Finance and Economics Discussion Series
Divisions of Research & Statistics and Monetary Affairs
Federal Reserve Board, Washington, D.C.

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2020-032

Please cite this paper as:
De Pooter, Michiel, Giovanni Favara, Michele Modugno, and Jason Wu (2020). "Monetary Policy Uncertainty and Monetary Policy Surprises," Finance and Economics Discussion Series 2020-032. Washington: Board of Governors of the Federal Reserve System, https://doi.org/10.17016/FEDS.2020.032.

Monetary Policy Uncertainty and Monetary Policy Surprises

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First version: May 2018

This version: March 2020

Abstract

Monetary policy uncertainty affects the transmission of monetary policy shocks to longer-term nominal and real yields. For a given monetary policy shock, the reaction of yields is more pronounced when the level of monetary policy uncertainty is low. Primary dealers and other investors adjust their interest rate positions more when monetary policy uncertainty is low than when uncertainty is high. These portfolio adjustments likely explain the larger pass-through of a monetary policy shock to bond yields when uncertainty is low. These findings shed new light on the role that monetary policy uncertainty plays in the transmission of monetary policy to financial markets.

Keywords: monetary policy surprises, monetary policy uncertainty, interest rates, primary dealers

JEL Codes: E4, E5, G1.

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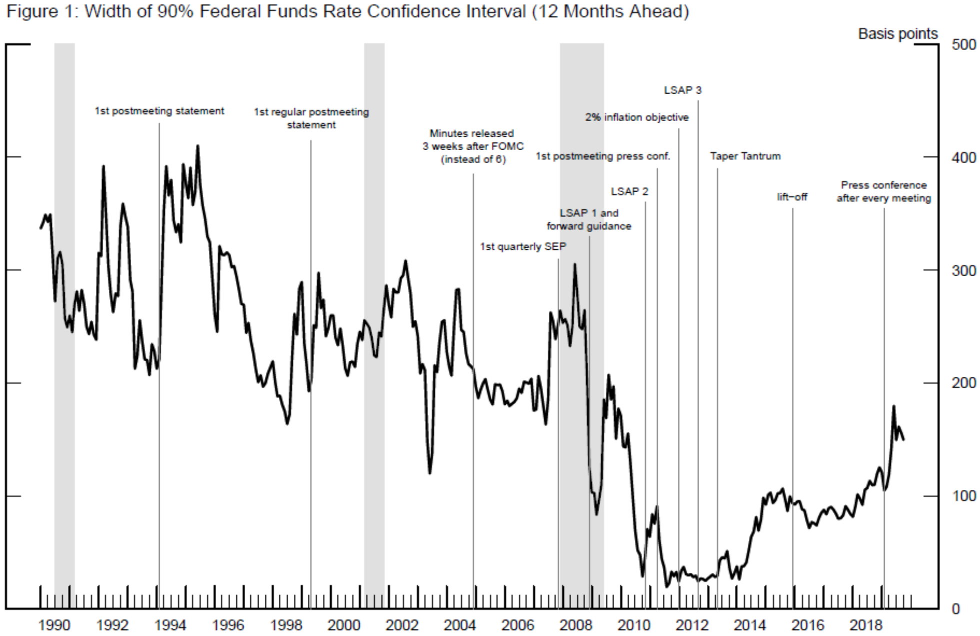
1. Introduction

Federal Reserve communications have changed significantly over the past two decades and have become increasingly transparent. In the early 1990s, monetary policy decisions by the Federal Open Market Committee (FOMC) were not announced to the public and decisions had to be inferred from movements in interest rates. Today, the FOMC uses a range of tools to communicate its economic and inflation outlook, policy decisions, and views about the future path of policy, including FOMC statements and minutes, post-meeting press conferences, the Summary of Economic Projections, as well as testimonies and speeches.[2]

In part reflecting these changes, the perceived uncertainty about the path of monetary policy in the U.S. has changed noticeably over time. Figure 1 shows one measure of this uncertainty based on Swanson (2006): the width of the probability distribution of the federal funds rate one year ahead, as implied by market prices on interest rate derivatives. As is evident, U.S. monetary policy uncertainty fluctuated pronouncedly in the early 1990s, declined in the 2000s, reached a trough during the zero lower bound (ZLB) period, and moved up again in recent years

Figure 1: Width of 90% Federal Funds Rate Confidence Interval (12 Months Ahead)



NOTE: Figure shows the level of monetary policy uncertainty, measured as the 90% width of the market-implied distribution for the effective federal funds rate at the one-year horizon, computed from at-the-money eurodollar futures options and adjusted for the level difference in volatility between the federal funds rate and eurodollar rates. Shaded areas reflect NBER recessions.

[2] For an overview of how FOMC communications have evolved over the past three decades, see for example Table A2 in Cecchetti and Schoenholtz (2019), as well as the event lines in Figure 1.

after the FOMC began to lift interest rates away from the ZLB.

Despite enhancements to FOMC communications, financial markets have at times been surprised by monetary policy announcements. These surprises could reflect either macroeconomic surprises or, as evident during the "taper tantrum" episode in 2013, a combination of misinterpretation of policy intentions and excessive investor risk-taking predicated on overconfidence about the future course of monetary policy. This paper shows that the pass-through of Fed policy surprises to medium- and long-term U.S. interest rates depends on investors' perceived level of uncertainty about the path of the federal funds rate. A positive 10-basis point (i.e., tightening) monetary policy shock—measured by the reaction in the 2-year nominal Treasury yield in a 60 minute window surrounding an FOMC announcement—is associated with a 20 basis points increase in the 10-year real rate when monetary policy uncertainty is low, i.e., at the lower quartile of its historical distribution. In contrast, the same 10-basis point tightening shock raises the 10-year real rate by only 4 basis points when uncertainty is high, i.e., in its upper quartile. Thus, the pass-through of monetary policy surprises to longer-term rates is larger when uncertainty is low than when uncertainty is high.

To understand the mechanism behind these results, we decompose bond yields into two components—the expected rate component, which is the market's average expectations for the future path of short rates, and the term premium, the compensation for bearing the risk of holding a long-term bond instead of a series of short-term bonds—to analyze whether the strong policy surprise pass-through amid low uncertainty is due to a re-evaluation of the economic outlook, or due to changes in risk premiums. While both components increase in response to a tightening monetary policy shock, our results show that the term premium displays a larger reaction than the expected rate component, especially when uncertainty is low. Specifically, when uncertainty is at the lower quartile, we find that a 10-basis point tightening shock leads to an 8 basis points increase in the 10-year real term premium and only a 2.4 basis point increase in the expected real rate component. In contrast, when uncertainty is at the upper quartile, both effects are only around 1.5 basis points.

