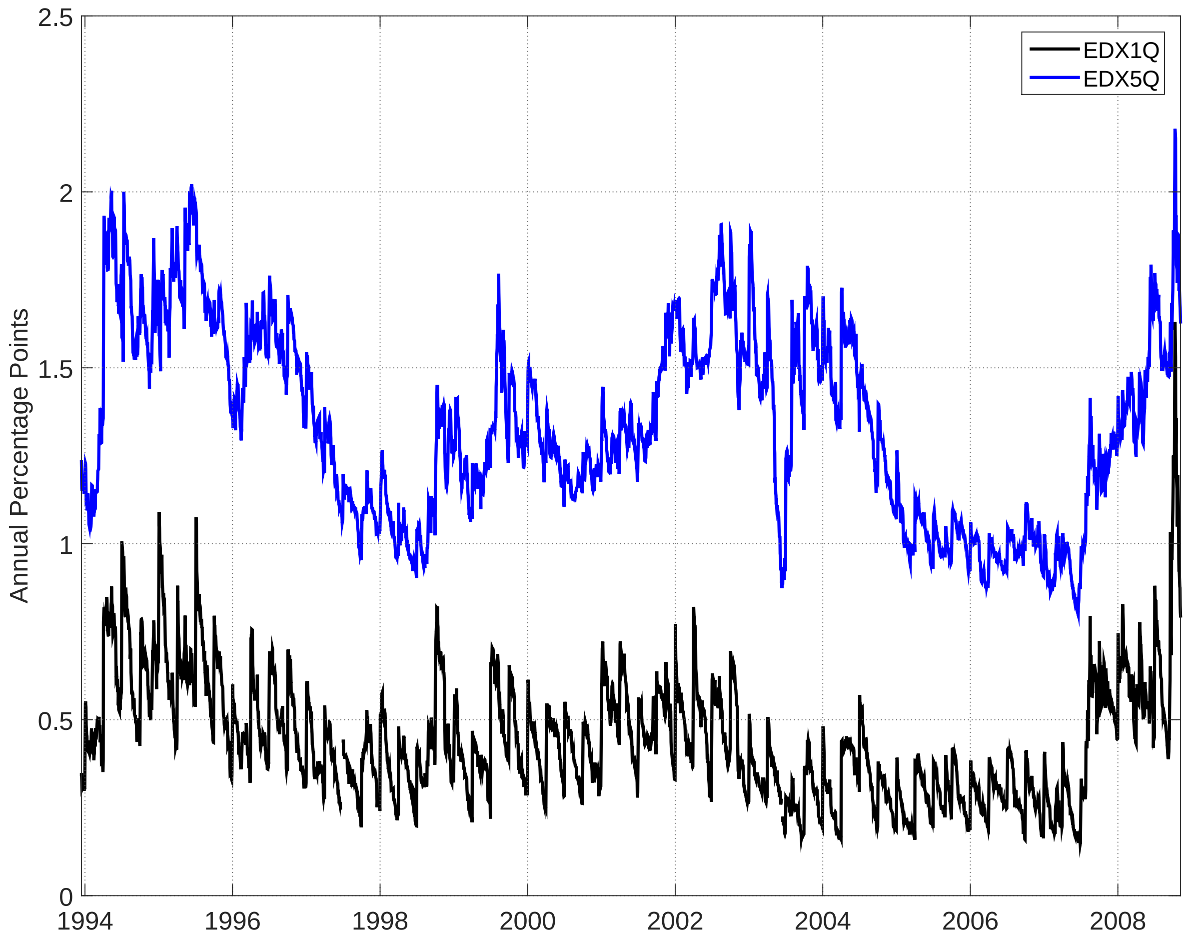
Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \beta^V \Delta VIX_t + \beta^M \Delta MOVE_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Adrian, Crump and Moench (2013) term premium of maturity n around an FOMC annoucement, ΔL_t is our level factor, and ΔS_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 4.1 for additional details.

Table 6: Kim and Wright (2005) Term-Premium Regressions with VIX & MOVE

Dependent Variable	EDX Level Factor	EDX Slope Factor	VIX Index	MOVE Index	R^2
1-Year Term Premium	0.30**	0.44***	−0.003	−0.05	0.22
	(0.12)	(0.12)	(0.003)	(0.06)	
2-Year Term Premium	0.43***	0.62***	−0.004	−0.07	0.23
	(0.16)	(0.17)	(0.003)	(0.09)	
3-Year Term Premium	0.50***	0.71***	−0.004	−0.09	0.23
	(0.18)	(0.18)	(0.004)	(0.10)	
4-Year Term Premium	0.53***	0.75***	−0.004	−0.09	0.24
	(0.19)	(0.19)	(0.004)	(0.11)	
5-Year Term Premium	0.54***	0.77***	−0.004	−0.09	0.24
	(0.19)	(0.18)	(0.004)	(0.11)	
6-Year Term Premium	0.53***	0.77***	−0.004	−0.09	0.23
	(0.19)	(0.18)	(0.004)	(0.11)	
7-Year Term Premium	0.53***	0.76***	−0.004	−0.09	0.23
	(0.19)	(0.17)	(0.004)	(0.11)	
8-Year Term Premium	0.52***	0.75***	−0.004	−0.09	0.23
	(0.19)	(0.17)	(0.004)	(0.11)	
9-Year Term Premium	0.50***	0.73***	−0.003	−0.09	0.22
	(0.19)	(0.16)	(0.003)	(0.11)	
10-Year Term Premium	0.49***	0.72***	−0.003	−0.09	0.22
	(0.19)	(0.16)	(0.003)	(0.11)	

