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The Term Structure of Monetary Policy Uncertainty*

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Abstract

This paper studies the transmission of Federal Reserve communication to financial markets and the economy using new measures of the term structure of policy rate uncertainty. Movements in the term structure of interest rate uncertainty around FOMC announcements cannot be summarized by a single measure but, instead, are two dimensional. We characterize these two dimensions as the level and slope factors of the term structure of interest rate uncertainty. These two monetary policy uncertainty factors significantly help to explain changes in Treasury yields and forward real interest rates around FOMC announcements, even after accounting for changes in the expected path of policy rates. Moreover, we demonstrate that focusing in just a single dimension of monetary policy uncertainty provides an inaccurate description of how policy uncertainty shapes the transmission of FOMC announcements. Finally, our policy uncertainty factors provide stronger first-stage instruments in a proxy SVAR setting, which implies more expansionary macroeconomic effects of forward guidance than those estimated only using the expected path of policy rates.

JEL Classification: E32, E52

Keywords: Monetary Policy Uncertainty, Forward Guidance, Proxy VAR

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1 Introduction

Recent research highlights uncertainty about future short-term interest rates as a salient factor shaping the transmission of monetary policy (Cieslak and Povala, 2016; Creal and Wu, 2017; Husted, Rogers and Sun, 2019; Tillmann, 2020; De Pooter et al., 2021; Bauer, Lakdawala and Mueller, 2021; Grisse, 2021). However, these recent contributions almost exclusively focus their attention on a single measure of monetary policy uncertainty, typically at a fixed horizon. This univariate characterization of monetary policy uncertainty is especially prevalent among recent work carrying out event studies of FOMC announcements on asset prices. In contrast, standard asset pricing frameworks predict that it is not just the amount of uncertainty that matters for asset prices, but that the timing of uncertainty is also highly relevant. For instance, common preferences used in asset pricing imply that investors may prefer the early resolution of uncertainty and therefore would require extra compensation to bear uncertainty at a longer horizon than at a shorter horizon.

We make a novel contribution to the flourishing literature on monetary policy uncertainty by studying shifts in the term structure of interest rate uncertainty around monetary policy announcements. We show that previous approaches, which focus on a single dimension of interest rate uncertainty, omit an important channel through which monetary policy announcements operate. Specifically, policy announcements transmit in part to financial markets and the macroeconomy by reshaping the term structure of interest rate uncertainty. Using data on interest rate options expiring at horizons ranging from 1-quarter to 5-quarters ahead, we formally test for the number of factors needed to summarize changes in interest rate uncertainty around FOMC announcements. We find strong evidence that two factors are necessary to approximate movements in the term structure. We refer to the first factor as the level factor as it is strongly correlated with changes in interest rate uncertainty at all horizons. We denote the second factor as the slope factor and it strongly correlates with changes in the spread between long- and near-horizon measures of interest rate uncertainty.

We establish that changes in the term structure of interest rate uncertainty are an important channel through which monetary policy announcements transmit to longer-term Treasury rates. For instance, adding our level and slope factors to the Hanson and Stein (2015) forward-rate regressions increases the R^2 by a factor of 1.5 to 3, depending on the maturity. These gains in explanatory power are concentrated in real rates, strengthening the evidence from Hanson and Stein (2015) and Nakamura and Steinsson (2018) that monetary policy has powerful effects on far forward real yields.

In contrast to the evidence from the existing monetary policy uncertainty literature, the explanatory power of our interest rate uncertainty factors in driving Treasury yields is not derived from the way in which they shape the transmission of first-moment monetary policy surprises. For example, De Pooter et al. (2021) and Bauer, Lakdawala and Mueller (2021) present evidence of a negative and statistically significant interaction term between the level of interest rate uncertainty ahead of the FOMC announcement and the first-moment monetary policy surprise in regressions of changes in Treasury yields around FOMC meetings. We however find that introducing the slope factor of interest rate uncertainty to this regression results in an insignificant interaction term and, instead, the slope factor itself is highly statistically significant. Based on these results, we argue that by disregarding the second factor from the term structure of monetary policy uncertainty, the existing literature may have overstated the importance of the interaction between the prevailing level of monetary policy uncertainty and first-moment monetary policy surprises.

Movements in the term structure of interest rate uncertainty around FOMC announcements appear to be predominantly driven by forward interest rate guidance. We document that the term structure of interest rate uncertainty slopes upward both on average and especially when the zero lower bound truncates the distribution of near-term interest rates from below. Thus, if policymakers convey a longer-than-expected stay at the zero lower bound, as the Federal Reserve did on August 9, 2011, not only is the level of interest rate uncertainty reduced, but the slope of the term structure of interest rate uncertainty is also reduced. This August 9, 2011 FOMC announcement is the largest observed 1-day flattening of the term structure of interest rate uncertainty in our sample which ranges from 1994 through 2019. However, we document that this uncertainty channel of forward guidance is also operative away from the zero lower bound. For instance, the next largest observed flattening of the term structure of interest rate uncertainty following a monetary policy announcement occurred on May 6, 2003, a forward guidance episode documented in Gurkaynak, Sack and Swanson (2005, pg. 81).

After establishing the importance of these level and slope factors as a channel through which forward guidance transmits to Treasury rates, we revisit the macroeconomic consequences of FOMC forward guidance announcements. While several studies have demonstrated the ability of forward guidance to shape medium- and longer-term interest rates, the existing literature finds much more varied evidence regarding the macroeconomic effects of FOMC forward guidance. This shortcoming has important implications for interpreting the sensitivity of forward real rates to FOMC announcements. If the movement in real yields reflects the "Fed information effect," as Nakamura and Steinsson (2018) argue, then economic activity would be expected to slow following an FOMC announcement which incites a decline in forward rates. On the other hand, if changes in forward rates reflect shifts in term premia, as Hanson and Stein (2015) conclude, then a decline in forward rates emanating from Federal Reserve forward guidance should boost economic activity. These alternative interpretations imply very different practical implications for the efficacy of forward guidance as a monetary policy tool.

A critical challenge in assessing the macroeconomic effects of forward guidance arises from the fact that high-frequency measures of forward guidance surprises derived solely from interest rate futures are typically weak instruments in proxy-SVAR settings. Specifically, measures of first-moment forward guidance surprises fail to explain a sufficient amount of the month-to-month variation in Treasury yields to serve as reliable instruments in a proxy structural vector autoregression (SVAR) (Gertler and Karadi, 2015). However, our event-study regressions suggest that our level and slope factors can better explain Treasury yields than can measures of forward guidance derived solely from first-moment interest rate futures and thus may strengthen the high-frequency forward guidance instrument set.

We therefore estimate a structural VAR model of the sorts estimated in Gertler and Karadi (2015) using both Swanson's (2021) forward guidance factor derived from interest rate futures and our level and slope factors derived from interest rate options. The proxy-SVAR models estimated with Swanson's forward guidance factor yield weak instruments and often contractionary effects from forward guidance inciting lower rates, consistent with the findings in Lakdawala (2019) who uses a similar proxy and argues in favor of a "Fed information effect."[1] In contrast, our level and slope factors can help to solve the weak-instrument problem, reflecting the power that these factors possess in explaining movements in Treasury yields around FOMC announcements. Moreover, when we use our level and slope factors as external instruments, we estimate that FOMC forward guidance which lowers Treasury rates leads to increases in economic activity. Therefore, we argue that evidence of a "Fed information effect" may be an artifact of weak-instrument bias that vanishes in the presence of stronger instruments.

These structural VAR results suggest that movements in forward real rates around FOMC announcements predominantly reflect movements in term premia, as suggested by Hanson

[1] Lakdawala (2019) uses an updated version of the Gurkaynak, Sack and Swanson (2005) "path factor," the predecessor to Swanson's (2021) "forward guidance factor".

and Stein (2015), rather than revisions to longer-run growth prospects associated with the "Fed information" effect posited in Nakamura and Steinsson (2018). To bolster this interpretation arising from our proxy SVAR results, we return to our event study regressions to decompose the source of the movements in longer-term Treasury yields between estimates of term premiums and estimates of expected future interest rates. These decomposition regressions suggest that changes in Treasury rates driven by the level and slope factors are indeed concentrated in term premia, consistent with the model of King (2019). However, in contrast to his mechanism, we show that changes in the term structure of interest rate uncertainty also transmit to Treasury term premia away from the zero lower bound.

The remainder of this paper proceeds as follows. Section 2 introduces the data and methodology we use to measure the term structure of interest rate uncertainty. Section 3 revisits event-study regressions of FOMC announcements on Treasury yields using our level and slope factors. Section 4 studies the macroeconomic effects of forward guidance using a proxy SVAR. Section 5 relates our findings to other recent research on monetary policy uncertainty and presents additional evidence on the channels through which FOMC announcements transmit to longer-term Treasury yields and the economy. Section 6 concludes.

2 The Term Structure of Interest Rate Uncertainty

Our primary objective is to measure and study how FOMC announcements reshape the term structure of interest rate uncertainty, which requires high-frequency measures of interest rate uncertainty at various horizons. Therefore, we apply the VIX methodology to Eurodollar options maturing at several horizons to measure uncertainty about future short-term interest rates at a daily frequency. In this section, we describe this methodology and use the resulting uncertainty measures to formally test for the number of factors needed to summarize changes in the term structure of interest rate uncertainty around FOMC announcements. We also relate our VIX-based approach to other measures of option-implied interest rate uncertainty from the previous literature.

2.1 Measuring Option-Implied Interest Rate Uncertainty

The VIX methodology was initially applied to measure option-implied volatility of S&P stock indexes, but the methodology has since been applied to measure option-implied volatility in a number of different markets, including foreign exchange and commodities. However, no exchange currently produces an index to measure option-implied volatility on Eurodollar futures. Eurodollar options are actively traded derivatives which provide investors the option to buy or sell Eurodollar futures at various strike prices. The existence of an active options market enables us to apply the widely-used, efficient, and model-free VIX methodology to calculate option-implied volatility of Eurodollar futures.[2] Eurodollar futures, and therefore options on these futures, 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 use the VIX methodology to calculate the option-implied volatility of short-term interest rates for each horizon from 1- to 5-quarters ahead.[3] 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.

We refer to our option-implied measures of short-term rate uncertainty by EDX, short for Eurodollar Volatility Index. By definition, the EDX index measures the implied volatility of *returns* on Eurodollar futures. However, to a first order approximation, the return on a Eurodollar future is proportional to the change in interest rates measured in annualized percentage points, with the coefficient of proportionality very close to one.[4] Therefore, we report the unit of measurement of our EDX series as annualized percentage points.