One potential explanation behind these findings is that investors are more complacent when monetary policy uncertainty is low. If so, they will be more willing to take larger and/or riskier (e.g., more duration risk) positions in interest rates. When subsequently confronted with a monetary policy surprise, they may need to make large and abrupt adjustments to "cut losses" or to scale down risk-taking, which moves risk premiums. Consistent with this explanation, we find evidence that uncertainty affects how investor risk positions respond to surprises: in response to a tightening monetary policy shock, primary dealers—the most important financial intermediaries in U.S. fixed income markets—reduce their net long positions in Treasury securities when prevailing monetary policy uncertainty is low; in contrast, position adjustments to the same shock are not statistically significant when uncertainty is high. Other market participants exhibit similar behavior: the Commodity Futures Trading Commission's (CFTC) measure of "speculative" positions in interest rate derivatives, a proxy of the net interest rate position of investors such as hedge funds and asset managers, are also reduced much more in response to a tightening shock when uncertainty is low than when uncertainty is high.

Our analysis is based on event study regressions. Following Hanson and Stein (2015) and Gilchrist, Lopez-Salido and Zakrajsek (2015), we use the change in the 2-year nominal Treasury yield in a 60-minute window around FOMC announcements as our main proxy of monetary policy surprises on FOMC days. We regress the two-day change in 5- and 10-year nominal and real Treasury yields on monetary policy surprise, the Swanson (2006) measure of market-implied monetary policy uncertainty, and the interaction between surprise and uncertainty. Our main interest is in this interaction term, which models the responses of yields to monetary policy surprises conditional on the level of uncertainty.

Our exploration of the mechanism behind the empirical relationship between yields, surprise and uncertainty also uses event study regressions. The analysis of term premium uses two-day changes in the term premium and expected rate component estimates of Kim and Wright (2005) and D'Amico, Kim, and Wei (2018) as dependent variables. As for the investigation into investor position changes after FOMC announcements, the dependent variable is either the weekly change in duration-weighted net primary dealer Treasury position, or the weekly change in duration-weighted net CFTC speculative position in interest rate futures and options on interest rate futures. Both types of weekly change encompass an FOMC announcement.

This paper is organized as follows: section 2 provides a brief review of related literature; section 3 describes the data; section 4 introduces our empirical framework; section 5 presents the main result that monetary policy uncertainty affects the transmission of monetary policy surprises to longer-term nominal and real Treasury yields; section 6 breaks down such effects into expected rates and term premium components of yields, and presents evidence that changes to investors' interest rate positions could explain why the term premium-channel dominates. Section 7 concludes.

2. Literature

Our main finding that monetary policy surprises have a sizable impact on longer-term real yields are consistent with recent papers by Hanson and Stein (2015) and Nakamura and Steinsson (2018). However, these two papers interpret the result through very different lenses. Hanson and Stein (2015) find that monetary policy surprises affect longer-term real rates mainly through changes in investors' risk-taking behavior and their impact on term premiums. Our findings lend support to this type of channel, and further demonstrate that the magnitude of effects depends on the prevailing level of monetary policy uncertainty. Our findings resonate less with the explanation of Nakamura and Steinsson (2018), which emphasizes that monetary policy surprises lead to re-evaluations about the state of economy and therefore tend to move the expected rates component of medium- and long-term yields.[3]

A paper related to ours is Tillmann (2019), which also demonstrates that uncertainty affects the pass-through of monetary policy surprises to yields and term premiums. There are several important ways the two papers differ. First, Tillmann (2019)'s analysis uses monthly data, whereas we use a high-frequency event study approach. An event study approach is predicated on its strength on purging the effects of other factors—such as macroeconomic news—on yields (see, e.g. Gűrkaynak, Sack and Swanson, 2005, for a discussion). Indeed, in a robustness check, we show that when the event window is further narrowed to just 60 minutes (rather than two days), during which virtually no other factors are driving yields, our main results continue to hold. Second, Tillmann (2019) uses the news-based approach of Husted, Rogers and Sun (2016) to capture monetary policy uncertainty, whereas we use a fed funds futures and eurodollar options-implied measure of uncertainty, which is more relevant in a study of Treasury yields assuming that similar cohorts of investors trade futures, options and yields. Finally, in contrast to Tillmann

[3] Bauer and Swanson (2020), however, do not find evidence consistent with the presence of a "Fed Information Effect" as argued by Nakamura and Steinsson (2018).

(2019), we conduct an explicit investigation into how investors' interest rate positions react to monetary policy surprises at varying levels of uncertainty, thus uncovering a potential mechanism behind our main results. Bauer, Lakdawala, and Mueller (2019), also study the role of uncertainty in the transmission of monetary policy to financial markets using high-frequency event study approach. As in Tillmann (2019), however, they do not offer a mechanism through which uncertainty affects the transmission of monetary policy.

One important paper that studies the role of monetary policy uncertainty on yields is Swanson and Williams (2014), who show that the response of bond yields to *macroeconomic news* is muted when monetary policy uncertainty is low. This finding seemingly contrasts with our main result that the response of yields to *monetary policy surprises* is exacerbated when monetary policy uncertainty is low. But both sets of results are not inconsistent with each other. Economic surprises may only move yields in limited ways when investors hold firm beliefs about the central bank's reaction function. The materialization of monetary policy surprises, on the other hand, could usurp investors' beliefs altogether and, as we demonstrate in this paper, force abrupt changes in investor positions based on that belief.

This paper may also shed some light on the debate about the issue of constructive ambiguity. Stein and Sunderam (2018) pointed out that investors could be complacent and monetary policy may suffer from time inconsistency if policymakers choose to reduce uncertainty about their reaction function. They could do so, for example, by adopting a policy rule (e.g., Taylor, 1993 or Taylor, 1999). According to our results, any deviations from such a rule prescription can cause large fluctuations in investor positions and term premiums because of the low uncertainty environment created by the adoption of the rule. That said, it should be acknowledged that in this paper we do not separately identify the part of monetary policy uncertainty that is due to uncertainty about the monetary policy reaction function from the part that is due to uncertainty about the macroeconomic outlook.