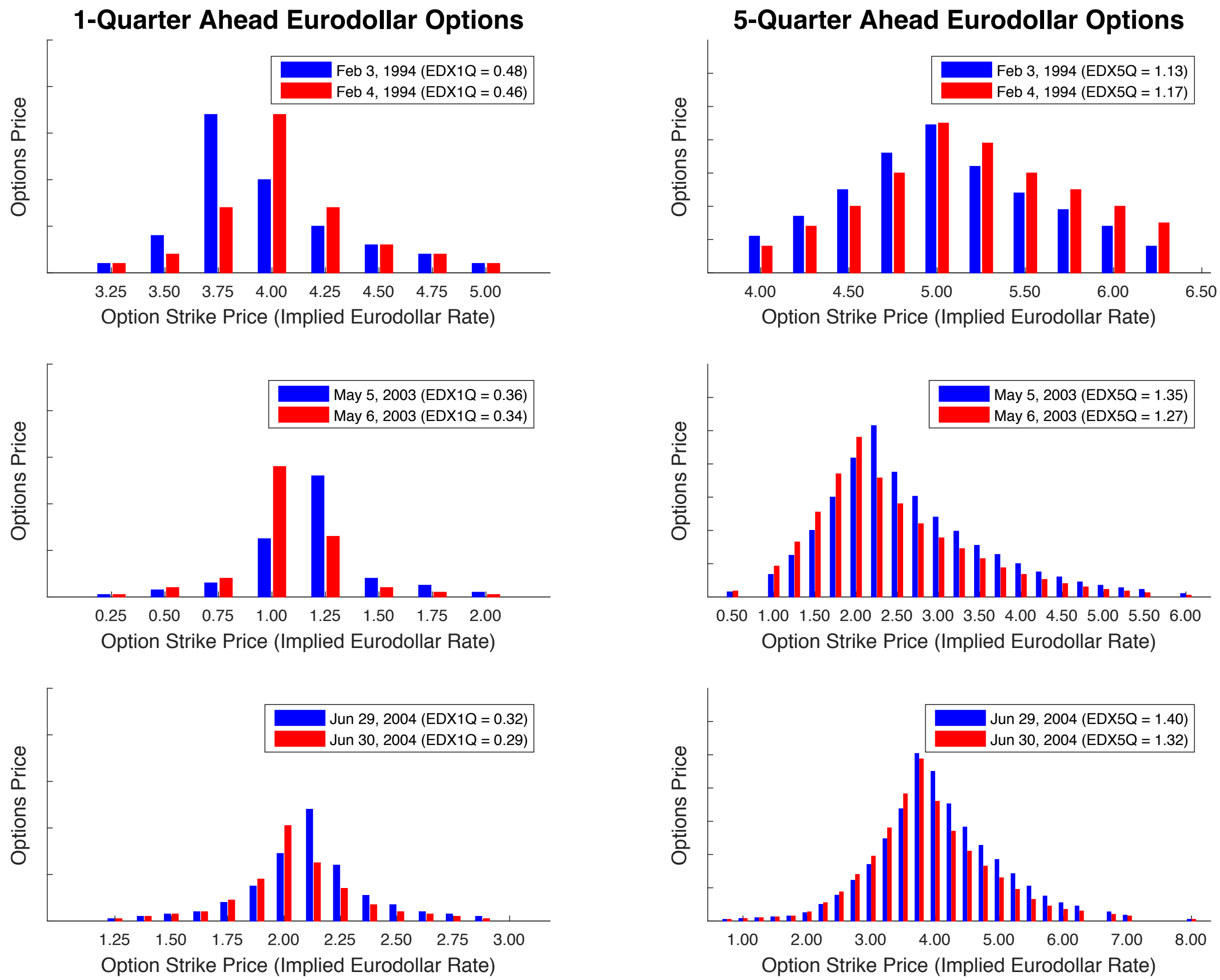
Coefficients β from the regressions: $\Delta TP_t^n = \alpha + \beta^L \Delta L_t + \beta^S \Delta S_t + \beta^V \Delta VIX_t + \beta^M \Delta MOVE_t + \varepsilon_t$ where ΔTP_t^n is the daily change in the Kim and Wright (2005) term premium of maturity n around an FOMC annoucement, ΔL_t is our level factor, and ΔS_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 through November 2008. See Section 4.1 for additional details.