Table 1 reports summary statistics of the EDX-implied term structure of interest rate uncertainty over our 1994-2019 sample. We highlight three key stylized facts. First, our EDX measure of implied volatility averages 0.95 percentage points at the four-quarter ahead

[2]The CBOE details the VIX methodology at `https://www.cboe.com/micro/vix/vixwhite.pdf`. We purchased the Eurodollar futures and options data from the CME Group.

[3]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 actually refers to a 3-6 month horizon depending on the exact date within the quarter. This method of assigning horizons leads to some predictable variation in interest rate uncertainty around the date that the options expire. 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. First, our primary interest is examining the one-day *changes* in our EDX measure, which is not affected by this variation around expiration. Second, averaging between two adjacent horizons would shorten our longest maturity horizon.

[4]Let $P'(h)$ denote the expected price of a Eurodollar future maturing h periods ahead and let $P(h)$ denote the current price. The expected percent return on the Eurodollar future is therefore given by $R(h) = 100\left(\frac{P'(h)}{P(h)} - 1\right) \approx \frac{100}{P}(P'(h) - P(h)) = \frac{100}{P}(i - i')$, where P denotes the price around which we approximate returns and the last equality uses the fact that Eurodollar futures prices are quoted as 100 less the LIBOR rate. For P near 100 (i near zero), the EDX closely approximates the implied-volatility in LIBOR rates.

horizon, which is within the range of root-mean squared error (RMSE) of historical one-year ahead short-term interest rate forecasts compiled by Reifschneider and Tulip (2019).[5] The proximity of the 4-quarter EDX to the RMSE of forecasts suggests that risk premiums do not significantly distort our implied volatility measures on average. Second, the term structure of interest rate uncertainty is upward sloping. Figure 1 shows that the 5-quarter ahead always lies above the shorter-horizon measures. Finally, the second and third rows of Table 1 show that the term structure of interest rate uncertainty shifted lower and flattened during the 2009-2015 zero lower bound period, likely reflecting not only the truncation of downside interest rate uncertainty by the zero lower bound but also the FOMC's increased transparency. Swanson (2006) and Bundick and Herriford (2017) document that greater transparency reduces market-implied interest rate uncertainty. To this point, Figure 1 shows that the flattening of the term structure of interest rate uncertainty persisted after rates were lifted from zero in late 2015. Recent changes in FOMC communication which increased transparency included the addition of interest rates to the quarterly Summary of Economic Projections, regular post-meeting press conferences, and forward guidance which became more explicit and covered longer time horizons.

2.2 Shifts in the Term Structure of Interest Rate Uncertainty Around FOMC Announcements

While we construct our EDX measures for every trading day, we aim to identify fluctuations in interest rate uncertainty arising from FOMC announcements. 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): the prices of Eurodollar options reflect the expected distribution of future policy rates on the day before FOMC announcements. Then, we attribute the change in the price of Eurodollar options on the day of an FOMC announcement to unanticipated monetary policy. For our baseline results, we study the one-day change in our EDX measures around scheduled FOMC meetings over the 1994-2019 period. We later demonstrate the robustness of our results to using a two-day window over the 1999-2012 sample, as in Hanson and Stein (2015).

The top panel of Figure 2 shows that shifts in the EDX measures around FOMC announcements exhibit some common variation across horizon. Therefore, following the ap-

[5] These authors report the average root-mean squared error of four-quarter-ahead short-term interest rate forecasts to be 1.40 percentage points with a range across forecast sources of 0.86 to 1.44 percentage points.

proach of Gurkaynak, Sack and Swanson (2005), Nakamura and Steinsson (2018), and Swanson (2021) for first-moment monetary policy surprises at various horizons, we look to reduce the dimensions needed for empirical analysis. Specifically, we analyze the principle components of the changes in the EDX 1-quarter through EDX 5-quarter measures around FOMC meetings. Table 2 shows the factor loadings of the first two principal components. These two principal components jointly explain 94% of the variation in the five EDX series around FOMC announcements. Therefore, it appears that we can capture much of the FOMC-induced shifts in the EDX term structure using only two dimensions. Importantly, using only one dimension of option-implied interest rate uncertainty, which has been the focus of the existing literature on market-based measures of monetary policy uncertainty, explains just 86% of the variation in these five components.

We use a statistical rank test to formally test for the number of factors necessary to summarize the observed changes in the term structure of option-implied interest rate uncertainty around FOMC announcements. We choose to work with the Kleibergen and Paap (2006) rk test statistic, implemented by way of the STATA module developed by Kleibergen and Schaffer (2015). When testing the null that the number of factors is zero under homoskedasticity, this test is equivalent to testing the joint significance of the coefficients from an OLS regression. However, the Kleibergen and Paap (2006) rk-statistics can be applied in more general settings, including situations in which residuals exhibit heteroskedasticity.

In principle, we would like to examine the number of factors needed to summarize all five horizons of our EDX measures, ranging from 1-quarter ahead to 5-quarters ahead. However, the changes in some of the EDX measures are highly correlated with one another, which leads to the inclusion of uninteresting factors summarizing these commonalities.[6] We therefore test for the number of factors needed to describe changes in the EDX 1-quarter, 4-quarter, and 5-quarter measures around FOMC announcements. We choose the 1-quarter and the 5-quarter contracts because they are, respectively, the shortest and longest horizons over which Eurodollar options reliably trade over our sample. We also elect to include changes in the 4-quarter ahead Eurodollar options contracts as this 1-year ahead horizon has been the focus of much of the recent empirical literature on monetary policy uncertainty (Husted, Rogers and Sun, 2019; De Pooter et al., 2021; Bauer, Lakdawala and Mueller,

[6]Indeed, when including EDX measures at all five contract horizons the Kleibergen and Paap (2006) test suggests that five factors are needed. Swanson (2021) also reduces the dimension of the asset price changes when testing for the number of factors needed to explain changes in interest rate futures and Treasury yields around FOMC announcements to avoid selecting uninteresting factors.

2021).[7] Our approach is conservative in the sense that if more than one factor is needed to explain changes across these three maturities of interest-rate options contracts, then one factor would similarly be insufficient to explain FOMC-induced shifts across a wider range of interest-rate options contracts.

Formally, we test whether one factor is sufficient to summarize the salient movements in EDX option-implied volatility contracts around FOMC meetings using the following specification:

$$Y_t = F_t \Lambda + \varepsilon_t$$

where Y_t is a 208×3 matrix containing the one-day change in the EDX 1-quarter, EDX 4-quarter, and EDX 5-quarter around scheduled FOMC meetings from 1994 through 2019, F_t is a $208 \times k$ matrix containing the time series of the $k \leq 3$ factors (principal components), and Λ is a $k \times 3$ matrix with the loading of the k factors on the changes in the three EDX contracts, and ε_t is a vector of residuals.

Table 3 shows the results which test the null hypothesis that: $\mathcal{H}_0 : k = k_0$ versus the alternative that $\mathcal{H}_1 : k > k_0$, for $k_0 = 0$, $k_0 = 1$, and $k_0 = 2$. We very strongly reject the null that $k_0 = 0$, consistent with the recent literature that has emphasized the importance of changes in monetary policy uncertainty around FOMC announcements in explaining the transmission of monetary policy. However, in sharp contrast to the existing literature studying monetary policy uncertainty, we also strongly reject the null that $k_0 = 1$, suggesting that a single measure of monetary policy uncertainty is insufficient to explain the observed shifts in the term structure of option-implied interest rate uncertainty around FOMC announcements. Finally, the last row shows that we can not reject the null that $k_0 = 2$ given observed changes in the 1-, 4-, and 5-quarter EDX measures.[8] We therefore choose to work with two factors to summarize changes in market-implied interest rate uncertainty around FOMC meetings.

[7] Gurkaynak, Sack and Swanson (2005) and Swanson (2021) similarly test for the number of factors needed to summarize changes in the first moment of market-implied interest rates around FOMC announcements but, instead, use the Cragg and Donald (1997) test. However, Kleibergen and Paap (2006) argue that this test is numerically unstable when testing the null that the number of factors is greater than the true number of factors. In their application, they show that the Cragg and Donald (1997) factor test could therefore overestimate the number of factors.

[8] The null that $k_0 = 2$ is also rejected under several choices of the three horizons, suggesting that three factors may be needed. However, to remain conservative, we choose work with two factors since the null that $k_0 = 2$ can not be rejected under every specification.

The factor loading of the first two principal components offer a relatively straightforward interpretation of these two factors: the first principal components loads evenly across most horizons of option-implied interest rate volatility whereas the second principal component loads negatively on the near-term measures and positively on longer-term measures of option implied interest rate volatility. Therefore, we will refer to a scaled version of the first principal component as the EDX Level, and we term a scaled version of the second principal component the EDX Slope. To reinforce these interpretations, we scale the first principal component to have a one-for-one effect on changes in 4-quarter ahead EDX measure around FOMC announcements and we scale the second principal component to have a one-for-one effect on the difference between changes in 5-quarter and 1-quarter ahead EDX measures around FOMC announcements.

We can also measure the term structure factors, level and slope, using the methodology in Swanson (2006) to compute kernel densities and implied standard deviations in interest rate level space rather than the return space of our VIX methodology.[9] Our key findings are robust to using this alternative measure of market-implied interest rate uncertainty and, therefore, our particular measure of interest rate uncertainty is not instrumental for our results.[10] Reinforcing this point, our EDX level and EDX slope and similar level and slope measures constructed from the PDF-methodology in Swanson (2006), denoted by PDF Level and PDF Slope possess the following correlation structure: Given the strong correlation

	PDF Level	PDF Slope
EDX Level	1.00	−0.02
EDX Slope	0.01	0.97

across the EDX and PDF-measures of the term structure of monetary policy uncertainty, our forthcoming regression results are very similar when we instead employ the PDF measures rather than the EDX measures.[11] For brevity, we report these robustness exercises in the appendix and employ our EDX measure for our baseline results.

A visual inspection of our EDX level and slope measures reveals that FOMC forward guidance has the potential to both reduce the level and flatten the slope of the term struc-

[9]We thank Eric Swanson for kindly sharing his code with us to calculate these PDF measures.

[10]Importantly, we find strong evidence from this test that rejects the null that $k_0 = 1$ when measuring monetary-policy uncertainty using the PDF-measure employed in Swanson (2006).