3. Data

Following Hanson and Stein (2015) and Gilchrist, Lopez-Salido and Zakrajsek (2015), we identify monetary policy surprises on FOMC days using the change in the 2-year on-the-run nominal Treasury yield over a 60-minute window surrounding an FOMC announcement (from 15 minutes prior to 45 minutes after the release).[4] Since no other economic news is typically released during this time window, changes in short-term interest rates can almost solely attributed to news in policy decisions and other FOMC communications that was not anticipated by market participants.[5]

Underlying our measure of monetary policy surprise is the assumption that changes in the 2-year yield capture both surprise changes in the target rate of the federal funds rate and in its expected path, which allows us to identify monetary policy surprises during both the conventional and the unconventional monetary policy regimes. Our choice for monetary policy shock is important given the consensus in the literature (Gürkaynak, Sack, and Swanson, 2005, and Campbell, Evans, Fisher, and Justiniano, 2012) that communications about the future path of the federal funds rate are the primary form of monetary policy news on FOMC announcement days. Indeed, Gürkaynak, Sack, and Swanson (2005) argue for distinguishing between a target and a path factor. Swanson (2019) goes one step further and advocates for distinguishing between surprise changes in the federal funds target rate, forward guidance, and large-scale asset purchases, showing that each of these can have quite different effects on yields. Here we use a single metric (changes in the 2-year yield) in part for ease of comparison with studies related to ours referenced earlier, but mostly because our focus is on the role that uncertainty plays in the transmission of monetary policy shocks rather than on the differential response of yields across monetary policy regimes.[6]

The daily data on 5- and 10-year zero-coupon nominal Treasury yields and instantaneous nominal forward rates at the 5- and 10-year horizon are described in Gürkaynak, Sack and Wright (2007). We also use 5- and 10-year real Treasury yields, derived from prices on Treasury Inflation-

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[4] We show in robustness exercises in the appendix that our main results are robust to using other proxies of monetary policy as well to using different event window lengths.

[5] This is a plausible assumption, as scheduled FOMC announcements have mostly occurred at either 12.30p.m., 2:00pm or 2:15p.m. in our sample (with the current practice of releasing the FOMC statement at 2p.m. having been in place since early 2013), while major macroeconomic data are usually released at either 8:30a.m.or 10:00a.m., and corporate news is typically released after 4:00p.m.

[6] We verified that changes in the 2-year yield around FOMC announcements indeed capture both target and path surprises. In particular, when we regressed changes in 2-year yields on the surprise in the change in the federal funds target rate of Gürkaynak, Sack and Wright (2007), we find that the residual of this regression is highly correlated with the path factor in Gürkaynak, Sack and Wright (2007). To address Swanson (2019)'s concern about using a single statistic for measuring monetary policy surprises, in a robustness exercise in Section 5 we show that our main results hold even if we separately use surprise changes in the federal funds target rate, forward guidance, and large-scale asset purchases.

Protected Securities (TIPS) as described in Gürkaynak, Sack and Wright (2010).[7] Both nominal and real zero-coupon yields are derived using the Svensson-Nelson-Siegel yield curve estimation approach; see Svensson (1994) for details.

We use the Kim and Wright (2005)'s model to decompose nominal Treasury yields into their expected rate and term premium components. Kim and Wright (2005) use the Gürkaynak, Sack and Wright (2007) nominal yields and survey forecasts of Treasury bill rates as input in a three-factor no-arbitrage term structure model to fit and estimate the dynamics of yields over time; we use the updated Kim and Wright (2005) estimates that are based on an expanded data sample.[8] The estimated term structure model allows us to decompose nominal yields of any maturity into their average expected short rate and term premium components. We use the model of D'Amico, Kim, and Wei (2018) to similarly decompose real (TIPS) yields into their expected rate and term premium components. D'Amico, Kim, and Wei (2018) estimate a no-arbitrage term structure on nominal yields, TIPS yields, and data on seasonally-adjusted CPI, supplemented by survey forecasts of inflation and Treasury bill rates.[9]

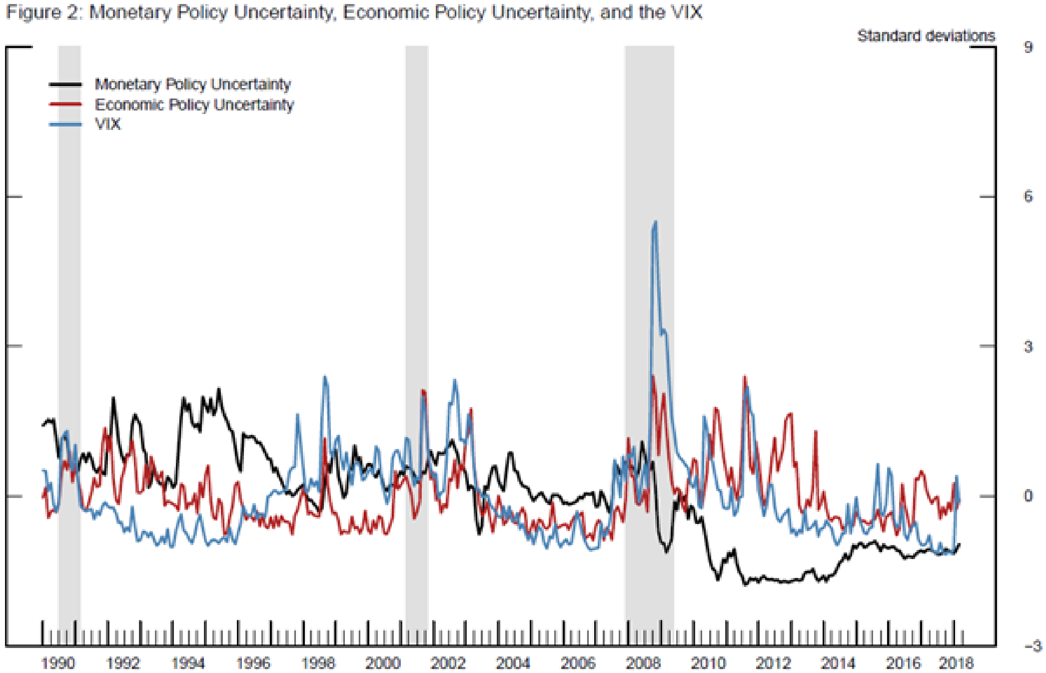
To measure uncertainty about the future path of monetary policy, we follow Swanson (2006) and Swanson and Williams (2012) and use the width of the market-implied distribution for the expected federal funds rate, in our case at the one-year horizon, as implied by interest rate derivatives prices.[10] We obtain the monetary policy uncertainty measure as follows. We first construct the implied path for the federal funds rate using fed funds futures contracts. We then use prices of at-the-money eurodollar futures options at different horizons to back out the implied volatility of the underlying eurodollar rate. These implied volatilities are adjusted for the level difference in volatility between the federal funds rate and eurodollar rates to arrive at estimated implied volatilities for the federal funds rate. Finally, using these implied volatilities we obtain an implied distribution for the federal funds rate at several fixed horizons. We then use the distance between the 5th and the 95th percentiles of the implied federal funds rate distribution one year-