Figure 1: Eurodollar Option-Implied Volatility Index (EDX)



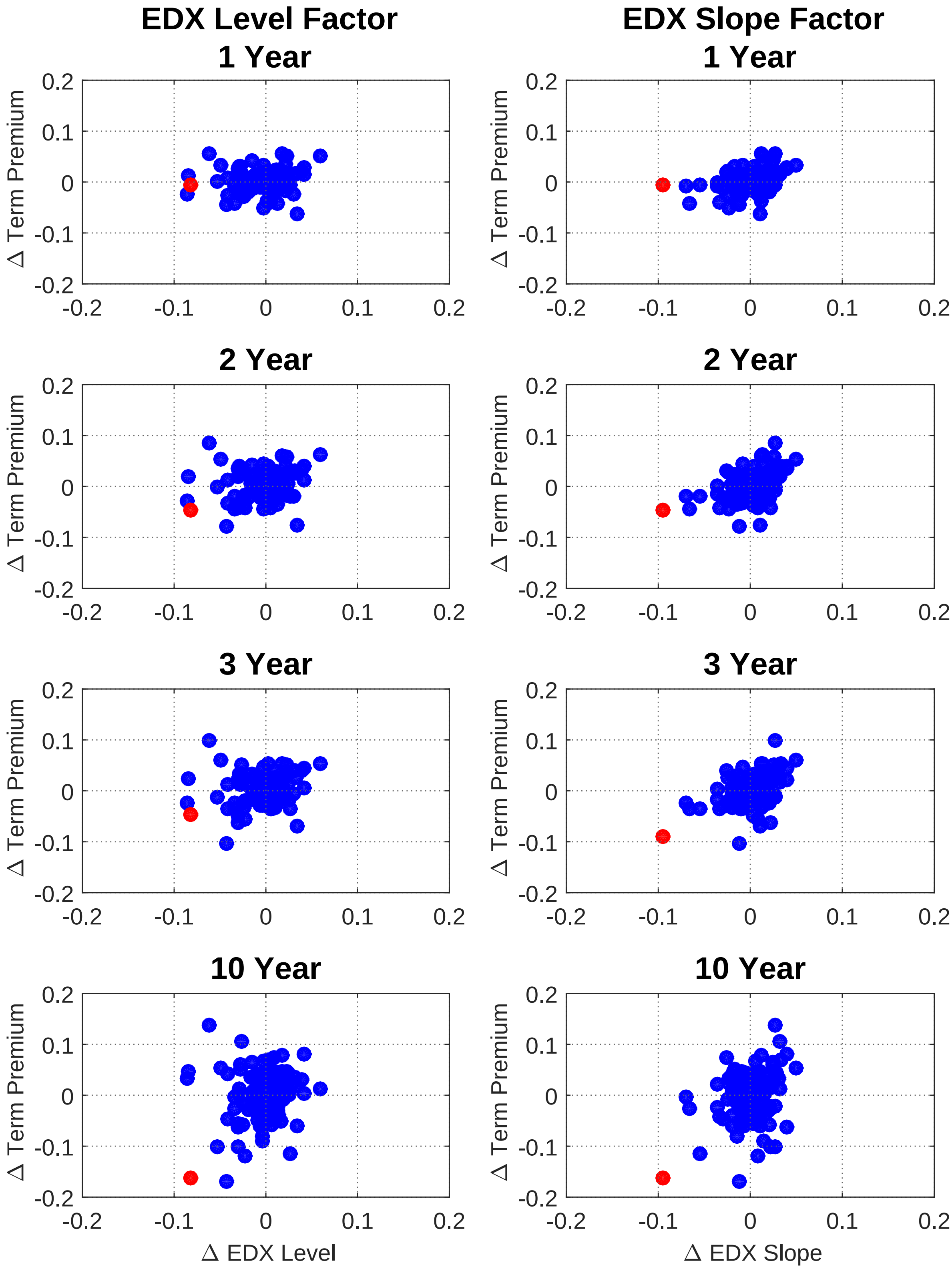
Note: This figure shows the one-quarter-ahead and five-quarter-ahead option-implied volatility calculated from out-of-the-money Eurodollar options. Daily Eurodollar options data are obtained from CME Group. See Section 3 for additional details.