[11]See Bauer, Lakdawala and Mueller (2021) for a comparison of alternative measures of market-based interest rate uncertainty, including a comparison between their measure and our 4-quarter EDX measure.

ture of interest rate uncertainty. The bottom panel of Figure 2 plots our EDX level and slope factors and annotates significant FOMC announcements that underlie the observed movements in the EDX level and slope factors. Many, but certainly not all, forward guidance announcements elicit sharp reductions in both the level and slope factors. This was the case for instance after the implicit forward guidance offered by the May-2003 and June-2004 FOMC post-meeting statements, as well as the more explicit rate guidance offered in Dec-2008, Mar-2008, and Aug-2011. The large declines in the EDX slope factor following these announcements underscores that forward guidance has the ability to significantly flatten the term structure of interest rate uncertainty when there is heightened uncertainty about the trajectory of the funds rate, as was the case following the initial Iraq invasion in early 2003; the early stages of the Great Financial Crisis in 2008-2009, which saw severe credit dislocations alongside inflationary pressures; and the summer of 2011 which saw diffuse expectations for the funds rate against a backdrop of rising inflation and still elevated unemployment.

However, there are other instances in which FOMC announcements elicited distinct effects on the level and slope of the term structure of interest rate uncertainty. For example, the July-1995 and January-2004 announcements — the two single largest changes Gurkaynak, Sack and Swanson (2005) document in their path factor — resulted in large adjustments in the level of interest rate uncertainty but had a much smaller impact on the slope of the term structure of interest rate uncertainty. This foreshadows the key theme of this paper: the term structure of interest rate uncertainty contains distinct information that cannot be sufficiently summarized by first-moment monetary policy surprises nor can this information be summarized solely by the level of interest rate uncertainty at a fixed future horizon.

3 The Effects of FOMC Announcements on Interest Rates

We first demonstrate the information contained in the term structure of interest rate uncertainty by revisiting event-study regressions which explore the effects of FOMC announcements on Treasury yields. This literature dates back to Kuttner (2001) who studied the surprise component of monetary policy announcements as measured by changes in interest rate futures around FOMC announcements. A seminal contribution from Gurkaynak, Sack and Swanson (2005) showed that changes in interest rate futures around FOMC announcements cannot be summarized by a single factor but rather require two factors, a target factor and a path factor. They show that the latter is closely linked to FOMC communication about future policy, or what is now called forward guidance, and transmits most strongly to longer-term Treasury rates.[12] Hanson and Stein (2015) and Nakamura and Steinsson (2018), among others, furthered this line of research by showing that, counter to conventional macroeconomic thought, forward guidance transmits most strongly through real rather than nominal interest rates.

More recent work has extended these event study regressions to show a link between the effect of monetary policy announcements on longer-term interest rates and the prevailing level of interest rate uncertainty just ahead of the announcement. De Pooter et al. (2021) show that high (low) levels of monetary policy uncertainty dampen (amplify) the response of longer-term Treasury yields to surprise monetary policy announcements. Bauer, Lakdawala and Mueller (2021) present similar evidence across a broader range of assets. Both papers explore this channel by studying the sign and significance of the coefficient on the interaction between the first-moment monetary policy surprise and the level of interest rate uncertainty ahead of the FOMC announcement.[13] Though these two papers ascribe these effects to different channels, they both find negative and statistically significant coefficients on this interaction term and therefore argue that the prevailing level of interest rate uncertainty is an important factor that shapes the transmission of monetary policy announcements. However, neither study explored the possible role played by shifts in both the level and slope of the term structure of interest rate uncertainty in driving these results.

In this section, we revisit these event studies using our broader, two factor, measurement of monetary policy uncertainty. We first study the role these uncertainty factors play in shaping the response of Treasury yields to FOMC announcements in the presence of first moment monetary policy surprises. We find that the EDX factors play an economically meaningful and statistically significant role in explaining the response of 10-year Treasury yields, regardless of which measure of first-moment monetary policy surprises are included in the regression. Importantly, in light of the work by De Pooter et al. (2021) and Bauer, Lakdawala and Mueller (2021), we find little evidence of significant interaction effects between first-moment monetary policy surprises and the level of interest rate uncertainty *after* accounting for shifts in both the level and slope of interest rate uncertainty incited by the announcement. These results therefore call into question the quantitative importance of

[12] Interestingly, the words "forward guidance" do not appear in their paper though this work is arguably the foundation for much of the existing forward guidance literature.

[13] Tillmann (2020) similarly shows that high levels of monetary policy uncertainty dampen the response of the Treasury yield curve to unexpected monetary tightenings, though not in an event-study framework.

both the Treasury positioning channel put forth by De Pooter et al. (2021) as well as the signal extraction channel put forth by Bauer, Lakdawala and Mueller (2021). Instead, our results suggest that FOMC announcements can broadly shape expectations as well as uncertainty surrounding the trajectory of future policy rates to a greater extent than previously recognized. In this regard, we revisit the Hanson and Stein (2015) regressions of Treasury forward rates around FOMC announcements. We find significant increases in explanatory power of nominal and real Treasury forward rates from our EDX level and slope factors.

3.1 Monetary Policy Uncertainty & The Response of Treasury Yields To FOMC Announcements

We begin by studying how our EDX level and slope factors correlate with the response of the benchmark 10-year Treasury yield around FOMC announcements. In Table 4, we report results from the following regression:

$$\Delta y_t^{10} = \alpha + \beta^L L_t + \beta^S S_t + \varepsilon_t, \tag{1}$$

where Δy_t^{10} is the one-day change in the zero coupon 10-year Treasury yield around FOMC announcements, L_t denotes our EDX level factor, and S_t denotes our EDX slope factor. Zero-coupon Treasury yield data is produced by the Federal Reserve Board (Gürkaynak, Sack and Wright, 2007) and was obtained from Haver Analytics. The far left column shows that including only the EDX level factor in regression (1) elucidates a large positive and statistically significant relationship between longer-term yields and changes in the level of interest rate uncertainty. However, the second column, which adds the EDX slope factor to the regression, shows that the relationship between longer-term yields and interest rate uncertainty is richer than a single measure of interest rate uncertainty might suggest. Adding the EDX slope factor to the regression more than doubles the regression R^2 and the regression coefficient on this slope factor is also positive and even larger in magnitude than the coefficient on the EDX level factor.

The last three columns of Table 4 explore the novelty of the information content of our EDX measures as they compare to various first-moment monetary policy surprises. There is no agreed upon measure of the first-moment monetary policy surprise. Therefore, to ensure that the most robust empirical evidence surfaces, we examine the three most commonly used measures of monetary policy surprises in the monetary policy event-study literature: the change in the nominal 2-year zero coupon Treasury yield (Hanson and Stein, 2015; De Pooter et al., 2021), the target & path factors (Gurkaynak, Sack and Swanson, 2005), and the policy news surprise (Nakamura and Steinsson, 2018; Bauer, Lakdawala and Mueller, 2021). To fix the horizon of these measures, we construct both the Gurkaynak, Sack and Swanson (2005) target and path factors and the Nakamura and Steinsson (2018) policy news surprise measure using Eurodollar futures out to 8 quarters (2 years). We note that this horizon is longer than was used in the original works of Gurkaynak, Sack and Swanson (2005) and Nakamura and Steinsson (2018), both of which used Eurodollar futures extending out to 4 quarters (1 year). However, expectations of interest rates 1-year ahead were constrained for much of the 2008-2015 zero-lower-bound period. Moreover, over this period, the Federal Reserve regularly offered forward guidance at horizons well beyond one year. Therefore, extending the horizon of these measures to 2-years is important to ensure that the role of the term structure of interest rate uncertainty isn't proxying for changes in the first-moment of monetary policy surprises at longer-horizons. In this sense, our measures of the first moment of monetary policy surprises provide a conservative estimate of the role of monetary policy uncertainty. For all three measures of monetary policy surprises, we use the same methodology used to construct our EDX factors and use a one-day window around scheduled FOMC meetings from January 1994 through December 2019. We scale both the path factor and the policy news surprise measure to have a one-for-one effect on the 8-quarter (2 year) ahead Eurodollar future rate.

We sequentially add each first-moment monetary policy surprise measure to our regression equation, which now takes the following form:

$$\Delta y_t^{10} = \alpha + \beta^L L_t + \beta^S S_t + \beta^F F_t + \varepsilon_t, \tag{2}$$

where F_t denotes one of the three measures of first-moment monetary policy surprises. The coefficient on each of the three first-moment measures is near 0.6 and strongly significant. Importantly though, none of the three first-moment measures of monetary policy surprises encapsulate the information contained in our EDX factors. The next-to-last row of Table 4 reports the p-value of the hypothesis test $\mathcal{H}_0 = \beta^L = \beta^S = 0$. Regardless of the first moment measure, the EDX term structure factors are jointly statically significant. Inspecting the individual β^L and β^S coefficients reveals that it is especially the slope factor that retains statistical significance in the presence of first-moment monetary policy surprises.

While the magnitude of the coefficient on the EDX slope factor, β^S, is reduced in the presence of these other shock measures, it remains just as large as the coefficients on first-moment policy shocks. This suggests that a 1-percentage point flattening of the term structure of interest rate uncertainty has a slightly larger effect on 10-year Treasury yields than does a 1 percentage point reduction in 2-year (ahead) interest rates.

For both historical and quantitative context, it is useful to revisit the August 9, 2011 forward guidance episode which is the largest one-day decline in our EDX slope factor. On this day, the FOMC revised its forward guidance from signaling low levels of the funds rate "for an extended period" to instead state that the Committee expects low levels of the funds rate "at least through mid-2013." Despite no adjustments in its asset purchase program, this first ever use of date-based forward guidance led the 10-year Treasury yield to fall more than 20 basis points. Regression (2), which includes the target and path factors, can explain all but 3 basis points of this decline. The decline in the EDX level factor explains a little more than 1 basis point of this decline whereas the decline in the EDX slope factor explains 5 basis points of this decline with the rest of the explained 10-year yield decline (about 11 basis points) attributed to a large change in the path factor.[14] Intuitively, we might expect that this announcement reduced uncertainty about the funds rate several years in the future, thereby explaining the flattening in the term structure of interest rate uncertainty. This episode therefore underscores the potential for forward guidance to operate through the term structure of interest rate uncertainty.