[7] Nominal and real yields are available at https://www.federalreserve.gov/data/yield-curve-models.htm.
[8] The term structure decomposition is available at https://www.federalreserve.gov/data/yield-curve-models.htm.
[9] We use the updated estimates of this model discussed in Kim, Walsh, and Wei (2019). The term structure decomposition results are available at https://www.federalreserve.gov/econres/notes/feds-notes/DKW-updates.csv.
[10] Swanson (2006) uses the same measure of monetary policy uncertainty as we do here to argue that since the late 1980s increased Federal Reserve transparency has contributed to market participants' increased ability to forecast future FOMC interest rate decisions.

ahead as our selected measure of uncertainty.[11] This measure, expressed in basis points, is plotted in Figure 1.[12]

Figure 2 compares our measure of monetary policy uncertainty with two common proxies for uncertainty: the VIX—the stock market volatility index constructed by the Chicago Board of Options Exchange—and the EPU—the economic policy uncertainty index proposed by Baker, Bloom, and Davis (2016). These two alternative indexes capture a broader concept of uncertainty than monetary policy and, like our measure, they are available at a daily frequency. We use them in our empirical exercises as control variables.[13]

Figure 2: Monetary Policy Uncertainty, Economic Policy Uncertainty, and the VIX



NOTE: Figure shows our measure of monetary policy uncertainty, based on Swanson (2006), and measured at the 12-month horizon (in black), the Economic Policy Uncertainty index of Baker, Bloom, and Davis (2016) (in red), as well as the VIX index (in blue). All series are daily and shown on the day before FOMC meetings in each year. Shaded areas reflect NBER recessions.

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[11] We also used the same measure at shorter (e.g., 6 months-ahead) and longer (e.g., 18 months-ahead) horizons; our main results are not materially changed.

[12] Bauer, Lakdawala, and Mueller (2019) also rely on derivatives data to estimate monetary policy uncertainty using a related methodology to ours. The correlation coefficient of their series with our measure of uncertainty is .86, and the thrust of our findings are unchanged when we use their measure of monetary policy uncertainty.

[13] The VIX is a popular forward-looking measure of uncertainty based on options with a 1-month expiration on the S&P 500 index. The Baker, Bloom, and Davis (2016) EPU index is an index of economic and political uncertainty based on the count of articles in leading U.S. newspapers that contain words related to uncertainty, the economy, and policy-relevant terms. In Figure 2, the three uncertainty measures are recorded on the days before an FOMC meeting; they are also standardized in order to facilitate the comparison.

As shown, although the three measures exhibit some degree of co-movement, independent variation is larger: the correlation between our measure of monetary policy uncertainty and the VIX is only 23 percent, while the correlation with the EPU is 12 percent. These correlations suggest that our monetary policy uncertainty measure captures specific episodes of uncertainty related to FOMC decisions that the other two measures of uncertainty are not able to capture.

Other measures of monetary policy uncertainty and macroeconomic uncertainty include those developed by Jurado, Ludvigson, Ng (2015) and Husted, Rogers, and Sun (2019).[14] However, these measures are only available at a monthly frequency and are therefore less suitable for conducting an event study analysis that relies on daily data around FOMC announcements.

Data on net positions of primary dealers in U.S. Treasury securities are published weekly by the Federal Reserve Bank of New York. This data, also known as the FR 2004, captures the directional exposure of the 23 primary dealers of the Federal Reserve in Treasury cash securities and forward contracts and is reported in current market values for different maturity buckets.[15] Duration for each bucket reflects the midpoint of that bucket, e.g., the duration for the 0-3 bucket is 1.5 years. Since long bets for rates to go down and short bets for rates to go up are reported separately, net positions are calculated as the difference between long and short positions while gross positions are the sum of the two. In addition, average daily transactions within the week are also reported. Data is published each Thursday, summarizing the positions as of at the end of Wednesday. Figure 3(a) shows that duration-weighted net positions range from -0.5 to 0.6 of gross position and that the net long position has gotten larger in recent years.

For other investors—such as hedge funds and asset managers—we proxy interest rate positions with the weekly data from the CFTC. Each Wednesday, the CFTC reports the numbers of long and short "speculative" derivative contracts—mostly futures on on-the-run Treasury

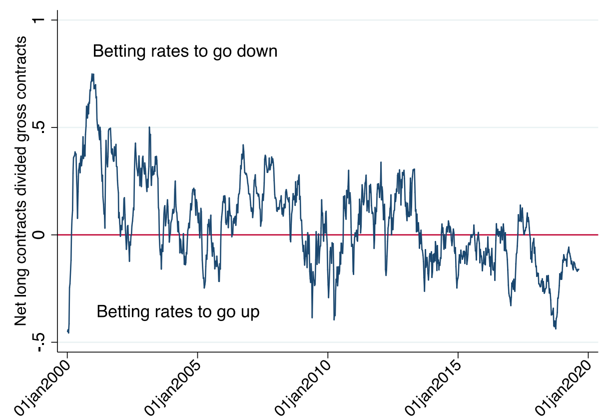
[14] Jurado, Ludvigson, and Ng (2015) measure time-varying macro uncertainty from a large set of monthly (mostly) macroeconomic series. Husted, Rogers, and Sun (2019) construct their monthly monetary policy index as the normalized frequency of news articles containing a combination of words related to uncertainty, monetary policy and interest rates, and the Federal Reserve. Finally, Baker, Bloom, David (2016) also construct a specific monetary policy index using the same methodology as for their EPU index, but only sum the count of articles on a monthly basis.