Figure 2: Eurodollar Options Around Select FOMC Announcements



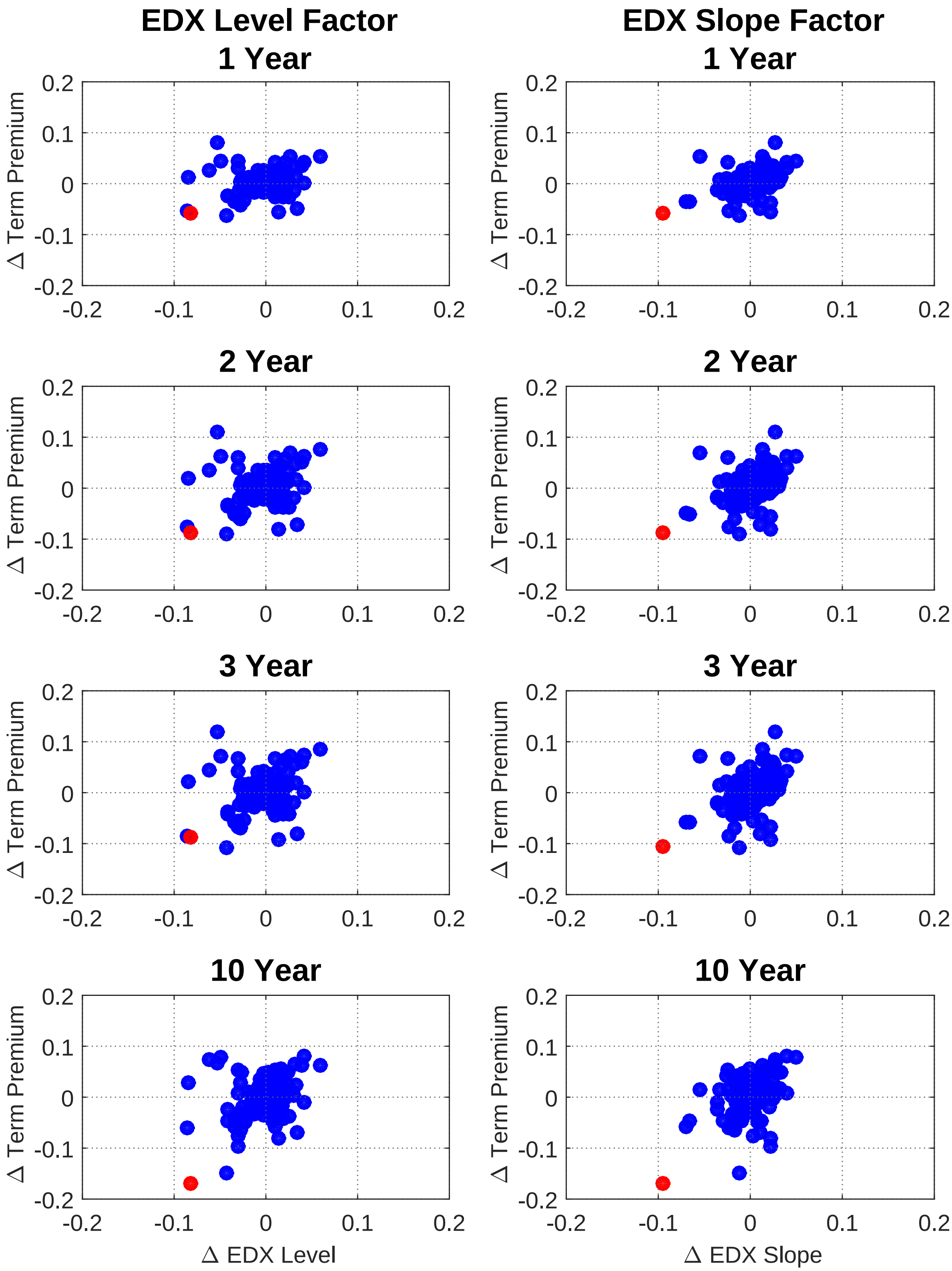
Note: This figure shows the prices of the Eurodollar options at all strikes used to calculate option-implied volatility. Since the options data was purchased from CME Group, we cannot release the raw options prices and leave the vertical axes unlabeled. The blue bars represent the prices on the day before 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 5 for more discussion of these events.