3.2 Revisiting the Role of Monetary Policy Uncertainty in Transmitting First-Moment Monetary Policy Surprises

Recent work exploring the response of Treasury yields to FOMC announcements, by De Pooter et al. (2021) and Bauer, Lakdawala and Mueller (2021), assigns an important role to the prevailing level of interest rate uncertainty ahead of an FOMC announcement. By omitting any interaction terms between first-moment monetary policy surprises in regression (2), we may have overstated the importance of shifts in the term structure of interest rate uncertainty around announcements. After all, for a monetary policy announcement to reduce or flatten the term structure of interest rate uncertainty, it must be the case that uncertainty was elevated ahead of the announcement, thereby giving policymakers some scope to reduce future uncertainty. We now more formally explore the distinct role played by the prevailing shape of the term structure of interest rate uncertainty ahead of the announcement versus shifts in the term structure of interest rate uncertainty incited by FOMC announcements.

[14]This episode is the 6th largest decline in the path factor over our sample. Dropping the EDX factors from regression (2) leads to a residual of 8 basis points rather than 3 basis points on August 9, 2011.

To this end, we consider the following regression model:

$$\begin{aligned}\Delta y_t^{10} &= \alpha + \beta^L L_t + \beta^S S_t + \beta^F F_t \\ &\quad + \beta^{F,L} F_t \times EDX4Q_{t-1} + \beta^{F,S} F_t \times (EDX5Q_{t-1} - EDX1Q_{t-1}) + \varepsilon_t,\end{aligned} \tag{3}$$

where $EDX4Q_{t-1}$ denotes the level of EDX4Q the day before the FOMC announcement and, similarly, $(EDX5Q_{t-1} - EDX1Q_{t-1})$ denotes the spread between the level of the EDX5Q and the EDX1Q the day before the FOMC announcement.[15]

Table 5 reports estimates from both a restricted and unrestricted version of regression (3) for each of the three measures of first-moment monetary policy surprises. The restricted regression restricts $\beta^S = \beta^{F,S} = 0$ in an effort to closely mirror the regressions estimated in De Pooter et al. (2021) and Bauer, Lakdawala and Mueller (2021), since both papers consider just the level of interest rate uncertainty. Consistent with their findings, in these restricted regressions, we estimate that the interaction term $\beta^{F,L}$ is negative and statistically significant across all three first-moment measures of monetary policy surprises. This suggests that, all else equal, a higher (lower) level of uncertainty ahead of an FOMC announcement dampens (amplifies) the effects of first-moment monetary policy surprises on Treasury yields.

The estimates from the unrestricted form of regression (3) reveal that, once we include the EDX slope factor in the De Pooter et al. (2021) and Bauer, Lakdawala and Mueller (2021) regressions, interaction effects largely vanish. Consistently across first-moment monetary-policy surprise measures, the negative and statistically significant estimates of $\beta^{F,L}$ decline in magnitude and lose statistical significance when the EDX slope factor and the slope interaction terms are added to the regression. Moreover, these regressions indicate that to the extent that a statistically significant relationship remains between prevailing interest-rate uncertainty and first moment monetary policy surprises, it operates through the slope — rather than the level — of interest rate uncertainty. For instance, the target and path factor regressions suggest no meaningful relationship exists between the prevailing level of interest rate uncertainty and first-moment monetary policy surprises. Instead, the only remaining evidence of interaction effects appears to operate between the path factor and the prevailing slope of interest rate uncertainty ahead of the announcement as $\beta^{F,S}$ is statistically significant at the 10 percent level. Though, this result is not robust across first-moment measures. Instead, the most robust empirical fact remains the importance of shifts in the level and slope of the term structure of interest rate uncertainty in explaining movements in Treasury yields, as indicated by the p-values of EDX F-tests across unrestricted specifications.

[15] We also include $EDX4Q_{t-1}$ and $(EDX5Q_{t-1} - EDX1Q_{t-1})$ in these regressions.

3.3 Monetary Policy Uncertainty & The Response of Nominal and Real Treasury Forward Rates to FOMC Announcements

Having established that shifts in the term structure of interest rate uncertainty transmit to the 10-year Treasury yield, we now seek a more granular view of this transmission mechanism. This leads us to study the response of nominal and real Treasury forward rates at various horizons to FOMC announcements using our EDX level and slope factors. In addition to detailing the breakdown between nominal and real interest rates, as well as isolating effects at specific points on the Treasury forward curve, this analysis also relates our work to Hanson and Stein (2015) and Nakamura and Steinsson (2018). In standard macroeconomic models, monetary policy only affects real variables due to sticky prices. Thus, after ten 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) and Nakamura and Steinsson (2018) document that FOMC forward guidance affects forward real rates ten or even twenty years into the future, albeit through different channels.

We specifically focus on the Hanson and Stein (2015) specification which regresses changes in n-year Treasury forward rates on the 2-year Treasury yield in a two-day window around FOMC announcements for nominal and real (Treasury Inflation Protected Securities, TIPS) instantaneous forward rates. Hanson and Stein (2015) explain the sensitivity of distant forward real rates to forward guidance 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) uncertainty about the future short-term policy rate, shifts in which should be captured by our EDX measures, and (2) a reach-for-yield term premium, which is affected by the expected path, or first-moment monetary policy surprises. They focus on the latter reach-for-yield channel, whereas our EDX measures provide a novel angle to explore the quantitative significance of the former, the short-rate uncertainty channel.

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

$$\Delta f_t^{X(n)} = a_X(n) + b_X(n)\Delta y_t^{\$(2)} + \varepsilon_t^{X(n)}, \tag{4}$$

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.[16] To examine the quantitative importance of both the interest rate uncertainty channel and the reach-for-yield channel, we augment their regression model with our EDX level and slope factors:

$$\Delta f_t^{X(n)} = a_X(n) + b_X(n)\Delta y_t^{\$(2)} + \beta_X^L(n)L_t + \beta_X^S(n)S_t + \varepsilon_t^{X(n)}, \tag{5}$$

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 6 reports the regression results for the regression models in equations (4) and (5) for forward nominal, real, and break-even inflation rates.[17]

We find that the uncertainty of future short-term policy rates plays a significant role in driving forward interest rates around FOMC announcements. The first row of each maturity replicates the 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 (5), which include our interest rate uncertainty factors. Focusing first on the results for forward nominal rates in the left panel of Table 6, 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. At the 10-year horizon, a 10 basis point increase in either of our uncertainty factors (holding all else equal), increases 10-year ahead nominal forward rates by about 7 basis points. Moreover, our uncertainty factors also add greatly to the statistical power of the regression model. The R^2 measure of fit increases by a factor of 1.5-3 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.

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

[17] For brevity, we focus on maturities of $n = 5, 10, 15$, and 20 in Table 6. Estimates for all maturities from $n = 5, ..., 20$ are available upon request.

The economic significance and increased explanatory power of nominal forward rates from our measures of interest rate uncertainty stem from their effects on forward real rates. In the middle and right panels of Table 6, 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. 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, we observe that the increases in R^2 measures from incorporating our EDX factors are concentrated on the real forwards more so than on the modest increases in explained variation in the break-even inflation regressions.[18] Focusing on the 5-year forward real rate, the R^2 nearly doubles from 0.24 to 0.46 when we introduce our EDX factors. In fact, we observe increases in explained variation in real forward rates across all horizons though the increases in explanatory power diminish at longer horizons.

Changes in interest rate uncertainty incited by FOMC announcements appear to be a primary driver of changes in forward real rates around policy announcements. Through the lens of Hanson and Stein's (2015) model of yield oriented investors, changes in interest rate uncertainty transmit to longer-term interest rates through term premiums rather than the expected path of rates. These regression results are therefore suggestive, though not conclusive, that changes in term premiums predominantly explain movements in real forward rates around FOMC announcements. In the next sections, we further explore this issue.

4 The Macroeconomic Effects of FOMC Announcements

The meaningful increases in R^2 that result from including our EDX level and slope factors in Hanson and Stein's (2015) regressions substantially strengthen the evidence that FOMC announcements transmit to far forward real rates. However, the mechanism through which

[18] 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 premiums as opposed to forward guidance, also help explain movements in term premiums in longer-term bonds. The regression results in Table 6 help to distinguish these channels.

these changes in real rates manifest remains unclear. Hanson and Stein (2015) argue that changes in forward real rates reflect "reach-for-yield" behavior by which announcements conveying a lower path of future policy rates reduce term premiums. Moreover, the results from our augmented Hanson and Stein (2015) regressions suggest that changes in interest rate uncertainty may be equally, or perhaps even more, important for term premiums than the reach-for-yield mechanism put forward by Hanson and Stein (2015). Nakamura and Steinsson (2018) instead put forth an alternative interpretation through which announcements conveying a lower path of future policy rates reduce expectations for future real rates, reflecting dimmer beliefs about the economy's growth prospects arising from "Fed information effects."

Since greater clarity about the trajectory of policy rates would arise from FOMC forward guidance under any of these mechanisms, our Treasury rate regressions cannot discriminate between these hypotheses. Where these two hypotheses diverge is in their predictions for the macroeconomic consequences of FOMC forward guidance. If reductions in forward rates primarily reflect reductions in term premiums, then FOMC forward guidance conveying a more accommodative path of policy rates should stimulate economic activity. On the other hand, if FOMC forward guidance conveying a more accommodative path of policy rates also conveys the FOMC's own concern about the economy's growth prospects, then the pace of economic activity should slow.

Recognizing these different predictions, Nakamura and Steinsson (2018) present evidence based on monthly-frequency regressions that professional forecasters revise down their growth expectations when the FOMC announces a lower-than-expected path for interest rates. Nakamura and Steinsson (2018) choose to study the response of survey expectations for future growth rather than a direct examination of the effects on future economic activity data due to the low power of high-frequency surprises to the expected policy path. They refer to this as the "power problem" of high-frequency monetary policy surprises which they describe as follows: "The monetary shocks we estimate are quite small (they have a standard deviation of only about 5 basis points). This 'power problem' precludes us from directly estimating their effect on future output. Intuitively, output several quarters in the future is influenced by myriad other shocks, rendering the signal-to-noise ratio in such regressions too small to yield reliable inference." (Nakamura and Steinsson, 2018, pg. 1284). While Nakamura and Steinsson's (2018) evidence is certainly suggestive of a Fed information effect, similar to the "Delphic" interpretation offered for similar regression results in Campbell et al. (2012), more recent work has questioned whether these monthly forecast-revision regressions are immune from endogeneity concerns that plague the literature seeking to isolate the macroeconomic effects of monetary policy (Bauer and Swanson, 2020). Therefore, direct evidence on the output implications of forward guidance remains elusive.