[15] The list of U.S. primary dealers and aggregate position and other aggregate data across the primary dealers can be found at https://www.newyorkfed.org/markets/primarydealers.html. At the time of our analysis, there were 23 primary dealers while at the time of writing this number had increased to 24.

securities and options on these futures—as of the end of Tuesday held by a range of traders for purposes other than "commercial" use (e.g., corporates trying to hedge a fixed-rate bond issuance). Net position is again calculated as the difference between long and short positions while the gross position is the sum of the two. CFTC also reports the number of contracts outstanding which is useful as a base to normalize the positions. We use the most commonly traded maturities, which are the 2-, 5-, and 10-year instruments. Figure 3(b) shows that duration-weighted net position ranges from -0.5 to 0.8 of gross position, and that a net short position has built up in recent years.

Figures 3(a): Primary dealers' net position

Figure 3(b): Speculators' net position



NOTE: Figure (a) shows the net weekly duration-weighted aggregated long position in U.S. Treasury securities of primary dealers as a fraction of gross position, based on weekly FR 2004 data from the Federal Reserve Bank of New York. Figure (b) shows the net weekly duration-weighted long position in futures on on-the-run Treasury securities, and options on these futures, of speculative investors as a fraction of gross positions, based on weekly data from the CFTC.

4. Empirical Framework

The empirical framework in this paper follows the event study approach of Gürkaynak, Sack, and Swanson (2005), Gilchrist, Lopez-Salido and Zakrajsek (2015), and Hanson and Stein (2015), among others. Specifically, we estimate the following regression model:

$$\Delta y_d^m = a + \beta \Delta mp_d + \gamma Uncertainty_{d-1} + \delta \Delta mp_d \times Uncertainty_{d-1} + \Omega_{d-1} + \epsilon_d \qquad (1)$$

where d is the second day (usually a Wednesday) of a FOMC meeting; Δy_d^m is the two-day change (from close-of-business on day $d-1$ to close-of-business day on $d+1$) in nominal or real

Treasury yields with maturity m (either 5- or 10-years); Δmp_d is the monetary policy surprise, as proxied by the 60-minute change in the 2-year Treasury yield around FOMC announcements; $Uncertainty_{d-1}$ is the one year-ahead measure of monetary policy uncertainty implied by market prices, discussed in Section 3.

Our regression framework posits that a monetary policy surprise, Δmp_d, affects yields linearly through the parameter β but also that its overall effect varies with the level of monetary policy uncertainty through the parameter δ. Throughout the rest of this paper, we focus on the overall effect of a monetary policy surprise—the values of $\beta + \delta \times Uncertainty_{d-1}$—conditional on uncertainty being at the lower quartile, the median, or the upper quartile of its historical distribution.

The vector Ω_{d-1} denotes other controls included in the regressions: the level of the 2-year Treasury yield, which controls for the mechanical relationship between the level of interest rates and uncertainty about monetary policy; the VIX and EPU indexes, which are included to assuage the concern that the response of yields to monetary policy surprises may also depend on the level of economic and political uncertainty. We do not show the coefficients on Ω_{d-1} in our results tables, but these are available upon request.

FOMC announcements in our sample are from May 1999, the first year the FOMC started releasing a post-meeting statement at each meeting, and through January 2018.[16] Our sample consists of 156 scheduled policy announcements during the conventional (May 1999 to December 2008), unconventional (January 2009 to November 2015) and post-ZLB monetary policy regime (December 2015 to December 2017).

The analysis of the two components of yields, the expected rates and term premium components, uses the same framework as regression (1). Denoting estimates of these two components as ΔER_d^m and ΔTP_d^m, respectively, for yields with maturity m, regressions (2) and (3) are applied to both nominal and real versions of the two.

$$\Delta ER_d^m = a + \beta \Delta mp_d + \gamma Uncertainty_{d-1} + \delta \Delta mp_d \times Uncertainty_{d-1} + \Omega_{d-1} + \epsilon_d \qquad (2)$$

[16] The beginning of the sample also coincides with the first year in which prices of TIPS securities are reliable enough from which to estimate a real yield curve.

$$\Delta TP_d^m = a + \beta \Delta mp_d + \gamma Uncertainty_{d-1} + \delta \Delta mp_d \times Uncertainty_{d-1} + \Omega_{d-1} + \epsilon_d \quad (3)$$

Finally, regressions of primary dealer and speculative positions use *weekly* changes in positions. It is crucial that the changes are calculated such that event windows include FOMC announcements. Since the data for primary dealer positions reports end-of-Wednesday (the day FOMC announcements are usually made) positions, the regression is:

$$DealerPos_d^m - DealerPos_{d-5}^m = a + \beta \Delta mp_d + \gamma Uncertainty_{d-1} + \delta \Delta mp_d \times Uncertainty_{d-1} + \Omega_{d-1} + \epsilon_d \quad (4)$$

where $d - 5$ is the position on the previous Wednesday. For speculative positions, since the CFTC data reports end-of-Tuesday positions, the appropriate change used as the dependent variable should be calculated based on the Tuesday before FOMC and the Tuesday after:

$$CFTCPos_{d+4}^m - CFTCPos_{d-1}^m = a + \beta \Delta mp_d + \gamma Uncertainty_{d-1} + \delta \Delta mp_d \times Uncertainty_{d-1} + \Omega_{d-1} + \epsilon_d \quad (5)$$

Both $DealerPos_d^m$ and $CFTCPos_d^m$ are first normalized (using gross positions, transaction volumes, or notional outstanding) and then duration-weighted. Duration-weighting helps assess the impact of the monetary policy surprise on dealers' and investors' entire portfolio.

5. Reactions of Nominal and Real Yields to Monetary Policy Surprises

Table 1 reports the main results of this paper: the response of nominal and real zero-coupon yields to monetary policy surprise when the one-year ahead measure of monetary policy uncertainty is low, medium, or high; that is when $Uncertainty_{d-1}$ is in the lower quartile (81 basis points), median (183 basis points) and upper quartile (234 basis points) of its historical distribution. Columns 1 and 2 use the change in the 5- and 10-year nominal rate as dependent variables, respectively; columns 3 and 4 use the TIPS-implied real rates for the same maturities. The table reports the *coefficients* on Δmp_d (β) and $\Delta mp_d \times Uncertainty_d$ (γ), as well as the *evaluation* of effects at the three levels of uncertainty ($\beta + \delta \times Uncertainty_{d-1}$).