Figure 3: EDX Volatility Factors vs Adrian, Crump and Moench (2013) Term Premium



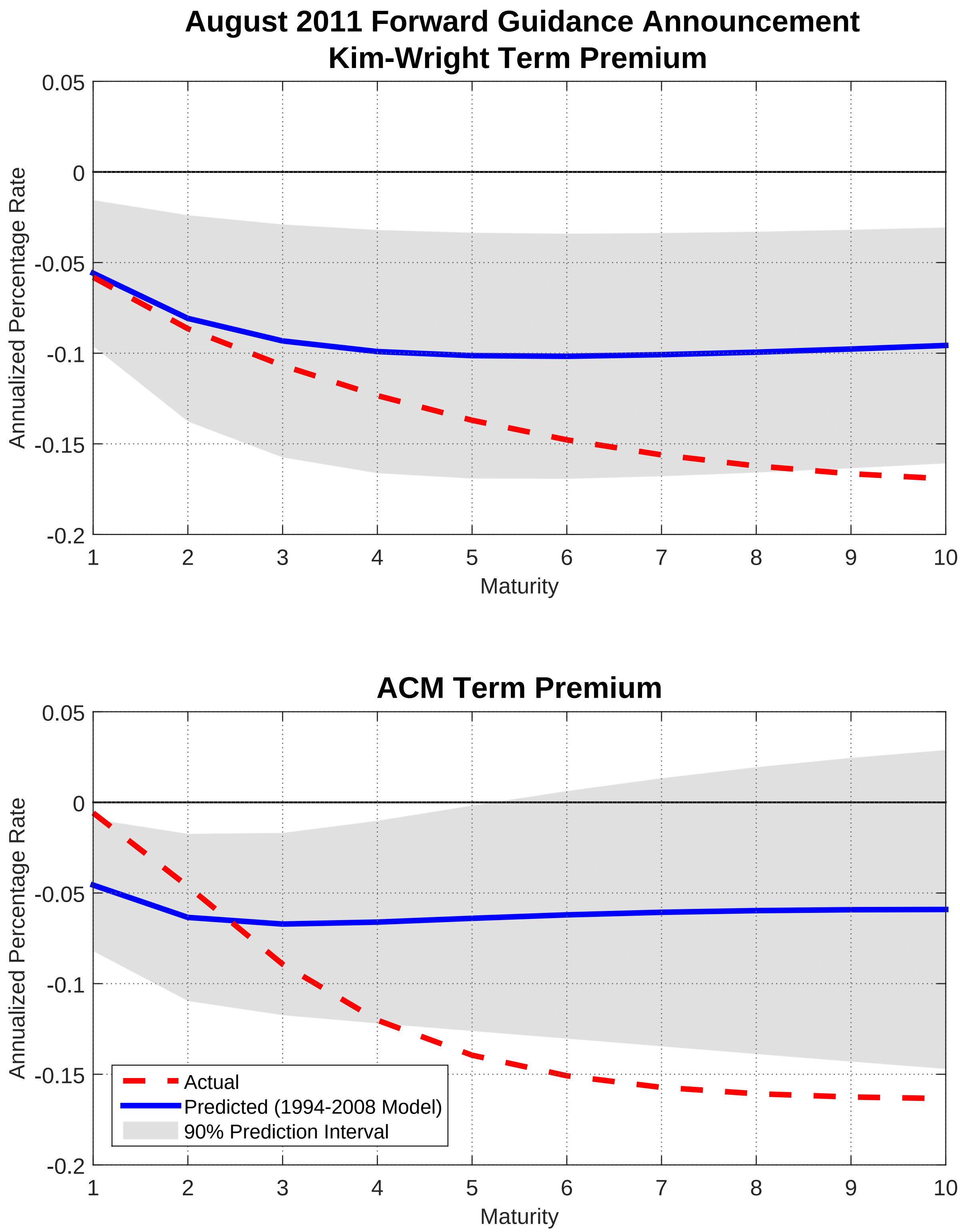
Note: The blue dots denote observations from January 1994 through November 2008 while the red dots denote the (out-of-sample) August 2011 observation. Term premia are measured using Adrian, Crump and Moench (2013). See Section 6 for additional details.

Figure 4: EDX Volatility Factors vs Kim and Wright (2005) Term Premium



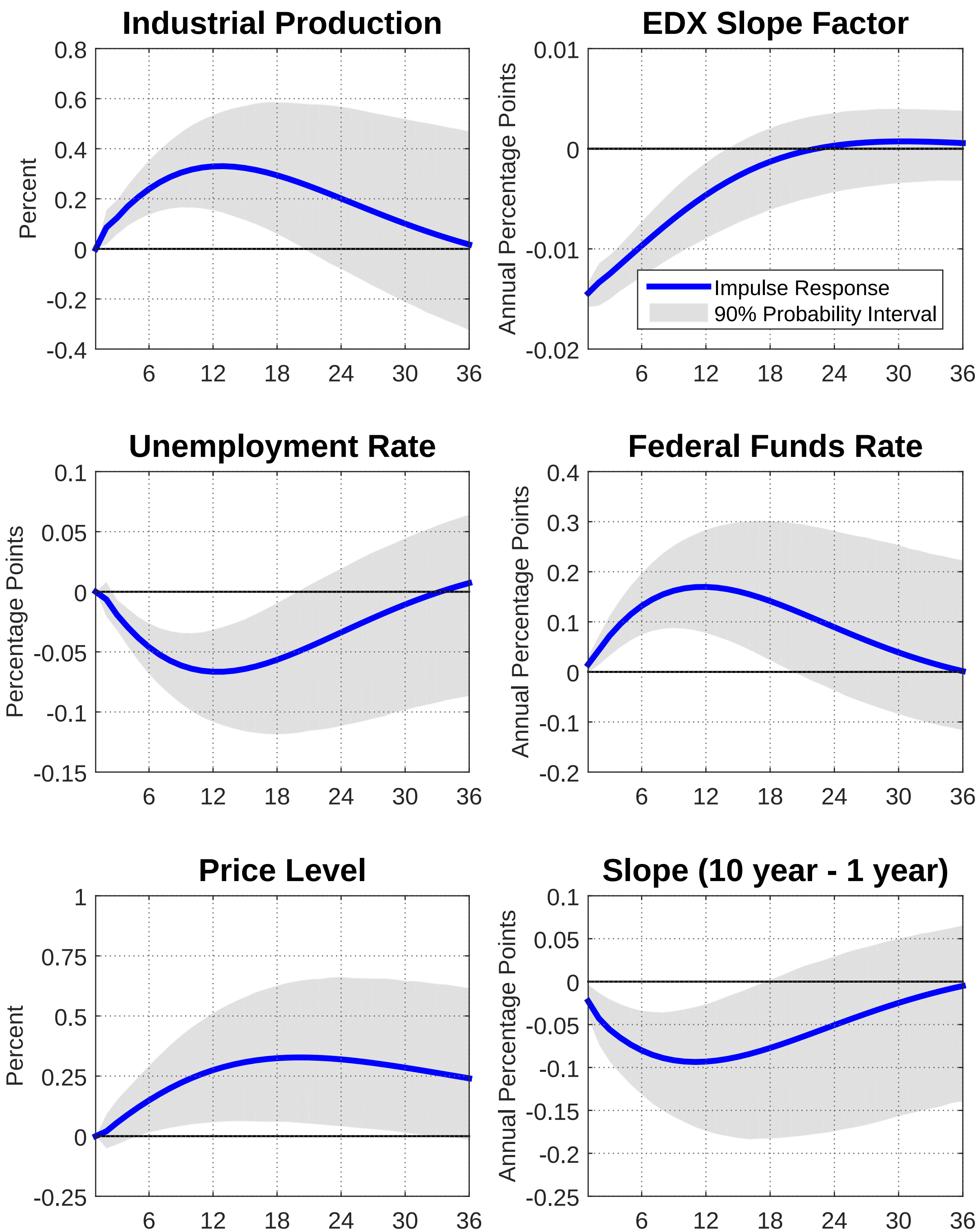
Note: The blue dots denote observations from January 1994 through November 2008 while the red dots denote the (out-of-sample) August 2011 observation. Term premia are measured using Kim and Wright (2005). See Section 6 for additional details.