Proxy SVAR models look to be a promising avenue to assess the macroeconomic effects of forward guidance due to their ability to directly incorporate high-frequency surprises in a time-series framework that can also account for the Fed's endogenous response to economic fundamentals (Caldara and Herbst, 2019). Nevertheless, the weak correlation between surprises to the expected path of policy rate and VAR-residuals is an evident challenge in the proxy-SVAR literature where, in practice, high-frequency forward guidance surprises have been found to be weak instruments. Gertler and Karadi (2015) for instance note that, "A conceptually nice way to assess the importance of forward guidance would be to follow GSS by isolating the component of the instrument set that reflects surprises in future rates that are orthogonal to surprises in the current rate. This component, which GSS refer to as the 'path' factor then in principle captures the effect of pure shocks to forward guidance. Unfortunately, this decomposition [...] leads to instruments that are too weak in the context of our external instruments setup to credibly identify pure surprises to forward guidance." (Gertler and Karadi, 2015, pg. 69)

We aim to directly assess the macroeconomic effects of FOMC forward guidance by expanding the high-frequency proxy set of forward guidance surprises. In particular, our event study evidence suggests that our level and slope term structure factors greatly enhance the explanatory power of high-frequency FOMC announcement surprises on Treasury yields. While these event-study regressions are in a 1- or 2-day window around FOMC announcements, we postulate that the increase in R^2 in these regressions may partly translate to the first-stage IV-type regressions of VAR residuals of Treasury yields on our proxy set. Indeed, we present evidence in this section that including our level and slope factors in a proxy SVAR setting can help to address the weak instruments and power problems that accompany Swanson's (2021) forward guidance factor – a successor to the Gurkaynak, Sack and Swanson (2005) path factor – which is derived from interest rate futures like the policy news surprise measure in Nakamura and Steinsson (2018). Moreover, we show that the increased strength of the forward guidance proxy set that arises from including our level and slope factors results in evidence that economic activity increases following an accommodative forward guidance announcement. Therefore, our results appear to support the term premium mechanism rather than the Fed information effect of forward guidance.

4.1 Proxy SVAR Data and Description

We closely follow the proxy SVAR specification in Gertler and Karadi (2015). We study a four variable monthly VAR model consisting of $y_t = [GS_t, 100 \times log(ip_t), 100 \times log(cpi_t), ebp_t]'$ where GS_t is the monthly-average yield on a U.S. government debt security which will serve as our indicator for forward guidance, $100 \times log(ip_t)$ is 100 times the natural log of the index of industrial production, $100 \times log(cpi_t)$ is 100 times the log of the Consumer Price Index (CPI), and ebp_t is the Gilchrist and Zakrajšek (2012) excess bond premium. In our analysis, we consider n-year zero coupon Treasury yields and n-year instantaneous Treasury forward rates with maturities $n = 2, 5, 10$. The use of forward rates as a policy indicator departs from Gertler and Karadi (2015) who end their sample in 2012. We argue in the following analysis that considering forward rates sharpens the identification of forward guidance over our sample that encompasses the full seven-year zero lower bound period of 2009-2015.

Consider the structural VAR representation of the vector of variables y_t, where a constant term is suppressed from the notation but is included in the estimation:

$$B_0 y_t = B(L) y_{t-1} + \varepsilon_t, \tag{6}$$

where B_0 is the matrix that describes the contemporaneous structural relationships between the variables, $B(L)$ is a 12-th order lag polynomial, and ε_t is a vector of i.i.d. structural shocks, each with unit variance. Without loss of generality, we assume that the first element of ε_t, denoted ε_t^{fg}, is the forward guidance shock that we seek to recover.

We estimate the reduced-form VAR model over an updated sample relative to Gertler and Karadi (2015), ranging from 1979:7 through 2019:6 using ordinary least squares:

$$y_t = A(L) y_{t-1} + u_t, \tag{7}$$

where $A(L) = B_0^{-1} B(L)$ is the 12-th order reduced-form lag polynomial and u_t is the mean zero vector of reduced-form VAR residuals with variance-covariance matrix Σ. The mapping between u_t and ε_t is given by:

$$u_t = [u_t^1, u_t^{q'}]' = B_0^{-1} \varepsilon_t = S \varepsilon_t = [S_1, S_2][\varepsilon_t^{fg}, \varepsilon_t^{q'}]' = \begin{bmatrix} s_{11} & s_{21} \\ s_{21} & s_{22} \end{bmatrix} [\varepsilon_t^{fg}, \varepsilon_t^{q'}]', \tag{8}$$

where $S_1 = [s_{11}, s'_{21}]'$ is a 4×1 vector. s_{11} is a scalar, which measures the impact effect of a one unit forward guidance shock on the forward guidance indicator, and s'_{21} is a 3×1 vector that measures the resulting impact effect from this forward guidance shock on the remaining three variables in the VAR. Once S_1 is identified, the impulses responses to a forward guidance shock can be estimated.

4.2 The Strength of Forward Guidance Proxies

We follow the proxy SVAR literature and look to recover S_1 by using external instruments (Stock and Watson, 2012; Mertens and Ravn, 2013; Gertler and Karadi, 2015). We focus our attention on forward guidance instruments that can capture changes in the distribution of policy rates over the coming quarters and years rather than unexpected changes in the current target rate. For this purpose, we define the instrument set Z_t to potentially consist of Swanson's (2021) forward guidance factor, which is derived from changes in interest-rate futures and Treasury yields around FOMC announcements, as well as our level and slope factors derived from options on interest rate futures. To ensure consistency in the availability of these instruments, we extend our level and slope factors back to 1991, using the 1-day change in the EDX 1- through 5-quarter around the same dates used to construct Swanson's (2021) forward guidance factor. Therefore, the instrument set is available from 1991:8 through 2019:6.[19] We therefore estimate the vector S_1 using a two-stage least squares regression of $u_t^{q'}$ on u_t^1 instrumented by Z_t.[20]

The strength of the instrument set, and therefore the ability to obtain unbiased and reliable estimates of the macroeconomic effects of forward guidance, is typically determined by the F-statistic from the first-stage regression:

$$u_t^1 = Z_t\phi + e_t, \tag{9}$$

where u_t^1 are the residuals from the forward guidance indicator equation (the first equation) in the reduced-form VAR model and e_t is a white noise error term. The residuals u_t^1 reflect the month-to-month variation in a Treasury yield or Treasury forward rate that cannot be predicted by lagged macroeconomic and financial variables. A fraction of this unpredictable variation undoubtedly reflects the unexpected announcements by the FOMC which economists are attempting to recover; however, it may be a small fraction relative to other forces shifting interest rates month-to-month. The low variation of high-frequency policy news or forward guidance surprises relative to the month-to-month variation in Treasury rates can therefore lead to a low R^2 and therefore a low F-statistic in the first-stage

[19] Swanson's (2021) forward guidance factor actually begins in 1991:7 however, due to the aggregation of the high-frequency surprises from daily to monthly, for which we follow the aggregation method outlined in Gertler and Karadi (2015) (cumulatively sum the daily values, aggregate this series to a monthly basis by averaging within the month, and then difference the resulting monthly series), we lose the first month's observation.

[20] Technically, this two-stage regression recovers the 1×3 vector $\hat{s}_{21}/\hat{s}_{11}$. $\hat{s}_{11}$ can then be recovered by combining the estimate of s_{21}/s_{11} with the estimate of Σ using the relationship $SS' = \Sigma$. See footnote 4 of (Gertler and Karadi, 2015) for details.

regression. Stock, Wright and Yogo (2002) present a broad review of the weak instruments IV literature and conclude that, in most applications, a first-stage F-statistic near ten is necessary to allay concerns over weak instruments. The primary challenge to date in identifying the effects of forward guidance shocks in this setting is that the F-statistics from regression (9) generally fall uncomfortably below ten when Z_t consists of measures of forward guidance surprises constructed from changes in interest rate futures around FOMC announcements, such as the Gurkaynak, Sack and Swanson (2005) path factor (Gertler and Karadi, 2015).

Table 7 shows the output of the first-stage regression defined in equation (9) using n-year Treasury yields and Treasury forward rates of various maturities n as the forward guidance indicator. Across all forward guidance indicators, using solely Swanson's (2021) forward guidance factor, denoted by "FG Factor" in the table, fails to register a first-stage F-statistic much above six, echoing the results from Gertler and Karadi (2015).[21] However, when the EDX level and slope factors are employed as forward-guidance proxies the first-stage F-statistics increase and even exceed ten in one instance. Table 7 also shows that including all three factors as instruments, Swanson's (2021) forward guidance factor, the level factor, and the slope factor, increases the first-stage F statistic for most indicators relative to solely using Swanson's (2021) forward guidance factor.

The strongest proxies arise when we use the 5-year Treasury forward rate as the forward guidance indicator. While Gertler and Karadi (2015) and Lakdawala (2019) employ the 1- or 2-year Treasury yield as forward guidance indicators over samples ending around 2012, the results in Table 7 call for using medium-term Treasury forwards as forward guidance indicators over our 1991-2019 sample. For instance, not one of the three forward guidance proxies is statistically significant when the 2-year Treasury yield is the forward guidance indicator. However, when we consider longer horizon, forward Treasury rates as our forward guidance indicator, we find a stronger relationship between the forward guidance indicator and the forward guidance instruments. Over roughly the same sample period we consider, Swanson (2021) shows that in a tight window around FOMC announcements, forward guidance has its largest effect on 5-year Treasury rates with a diminishing effect at shorter and longer

[21] The F-statistics are not directly comparable to Lakdawala (2019) as he includes both the Gurkaynak, Sack and Swanson (2005) target and path factors in the first-stage regression. Gurkaynak, Sack and Swanson (2005) shows that the target factor has a large and statistically significant effect on 2-year Treasury yields, Lakdawala's (2019) forward guidance indicator. Similarly, Jarociński and Karadi (2020) and Caldara and Herbst (2019) use near-term futures surprises which reflect both forward guidance as well as unexpected changes in the current policy rate.

maturities. The need to consider longer-horizon policy indicators to capture the full effects of forward guidance is therefore a likely consequence of our more modern sample which, unlike Gertler and Karadi (2015) and Lakdawala (2019), encompasses the full seven year zero lower bound period of 2009 through 2015.