Table 1: Response of U.S. Treasury nominal and real yields to monetary policy surprises

	Dependent Variable			
	Nominal Yields		TIPS Yields	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	2.138***	2.140***	3.423***	2.816***
	(5.72)	(3.95)	(7.05)	(5.57)
Δmp_d x $uncertainty_{d-1}$	-0.678***	-0.757***	-1.201***	-0.998***
	(-4.01)	(-3.21)	(-5.99)	(-4.75)
Evaluation				
Low Uncertainty	1.580***	1.517***	2.434***	1.995***
(25th perc.)	(6.42)	(4.28)	(7.44)	(5.92)
Medium Uncertainty	0.868***	0.723***	1.174***	0.948***
(50th perc.)	(6.94)	(4.82)	(8.00)	(6.89)
High Uncertainty	0.521***	0.336***	0.560***	0.438***
(75th perc.)	(4.05)	(2.61)	(5.11)	(4.92)
Observations	156	156	156	156
R-squared	0.30	0.21	0.46	0.40

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of nominal and real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

The estimated effects suggest that positive monetary policy surprises, or “tightening” shocks, are associated with an increase in nominal and real rates (first row in the table), but this increase is muted during periods of high monetary policy uncertainty (second row). Based on columns 2 and 4, a 10-basis point tightening shock (approximately a two standard deviation move) leads on average to a 7 and 9 basis point increase in 10-year nominal and real rates, respectively, when the level of monetary uncertainty is at its median value (fourth row). The response of nominal and real rates increases to 15 and 20 basis points when the uncertainty about monetary policy is at the lower quartile of its historical distribution. In contrast, the responses fall to just 3 to 4 basis points when the uncertainty about monetary policy is at its upper quartile.

Altogether, the results in Table 1 are consistent with the event-study literature showing that monetary policy surprises have large effects on long-term interest rates (Gilchrist, Lopez-Salido, and Zakrajsek, 2015; Gertler and Karadi, 2015; Hanson and Stein, 2015; Altavilla, Giannone and Modugno 2017; Nakamura and Steinsson, 2018). Our findings expand on these existing studies by showing that the pass-through of monetary policy surprises to longer-term yields depends on the prevailing level of monetary policy uncertainty.

Robustness Tests

The Appendix contains a battery of robustness checks on this main result. Table A1 is the same as Table 1, except we use instantaneous forward rates instead of zero-coupon rates as some (e.g., Hanson and Stein 2015) argue that reaction of far-ahead forward rates best illustrates the degree of long-run non-neutrality of monetary policy. Table A1 confirms that our key result of larger reaction in rates when uncertainty about monetary policy is low holds when forward rates far-ahead are used.

Tables A2 and A3 test sub-sample robustness: in A2, we show that the effects of monetary policy uncertainty on the pass-through of monetary policy surprises to real yields are present during both pre- and post-crisis periods. One can also see that the effects are far more pronounced in the post-crisis period, perhaps as more intense "search for yield" behavior or lower market-making capacity amplify yield moves (see, for example, Adrian, Fleming, Goldberg, Lewis, Natalucci, and Wu, 2013).[17] Table A3 aims to show that the main results are not due to the ZLB period—a period featuring historically low uncertainty. The coefficient of interest in this Table is the triple interaction term $\Delta mp_d \times Uncertainty_{d-1} \times ZLB_d$ where ZLB_d is a dummy variable indicating the ZLB period, which is equal to 1 between January 2009 and November 2015 and is 0 elsewhere. As shown, accounting for the ZLB does not materially affect our main result that the transmission of monetary policy surprises to yields is muted when monetary policy uncertainty is high. In Table A4 the dependent variables are measured around the 60-minute window of FOMC announcements,

[17] Gilchrist, López-Salido, and Zakrajšek (2015) also find larger responses of yields to monetary policy surprises during the Fed's unconventional monetary policy period.

rather than 2-day changes to the nominal and real yields; as can be seen, the main results continue to hold.

Recognizing that monetary policy surprises can be measured in various ways, Table A5 replaces the 60-minute window change in the 2-year yield measure of surprise with a 30-minute window change (columns 1 and 2), and the Nakamura and Steinsson (2018) monetary policy surprises.[18] Our main results continue to hold with either measures of monetary policy surprises; they in fact are estimated to be stronger.

We also address the critique of Swanson (2019) that using a single statistic around FOMC communications for measuring monetary policy surprises is unlikely to capture the multiple dimensions of monetary policy. Instead of including changes in 2-year yields and 2-year yield changes interacted with our measure of monetary policy uncertainty, we run regressions using the three separate shocks of Swanson (2019) – federal funds target rate, forward guidance, and large-scale asset purchase shocks – all interacted with our uncertainty measure. The results are reported in Table A6. As shown, our main results continue to hold: the pass-through of monetary policy surprise, particularly the target and forward guidance shocks, to longer-term yields is amplified when uncertainty about monetary policy is low.

Finally, in Table A7, we also interact monetary policy surprises with two other measures of uncertainty, the VIX and EPU, to ascertain that the effects coming from $Uncertainty_{d-1}$ are indeed due to genuine monetary policy uncertainty, rather than driven by financial or economic uncertainty that are embedded in the measures of monetary policy uncertainty. It turns out that neither VIX nor EPU affect the response of nominal and real yields to monetary policy surprises the same way that monetary policy uncertainty does. In Table A7, the interaction coefficients $\Delta mp_d \times VIX_{d-1}$ and $\Delta mp_d \times EPU_{d-1}$ have a positive sign, indicating that the pass through of monetary policy surprise to yields is amplified when uncertainty related to the stock market or economic policy is high. This result suggests that our choice for monetary policy uncertainty is not just picking up other types of uncertainty.

[18] Nakamura and Steinsson (2018)'s monetary policy shock is the first principal component of 30-minute changes around FOMC announcements in a set of federal funds futures and eurodollar futures with maturities up to one year.

6. Investigating the Mechanism

Table 2 decomposes the changes in 5-, and 10-year nominal Treasury yields into their changes in the average expected short rate component (columns 1 and 2) and changes in the term premium component (columns 3 and 4), using the Kim and Wright (2005) estimate of each component. This exercise helps determine whether the strong policy surprise pass-through amid low uncertainty is due to a re-evaluation of the economic outlook, or due to changes in risk premiums.