Figure 5: Out-of-Sample Prediction: Date-Based Forward Guidance



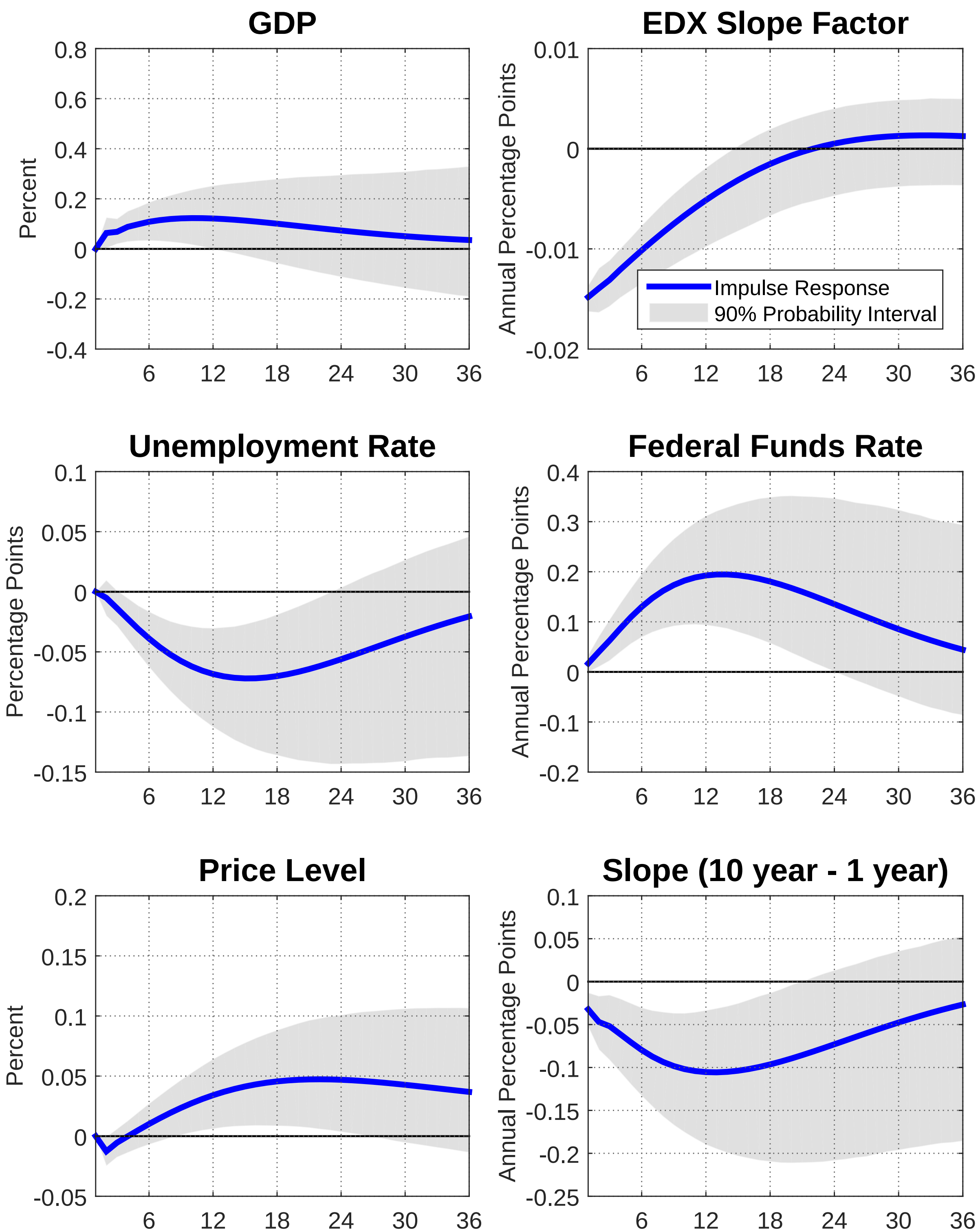
Note: The prediction emerges from our regression model in Equation 6 evaluated at $T_t^n = \hat{\alpha} + \hat{\beta}^L \Delta L_t + \hat{\beta}^S \Delta S_t$ on August 9, 2011. See Section 6 for additional details.