4.3 Estimated Impulse Responses to a Forward Guidance Shock

The extent to which the documented instances of weak instruments in Table 7 bias the estimated output effects from forward guidance is ultimately application specific. Therefore, we next study the estimated impulse responses across alternative instruments. Figure 3 shows the impulse responses from a forward guidance shock which reduces the 5-year forward Treasury rate by 25 basis points across three different instrument sets. Confidence bands are calculated using 10,000 replications of the moving block bootstrap procedure proposed in Jentsch and Lunsford (2019), which Mertens and Ravn (2019) contend are conservative in cases that the instruments may be weak. The first column shows that when Swanson's (2021) forward guidance factor is the sole proxy, industrial production declines for the first year following a surprise reduction in expected future interest rates, consistent with the evidence presented in Nakamura and Steinsson (2018) and Lakdawala (2019) in favor of a Fed information effect. We also estimate a temporary decline in prices, although the price response is not estimated with much precision. However, these contractionary effects from FOMC forward guidance on economic activity and prices may well reflect bias arising from weak instruments. For instance, if this was a pure Fed information effect then we might expect excess bond premiums to rise but, instead, they fall. Therefore, the responses of industrial production and consumer prices seem out of sync with the response of bond premiums and may therefore reflect the lack of explanatory power of futures-based forward guidance surprise measures rather than a Fed information effect.

The second column provides evidence that when the instruments are sufficiently strong, forward guidance announcements which lower forward rates lead to increases — rather than declines — in economic activity and prices. Importantly, the paths for 5-year forward rates are virtually identical across columns 1 and 2 of Figure 3. However, unlike in column 1, when the level and slope factors are used as forward guidance proxies, industrial production moves persistently higher in a hump-shaped pattern. The peak response of industrial production is larger and more precisely estimated when the level and slope factors are used as proxies relative to when Swanson's (2021) forward guidance factor is used as a proxy. Similarly, prices steadily rise over the months following the forward guidance intervention when using the

EDX factors as forward guidance proxies, rather than initially declining when the Swanson's (2021) forward guidance factor is used as the forward guidance proxy. Though the differences between the price responses across columns 1 and 2 of Figure 3 are less pronounced. Therefore, the primary effect of weak forward guidance instruments appears to be concentrated in the response of real economic activity, the key variable of interest in interpreting forward real rate responses to FOMC announcements.

The third column of Figure 3 employs all three forward guidance proxies as first-stage instruments in the SVAR. The response of the 5-year forward rate, the price level, and the excess bond premium is essentially unchanged from column 2, perhaps unsurprisingly given the similarity in these responses across columns 1 and 2. However, given the contrasting predictions regarding the response of real activity across proxies, the industrial production response in column 3 of Figure 3 is worth noting. Although the strength of the instrument set is diluted by including the forward guidance factor in the instrument set, illustrated by the decline in the F-statistic moving from column 2 to column 3, the output response is not materially affected. The peak industrial production response is virtually identical to that found in column 2, offering further evidence that the initial decline in industrial production and tepid increase shown in column 1 may be an artifact of weak instruments that vanishes in the presence of stronger instruments.

5 Relationship to Other Work and Additional Results

We find evidence that forward guidance increases economic activity when responses are estimated using sufficiently strong forward guidance proxies. Importantly, these same proxies imply that forward guidance announcements simultaneously increase economic activity and reduce far-forward real yields. Therefore, the evidence presented from our event-study regressions in Section 3.3, as well as the proxy SVAR models presented in Section 4, offer support for the "term premium" interpretation of the effects of monetary policy announcements on far forward yields rather than the "Fed information effect."

We now further explore this interpretation by directly regressing our level and slope factor on individual components of Treasury yields as estimated by affine term structure models: the risk-neutral yield which proxies the expected path of future interest rates and the estimated term premium component. The specific decomposition we rely is generated by the model of Adrian, Crump and Moench (2013).[22] Estimates of the risk-neutral expected path of rates and the term premium are available at a daily frequency from the Federal Reserve Bank of New York for 1- to 10-year zero-coupon bonds and were obtained through Haver Analytics. We focus on the benchmark 10-year yield which was the focus of our analysis in Section 3.1. We estimate regressions of the form:

$$\Delta rn_t^{10} = \alpha_{rn} + \beta_{rn}^L L_t + \beta_{rn}^S S_t + \beta_{rn}^F F_t + \varepsilon_t^{rn}, \tag{10}$$

$$\Delta tp_t^{10} = \alpha_{tp} + \beta_{tp}^L L_t + \beta_{tp}^S S_t + \beta_{tp}^F F_t + \varepsilon_t^{tp}, \tag{11}$$

where Δrn_t^{10} denotes the one-day change in the risk-neutral component of the zero coupon 10-year Treasury yield and Δtp_t^{10} denotes the one-day change in the term premium component of the zero coupon 10-year Treasury yield, calculated around scheduled FOMC meetings.

These regression results further suggest that policy announcements operate on longer-term yields in large part through term premiums. In particular, these two regression equations essentially decompose the coefficient estimates on the 10-year yield from Table 4 into two additive terms, a term on the risk neutral yield and term on the term premium.[23] The estimates in Table 8 reveal that the positive relationship between our EDX factors and the 10-year Treasury yield emanate exclusively through the term premium component. In particular, the coefficients β_{tp}^L and β_{tp}^S are estimated to be positive and are statistically significant across measures of first-moment monetary policy shocks. In contrast, the coefficient β_{rn}^S is estimated to be negative and statistically insignificant for the EDX slope factor which, according to Table 4, is the factor which we find most robustly loads positively and significantly on the 10-year Treasury yield.

These yield component regressions offer further evidence that policy announcements operate on longer-term yields in large part by moving the term structure of interest rate uncertainty which translates positively to term premiums. The theoretical model in King (2019) posits a similar mechanism through which forward guidance operates on longer-term yields when policy rates are resting at the zero lower bound. However, in the far right columns of Table 8, we provide empirical evidence that the linkages between interest rate uncertainty and longer-term yields remains operative in samples when policy rates are not at

[22]We reserve this exercise for further exploration, as opposed to including it in our baseline analysis, because typical term structure models assume homoskedasticity. Therefore, there is some tension by regressing term-premium measures derived from models assuming constant variances on time-varying measures of interest rate volatility.

[23]The decomposition is not exact due to fitting errors in the affine term structure model.

their lower bound. We re-estimate the regression model in equation (11) over our Non-ZLB sample which drops the December-2008 through December-2015 period from our regression model. Over this sub-sample, we continue to estimate that β_{tp}^{S} is positive and statistically significant. Moreover, over this sub-sample, the F-statistic testing the null hypothesis that $\mathcal{H}_0 : \beta_{tp}^{L} = \beta_{tp}^{S} = 0$ remains reliably above the five percent critical value. Therefore, these sub-sample estimates suggest that channels other than those put forth by King (2019), such as those present in the model of Hanson and Stein (2015), are quantitatively important in understanding the transmission of forward guidance to longer-term rates. However, consistent with King's (2019) prediction that the effects of forward guidance on term premiums are stronger at the zero lower bound, we estimate larger effects from changes in interest rate uncertainty on term premiums over our full sample versus the Non-ZLB sample.

6 Conclusion

This paper argues that the effects of monetary policy announcements on interest rates and economy activity partly transmit through changes in the term structure of interest rate uncertainty. While several recent contributions have pointed to changes in interest rate uncertainty as an important mechanism through which monetary policy operates, our results suggest that focusing on just a single dimension of interest rate uncertainty can be misleading. Therefore, much in the spirit of Gurkaynak, Sack and Swanson (2005), we argue that there is not just one, but rather there are two relevant dimensions of monetary policy uncertainty. One implication of our proposal of a more encompassing approach to measuring monetary policy uncertainty is that forward interest rate guidance — operating through changes in the term structure of interest rate uncertainty — appears to be a more efficacious policy tool than currently available forward guidance proxies might otherwise suggest.

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Table 1: Summary Statistics of EDX Measures of Market-Implied Interest Rate Uncertainty

	EDX 1Q	EDX 2Q	EDX 3Q	EDX 4Q	EDX 5Q
Full Sample Mean	0.36	0.57	0.77	0.95	1.11
Non-ZLB Sample Mean	0.40	0.63	0.84	1.03	1.19
ZLB Sample Mean	0.27	0.41	0.57	0.74	0.92

The units of the EDX series are annualized percentage points. The full sample period is 1994 through 2019. The ZLB Sample encompases the period from December 16, 2008 through December 16, 2015.

Table 2: Principle Component Analysis of the Changes in the Term Structure of Interest Rate Uncertainty Around FOMC Announcements

	EDX Level Factor	EDX Slope Factor
ΔEDX 1Q	0.80	−0.56
ΔEDX 2Q	0.93	−0.27
ΔEDX 3Q	1.01	0.10
ΔEDX 4Q	1.00	0.31
ΔEDX 5Q	0.92	0.44
Cumulative R^2	0.86	0.94

The first column reports the factor loadings on the (rotated) first principal component while the second column reports the factor loadings on the (rotated) second principal component. As these loadings suggest, we normalize the EDX Level Factor to have a one for one effect on the ΔEDX 4Q and we normalize the EDX Slope Factor to have a one for one effect on the ΔEDX5Q - ΔEDX1Q. The change in the EDX measures are calculated over a one-day window around scheduled FOMC meetings. The sample period is January 1994 – December 2019, resulting in 208 observations.

Table 3: Testing the Number of Factors Needed to Summarize Changes in the Term Structure of Interest Rate Uncertainty Around FOMC Announcements

Number of factors under the null	Degrees of Freedom (dof)	rk-statistic $\sim \chi^2(dof)$	p-value
$k_0 = 0$	9	51.82	[0.00]
$k_0 = 1$	4	26.97	[0.00]
$k_0 = 2$	1	0.91	[0.34]

This table shows results from the Kleibergen and Paap (2006) test for the number of factors underlying changes in the EDX 1-quarter, EDX 4-quarter, and EDX 5-quarter measures of option-implied interest rate uncertainty around scheduled FOMC meetings. Eicker-White heteroskedasticity-robust covariance matrix is used in constructing the test statistic. Number of observations: 208. The sample period is January 1994 – December 2019. The change in the EDX measures are calculated over a one-day window around scheduled FOMC meetings.