Table 2: Response of expected future nominal rates and term premiums to monetary policy surprises

	Dependent Variable			
	Expected rates		Term premium	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	0.722***	0.671***	0.913***	1.116***
	(5.31)	(5.53)	(5.62)	(5.30)
Δmp_d x $uncertainty_{d-1}$	-0.217***	-0.216***	-0.303***	-0.385***
	(-3.13)	(-3.68)	(-4.04)	(-4.02)
Evaluation				
Low Uncertainty	0.543***	0.493***	0.663***	0.799***
(25th perc.)	-5.85	(6.00)	(6.31)	(5.85)
Medium Uncertainty	0.316***	0.265***	0.345***	0.395***
(50th perc.)	-4.23	(4.55)	(6.85)	(6.25)
High Uncertainty	0.204**	0.155**	0.191***	0.198***
(75th perc.)	-2.3	(2.30)	(3.55)	(3.07)
Observations	156	156	156	156
R-squared	0.27	0.27	0.28	0.27

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of future expected rates and term premiums for nominal U.S. Treasury yields (with five- and ten- year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Expected rates and term premiums are estimated using the Kim and Wright (2005) model. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1991 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

As shown in Table 2, the response of nominal rates to monetary policy surprises reflects predominantly changes to the term premium, especially for the 10-year yield. When the results in columns 2 and 4 are compared, it is evident that although both components react in a statistically significant way, the response of the 10-year term premium is much larger than the response of the 10-year expected rate component, irrespective of the level of uncertainty. Similar to the results in Table 1, the lower monetary policy uncertainty, the larger the responses. When uncertainty is in the lower quartile of its distribution, a 10 basis point tightening shock leads to an 8 basis point increase in the 10-year term premium; the response drops to just 2 basis points when uncertainty is in the upper quartile. As expected, the differences in reaction between the expected rate and term premium components are less marked for the 5-year yield, given that the term premium component is smaller for shorter-maturity Treasury securities.[19]

Table 3 contains the results of the same exercise applied to a decomposition of real yields into their average expected real short rate and real term premium components using the approach of D'Amico, Kim, and Wei (2018). While the responses of the 5-year expected real rates to a given 10-basis point monetary policy surprise is roughly the same for different levels of $Uncertainty_{d-1}$ (about 2 basis points), the responses of the term premium to a similar monetary policy shock vary greatly: a 10 basis point monetary policy shock moves the 5-year real term premium by 6.6 basis points when uncertainty is at its lower quartile, while this response drops to 1.6 basis points with uncertainty at its upper quartile (column 3). The effects of uncertainty are even stronger for the 10-year real term premium (column 4).

In sum, these results strongly suggest that uncertainty changes the pass-through of monetary policy surprises through real risk premiums.

[19] In a robustness check, we also replaced the Kim and Wright (2005) expected rates and term premiums with the decomposition estimates of Adrian, Crump, and Moench (2013) While the level of monetary policy uncertainty matters for pass-through of surprises to both the expected rate and term premium components, the reaction of term premiums are stronger. This again suggests that uncertainty changes the pass-through of monetary policy surprises through a risk premium channel.

Table 3: Response of expected future real rates and real term premiums to monetary policy surprises

	Dependent Variable			
	Expected real rates		Real term premium	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	0.119	0.300***	0.922***	1.119***
	(0.88)	(4.39)	(5.45)	(5.06)
Δmp_d x $uncertainty_{d-1}$	0.043	-0.071**	-0.319***	-0.405***
	(0.65)	(-1.98)	(-4.20)	(-4.13)
Evaluation				
Low Uncertainty	0.154*	0.242***	0.660***	0.785***
(25th perc.)	(1.72)	(5.19)	(5.99)	(5.46)
Medium Uncertainty	0.199***	0.168***	0.325***	0.360***
(50th perc.)	(3.28)	(4.36)	(6.72)	(5.92)
High Uncertainty	0.221***	0.132***	0.161***	0.153***
(75th perc.)	(3.12)	(2.85)	(3.46)	(2.75)
Observations	156	156	156	156
R-squared	0.23	0.3	0.3	0.28

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of future expected rates and term premiums for nominal U.S. Treasury yields (with five- and ten- year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Expected rates ad term premiums are estimated using the D'Amico, Kim, and Wei (2018) model. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1991 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. t-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Position adjustments by primary dealers and speculators

The results in the previous section are consistent with the view of Hanson and Stein (2015) that tightening shocks cause investors to sell long-term bonds, above and beyond what is required by the revelation of news about the expected path of policy. However, compared to Hanson and Stein (2015), we investigate whether such selling is especially large when uncertainty is low.

This investigation begins with primary dealers. Fleming, Keane, and Schaumburg (2016) and Brain, et al. (2018), estimate that primary dealers are the largest participants in the Treasury cash securities market, accounting for roughly 50 percent of trading activity. As described in section 3, the quantity of interest is primary dealers' net duration-weighted position in U.S. Treasury securities, which captures the directional exposure of primary dealers to Treasury yields averaged across a number of maturity buckets. We apply the regression in (4) to the net position variable. The results are displayed in Table 4, when either net position is normalized by gross position (column 1), or by transaction volume (column 2).

Table 4: Response of broker dealers' net U.S. Treasury positions to monetary policy surprises

	Dependent Variable	
	ΔNet dealer position (norm. by gross positions)	ΔNet dealer position (norm. by transactions)
	(1)	(2)
Coefficients		
Δmp_d	-0.247***	-0.299***
	(-4.48)	(-3.18)
Δmp_d x $uncertainty_{d-1}$	0.131***	0.156***
	(4.45)	(3.07)
Evaluation		
Low Uncertainty	-0.147***	-0.180***
(25th perc.)	(-4.06)	(-2.84)
Medium Uncertainty	-0.101***	-0.125***
(50th perc.)	(-3.45)	(-2.37)
High Uncertainty	0.049	0.054
(75th perc.)	(1.66)	-0.94
Observations	129	129
R-squared	0.20	0.13

NOTE: Reported coefficients denote the five-day changes, around FOMC dates, of primary dealers' duration-weighted net positions to 0-3 year, 3-6 year, 6-11 year, and 11-30 year U.S. Treasury securities (reported by FRBNY) normalized by gross positions (column 1) or transactions (column 2) to monetary policy surprises for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is January 2005 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Both columns suggest that net position adjustments are sizeable when uncertainty is low. Upon a 10-basis point tightening shock, net position as a fraction of gross position declines by 1.5 percentage points, while as a fraction of transaction volume it declines by 1.8 percentage points; both of these moves are just shy of one standard deviation. When uncertainty is high, net position adjustments by dealers are not statistically significant. These results are consistent with our conjecture that dealers are positioned aggressively when monetary policy uncertainty is low and when a positive monetary policy surprise realizes, their attempts to cut losses or to scale down risk-taking lead to rises in term premiums and ultimately, longer-term interest rates.