Figure 6: Impulse Responses to a Monetary Policy Uncertainty Shock



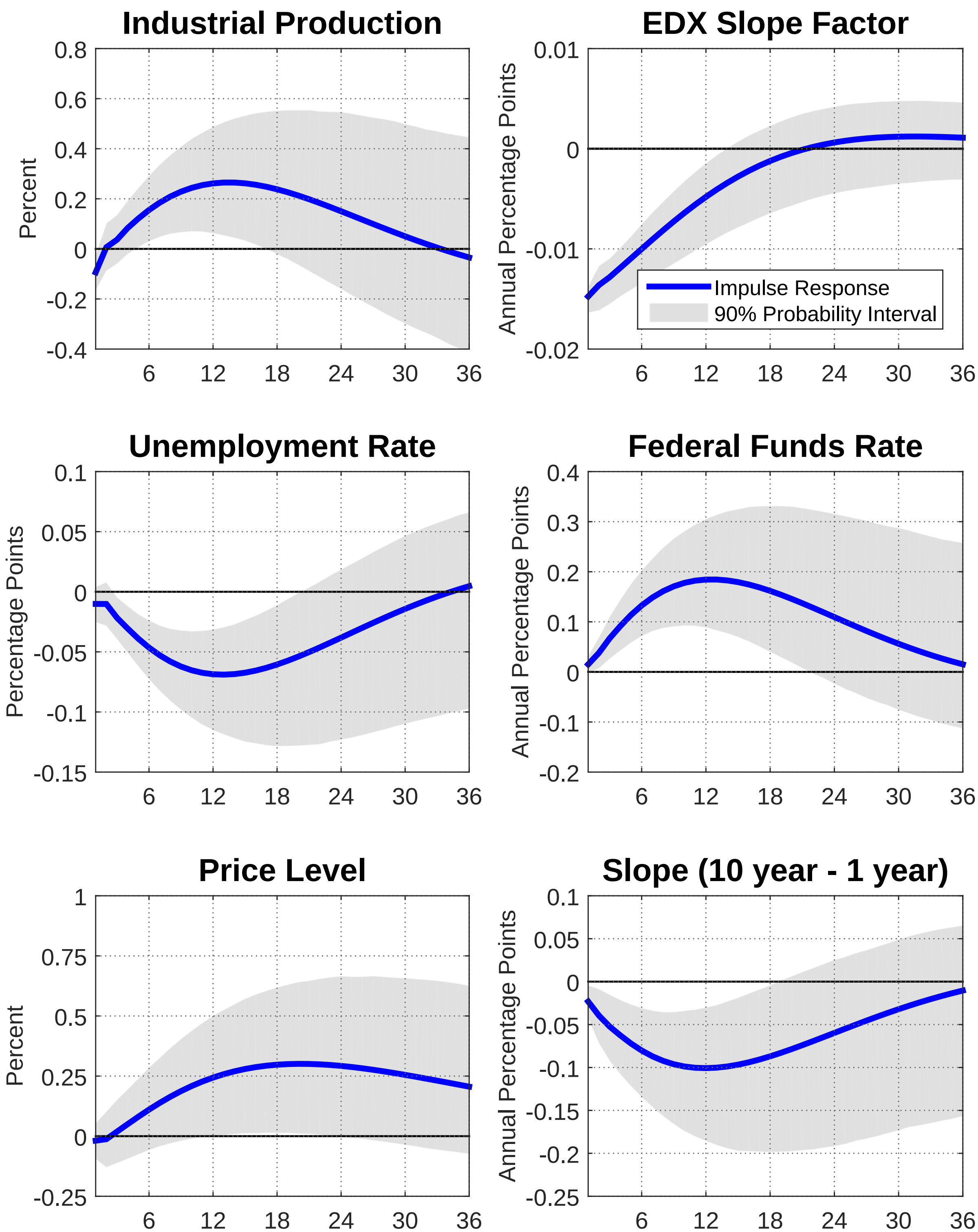
Note: The solid blue line denotes the empirical point estimate to a one standard deviation shock and the shaded regions denote the 90% probability interval of the posterior distribution. The sample period is January 1994 through November 2008. Two lags are included for each variable, selected using the AIC criterion. See Section 7.1 for additional details.