Table 4: Monetary Policy Surprises & The Term Structure of Monetary Policy Uncertainty

	Dependent Variable: Δ 10-yr Treasury Yield				
	Excluding First-Moment Monetary Policy Surprises		Including First-Moment Monetary Policy Surprises		
EDX Level	0.99***	0.99***	0.42**	0.14	0.16
	[0.00]	[0.00]	[0.01]	[0.27]	[0.31]
EDX Slope		1.51***	0.84***	0.62***	0.76***
		[0.00]	[0.00]	[0.00]	[0.00]
Δ 2-yr			0.65***		
			[0.00]		
Target				0.00	
				[0.99]	
Path				0.60***	
				[0.00]	
PNS					0.56***
					[0.00]
R^2	0.14	0.32	0.57	0.59	0.55
EDX F-test	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

The EDX F-test row shows the [p-value] for the hypothesis test that the regression coefficients on the EDX Level and EDX Slope are jointly zero. Eicker-White standard errors are used to calculate [p-values] shown below coefficient estimates. Number of observations: 207. The sample period is January 1994 – December 2019. All changes in yields and the EDX measures are calculated over a one-day window around scheduled FOMC meetings.

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

Table 5: Monetary Policy Surprises Interacted with The Term Structure of Monetary Policy Uncertainty

	Dependent Variable: Δ 10-yr Treasury Yield					
	Δ 2-yr Treas Yield		Target & Path Factors		Policy News Surprise (PNS)	
EDX Level	0.54***	0.53***	0.22	0.26*	0.25	0.26
	[0.00]	[0.00]	[0.10]	[0.07]	[0.14]	[0.12]
EDX Slope		0.72***		0.39**		0.61***
		[0.00]		[0.03]		[0.00]
Δ 2-yr	1.03***	0.99***				
	[0.00]	[0.00]				
Target			−0.30	−0.31		
			[0.30]	[0.34]		
Path			1.01***	1.05***		
			[0.00]	[0.00]		
PNS					1.03***	1.01***
					[0.00]	[0.00]
Δ 2-yr x L EDX 4Q	−0.27*	−0.10				
	[0.08]	[0.64]				
Δ 2-yr x L EDX 5Q-1Q		−0.28				
		[0.50]				
Target x L EDX 4Q			0.21	0.06		
			[0.32]	[0.81]		
Target x L EDX 5Q-1Q				0.25		
				[0.60]		
Path x L EDX 4Q			−0.31***	0.03		
			[0.01]	[0.88]		
Path x L EDX 5Q-1Q				−0.54*		
				[0.07]		
PNS x L EDX 4Q					−0.36**	−0.13
					[0.02]	[0.41]
PNS x L EDX 5Q-1Q						−0.35
						[0.23]
R^2	0.55	0.58	0.60	0.61	0.54	0.56
EDX F-test	[0.00]	[0.00]	[0.10]	[0.02]	[0.14]	[0.00]

The EDX F-test row shows the [p-value] for the hypothesis test that the regression coefficients on the EDX Level and EDX Slope are jointly zero. Eicker-White standard errors are used to calculate [p-values] shown below coefficient estimates. Number of observations: 207. The sample period is January 1994 – December 2019. All changes in yields and the EDX measures are calculated over a one-day window around scheduled FOMC meetings.

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

Table 6: The Response of US Treasury Forwards Around FOMC Announcements

	Nominal Forward Rates				Real Forward Rates				Inflation Forward Rates			
Maturity	Δ 2-yr	EDX Level	EDX Slope	R^2	Δ 2-yr	EDX Level	EDX Slope	R^2	Δ 2-yr	EDX Level	EDX Slope	R^2
5-Year	0.84***			0.30	0.65***			0.24	0.19**			0.05
	[0.00]				[0.00]				[0.01]			
	0.54***	0.96***	0.93***	0.55	0.43***	0.86***	0.61***	0.46	0.11	0.11	0.32**	0.10
	[0.00]	[0.00]	[0.00]		[0.00]	[0.01]	[0.00]		[0.20]	[0.42]	[0.05]	
10-Year	0.45***			0.09	0.42***			0.18	0.03			0.001
	[0.00]				[0.00]				[0.81]			
	0.23*	0.75***	0.67***	0.26	0.27***	0.43**	0.50***	0.31	−0.05	0.32**	0.17	0.06
	[0.08]	[0.01]	[0.00]		[0.00]	[0.02]	[0.01]		[0.69]	[0.03]	[0.27]	
15-Year	0.29***			0.07	0.35***			0.15	−0.06			0.004
	[0.01]				[0.00]				[0.56]			
	0.18	0.14	0.46**	0.11	0.25***	0.29**	0.35*	0.23	−0.07	−0.15	0.11	0.02
	[0.12]	[0.43]	[0.02]		[0.00]	[0.04]	[0.06]		[0.52]	[0.45]	[0.49]	
20-Year	0.18			0.03	0.30***			0.10	−0.12			0.01
	[0.17]				[0.00]				[0.42]			
	0.08	−0.12	0.51***	0.10	0.20**	0.33**	0.31*	0.17	−0.12	−0.45	0.20	0.11
	[0.54]	[0.50]	[0.01]		[0.02]	[0.04]	[0.09]		[0.41]	[0.10]	[0.36]	

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 changes in EDX 1Q through EDX 5Q around FOMC meetings). All changes in yields and the EDX measures are calculated over two days, following Hanson and Stein (2015). The sample period is January 1999 through February 2012, dropping 5 LSAP dates omitted by Hanson and Stein (2015), resulting in 107 observations.
Eicker-White standard errors are used to calculate [p-values] shown below coefficient estimates. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

Table 7: The Strength of Forward Guidance Proxies: First-Stage Regressions

Instrument Set: Swanson (2021) Forward Guidance Factor

Forward Guidance Indicator	FG Factor	EDX Level	EDX Slope	F-statistic
2-year Treasury Yield	0.00			0.07
5-year Treasury Yield	0.02			0.84
10-year Treasury Yield	0.02			2.37
2-year Forward Rate	0.01			0.50
5-year Forward Rate	0.04**			6.14
10-year Forward Rate	0.03			3.49

Instrument Set: EDX Factors

Forward Guidance Indicator	FG Factor	EDX Level	EDX Slope	F-statistic
2-year Treasury Yield		0.78	−0.06	1.17
5-year Treasury Yield		1.28*	1.13	3.83
10-year Treasury Yield		1.34**	1.42*	5.70
2-year Forward Rate		0.82	1.50*	2.53
5-year Forward Rate		2.10**	2.22**	11.05
10-year Forward Rate		0.75	1.16	2.28

Instrument Set: Swanson (2021) Forward Guidance Factor & EDX Factors

Forward Guidance Indicator	FG Factor	EDX Level	EDX Slope	F-statistic
2-year Treasury Yield	−0.02	0.99	0.11	1.07
5-year Treasury Yield	−0.01	1.34*	1.20	2.59
10-year Treasury Yield	0.00	1.33**	1.41*	3.79
2-year Forward Rate	−0.01	0.89	1.56*	1.70
5-year Forward Rate	0.01	1.98*	2.12*	7.43
10-year Forward Rate	0.02	0.51	0.96	1.90

Notes: Sample Period: 1991:07 – 2019:06. Observations: 258. Eicker-White standard errors are used to calculate [p-values]. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

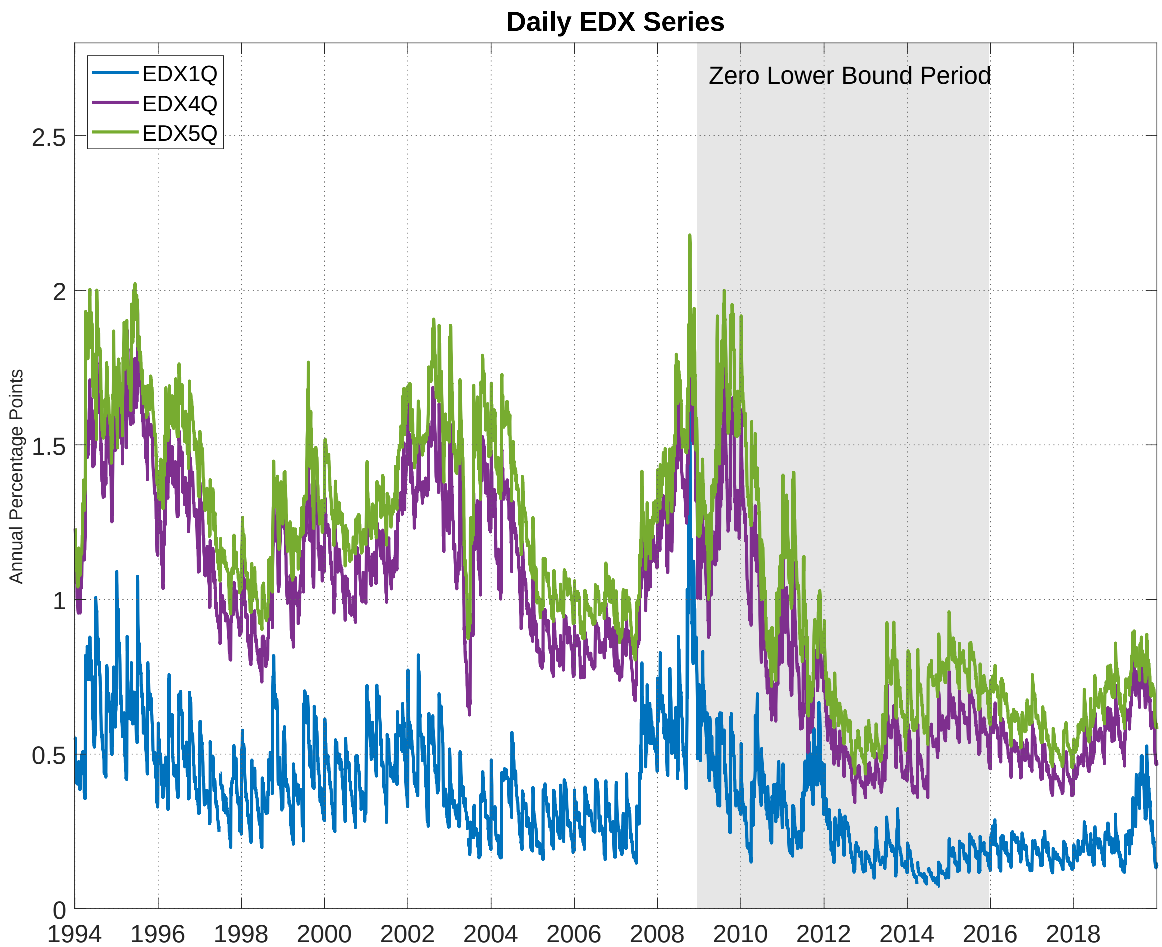
Table 8: 10-yr Yield Decomposition: Monetary Policy Surprises & The Term Structure of Monetary Policy Uncertainty