Figure 7: Impulse Responses Using Alternative Measures of Activity & Prices



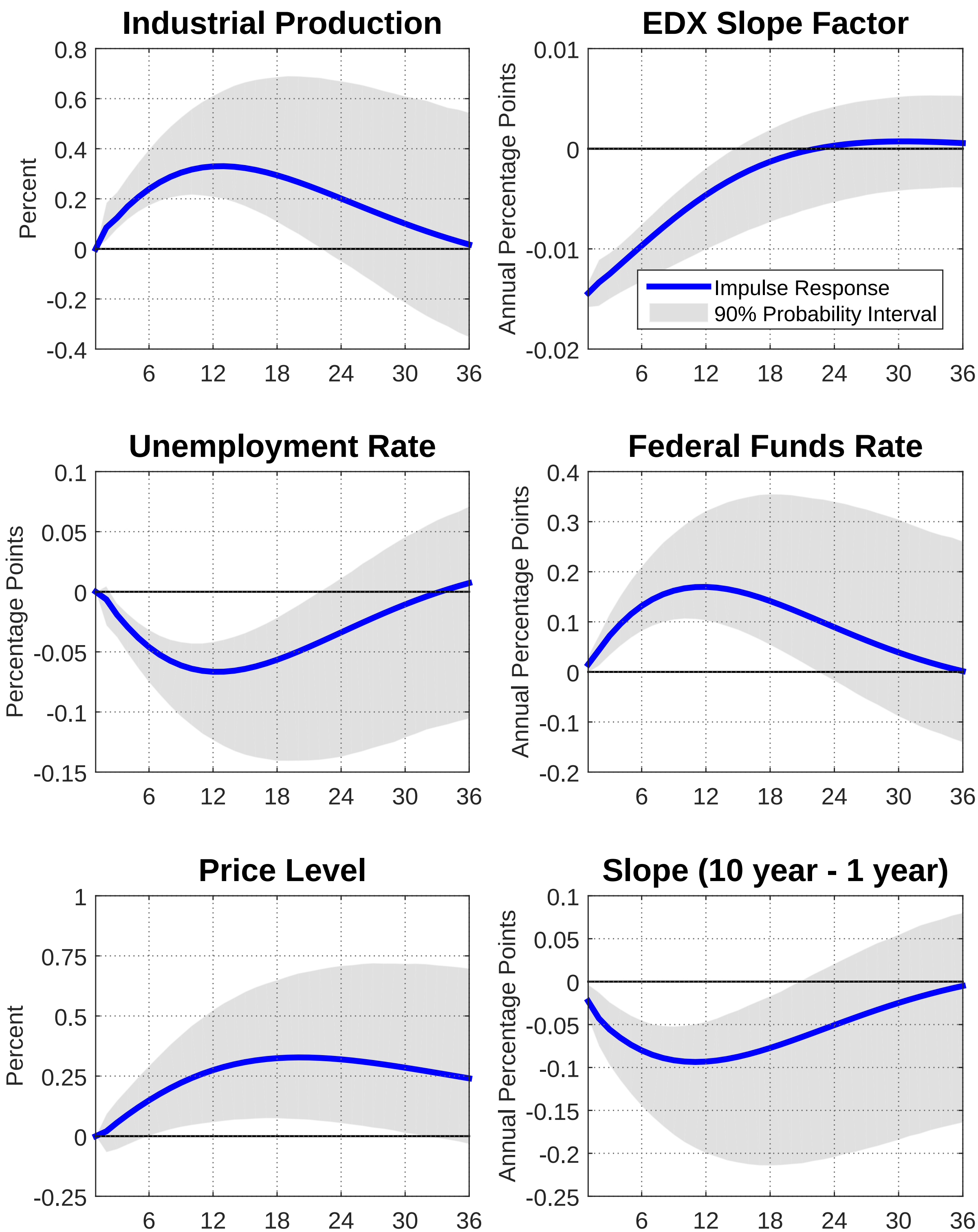
Note: The solid blue line denotes the empirical point estimate to a one standard deviation shock and the shaded regions denote the 90% probability interval of the posterior distribution. The sample period is January 1994 through November 2008. Two lags are included for each variable, selected using the AIC criterion. See Section 7.2 for additional details.

Figure 8: Impulse Responses with EDX Slope Factor Ordered First



Note: The solid blue line denotes the empirical 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. Two lags are included for each variable, selected using the AIC criterion. See Section 7.3 for additional details.

Figure 9: Impulse Responses With Additional Controls for Expected Path of Rates



Note: The solid blue line denotes the empirical 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. Two lags are included for each variable, selected using the AIC criterion. See Section 7.3 for additional details.