	Full Sample:						Non-ZLB Sample:		
	Δ 10-yr Risk Neutral Yield			Δ 10-yr Term Premium			Δ 10-yr Term Premium		
EDX Level	0.04	-0.23^{**}	-0.23^{**}	0.41^{**}	0.41^{**}	0.42^{**}	0.22	0.23	0.23
	[0.43]	[0.01]	[0.01]	[0.02]	[0.02]	[0.03]	[0.26]	[0.20]	[0.26]
EDX Slope	-0.02	-0.11	-0.08	0.89^{***}	0.76^{***}	0.88^{***}	0.62^{***}	0.51^{**}	0.60^{***}
	[0.84]	[0.34]	[0.45]	[0.00]	[0.00]	[0.00]	[0.00]	[0.02]	[0.01]
Δ 2-yr	0.73^{***}			-0.08			-0.18^{***}		
	[0.00]			[0.45]			[0.01]		
Target		0.22^{***}			-0.22^{**}			-0.21^{*}	
		[0.00]			[0.03]			[0.05]	
Path		0.60^{***}			0.01			-0.07	
		[0.00]			[0.92]			[0.28]	
PNS			0.62^{***}			-0.06			-0.13^{*}
			[0.00]			[0.50]			[0.06]
EDX F-test	[0.66]	[0.04]	[0.04]	[0.00]	[0.00]	[0.00]	[0.01]	[0.05]	[0.02]
R^2	0.87	0.79	0.79	0.11	0.16	0.11	0.10	0.14	0.08

The EDX F-test row shows the [p-value] for the hypothesis test that the regression coefficients on the EDX Level and EDX Slope are jointly zero. Eicker-White standard errors are used to calculate [p-values] shown below coefficient estimates. The "Full Sample" period is January 1994 – December 2019 resulting in 207 observations. The "Non-ZLB Sample" period is January 1994 – December 2019, excluding December 2008 – December 2015, resulting in 150 observations. The risk neutral yield and term premium measures are the Adrian, Crump and Moench (2013) estimates provided by the Federal Reserve Bank of New York. All changes in yields and the EDX measures are calculated over a one-day window around scheduled FOMC meetings.

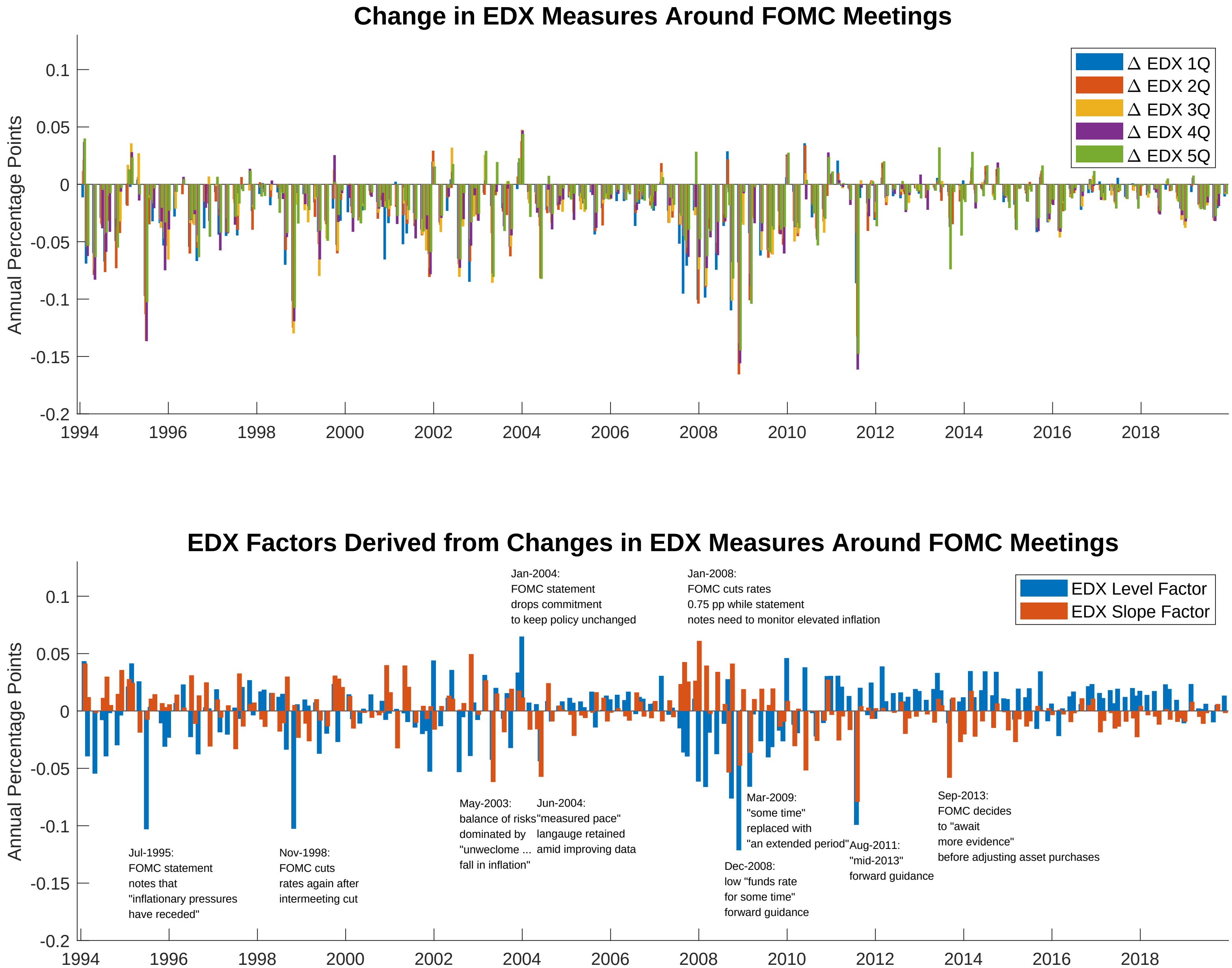
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$

Figure 1: Daily EDX Measures of Option-Implied Interest Rate Volatility at Select Horizons



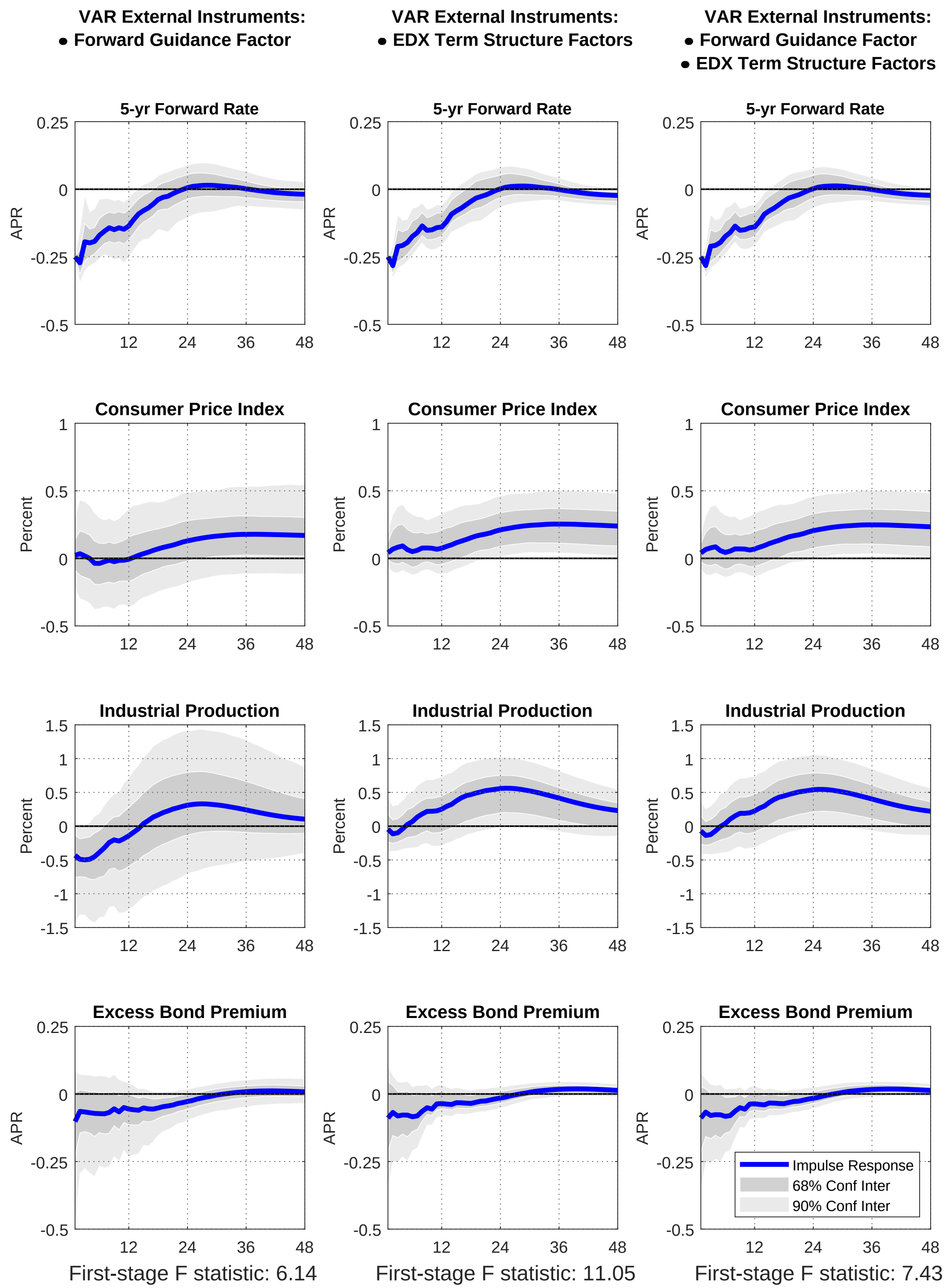
Note: This figure plots the daily EDX 1Q, EDX 4Q, and EDX 5Q from 1994 through 2019.

Figure 2: Changes in the Term Structure of Interest Rate Uncertainty Around FOMC Announcements



Note: The top panel shows the 1-day change in the EDX 1Q through the EDX 5Q around scheduled FOMC meetings from 1994 through 2019. The bottom panel shows the first two principal components from these five series which, after scaling, we call the EDX Level and EDX Slope Factors.

Figure 3: Proxy VAR Impulse Responses to Identified Forward Guidance Shocks



Note: Each column shows impulse responds from a separate structural VAR identified using external instruments. The reduced form VARs are estimated from 1979:07 through June 2019:06 and the external instruments identifying equations are estimated from 1991:08 through 2019:06.