While primary dealers are important players in the interest rate market, they are certainly not the only investors. To provide further support to our position adjustment hypothesis, we assess the behavior of other investors—in particular hedge funds and asset managers—using data on "speculative" positioning in Treasury futures and options on futures. Table 5 contains the results of running regression (5). Column 1 displays the results when net position of speculators is normalized by their gross position and column 2 when net position is normalized by aggregate open interest.

Table 5: Response of changes in CFTC speculative futures positions to monetary policy surprises

	Dependent Variable	
	ΔNet spec position (norm. by gross positions)	ΔNet spec position (norm. by open interest)
	(1)	(2)
Coefficients		
Δmp_d	-0.757**	-0.165**
	(-2.38)	(-2.32)
Δmp_d x $uncertainty_{d-1}$	0.364***	0.080**
	(2.73)	(2.58)
Evaluation		
Low Uncertainty	-0.474**	-0.103**
(25th perc.)	(-2.18)	(-2.14)
Medium Uncertainty	-0.087	-0.019
(50th perc.)	(-0.94)	(-0.88)
High Uncertainty	0.101	0.022
(75th perc.)	(1.59)	(1.25)
Observations	128	128
R-squared	0.09	0.07

NOTE: Reported coefficients denote the five-day changes, around FOMC dates, of speculative investors' duration-weighted sum of the number of net non-commercial futures and options futures contracts outstanding for 2-year, 5-year, and 10-year U.S. Treasury securities (reported by CTFC) normalized by gross positions (column 1) or open interest (column 2) to monetary policy surprises for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is January 1995 to December 2017. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. t-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

When uncertainty is low, upon a 10-basis point tightening shock, speculative net position as a fraction of gross position moves down by 4.7 percentage points, while net position as a fraction of open interest goes down by 1 percentage point. As is the case of primary dealers, these moves are roughly equal to one standard deviation. In contrast, when uncertainty is high such adjustments do not occur.

Our results in Tables 4 and 5 clearly demonstrate that position adjustments made by dealers and speculative investors depend on the prevailing level of uncertainty about monetary policy. Although the magnitudes of adjustment are somewhat moderate for both types of investors during low uncertainty, adjustments are statistically significant and their combined effects could certainly significantly move term premiums and yields. That said, our results do not rule out other possible mechanisms behind the term premium channel, including shifts in risk aversion and other factors (see, for example, Ray 2019).

7. Conclusions

In this paper we provided evidence that the level of uncertainty about the path of monetary policy matters for the transmission of monetary policy to medium- and long-term interest rates. We first show that for a given monetary policy surprise, the reaction of 5- and 10-year nominal and real yields is more pronounced when the level of monetary policy uncertainty is low than when it is high. We next show that this result is predominantly driven by the term premium component of yields, suggesting that uncertainty affects risk premiums. In support of this evidence, we document that both primary dealers and speculators typically unwind their positions in Treasury securities and associated derivatives when a positive monetary policy surprises arrives, thereby amplifying the pass-through of the surprise to term premiums and overall yields.

There are a number of ways in which our analysis can be extended and strengthened. A promising avenue for further research is to investigate the role of institutional investors such as pension funds and insurance companies, whose demand have been shown to play an important role in driving the long end of the yield curve (see Greenwood and Vissing-Jorgensen, 2018). One can also examine whether alternative channels could be responsible for the empirical results we document in this paper, such as shifts in broker dealers' risk aversion (see He, Kelly, and Manela, 2017). Another extension is to consider a wider set of asset prices, including corporate bond yields, equity prices, exchange rates, and foreign yields.

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Appendix: robustness tests

Table A1: Response of U.S. Treasury instantaneous forward rates to monetary policy surprises

	Dependent Variable			
	Nominal instantaneous forward ending in forward ending in		TIPS instantaneous forward ending in forward ending in	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	2.773***	1.483*	3.329***	1.246*
	(3.94)	(1.96)	(4.74)	(1.88)
Δmp_d x $uncertainty_{d-1}$	-1.036***	-0.596*	-1.109***	-0.495*
	(-3.41)	(-1.81)	(-3.66)	(-1.76)
Evaluation				
Low Uncertainty	1.921***	0.993**	2.417***	0.838*
(25th perc.)	(4.15)	(2.01)	(5.20)	(1.91)
Medium Uncertainty	0.833***	0.367*	1.254***	0.319*
(50th perc.)	(4.38)	(1.88)	(6.00)	(1.74)
High Uncertainty	0.303**	0.063	0.687***	0.065
(75th perc.)	(1.98)	(0.40)	(3.80)	(0.48)
Observations	156	156	156	156
R-squared	0.20	0.08	0.08	0.08

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of instantaneous forward nominal and real U.S. Treasury rates ending in 5 and 10 years ahead to monetary policy surprises, for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Table A2: Response of U.S. real yields to monetary policy surprises in different sample periods

	1999-2007		2008-2018	
	Dependent Variable		Dependent Variable	
	Tips Yields		Tips Yields	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	3.927***	3.593***	3.686***	2.449***
	(4.64)	(4.13)	(5.28)	(3.11)
Δmp_d x $uncertainty_{d-1}$	-1.403***	-1.314***	-1.814**	-1.067
	(-4.05)	(-3.64)	(-2.57)	(-1.34)
Evaluation				
Low Uncertainty	1.188***	1.028***	3.089***	2.097***
(25th perc.)	(5.96)	(5.54)	(6.40)	(3.88)
Medium Uncertainty	0.681***	0.553***	2.348***	1.661***
(50th perc.)	(5.56)	(5.71)	(9.10)	(6.03)
High Uncertainty	0.327**	0.221**	2.103***	1.517***
(75th perc.)	(2.57)	(2.01)	(9.59)	(6.70)
Observations	92	92	64	64
R-squared	0.48	0.45	0.50	0.40

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Columns 1 and 2 use FOMC dates between 1999 and 2007 (pre-crisis), while columns 3 and 4 uses dates between 2008 and 2018. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Table A3: Response of nominal and real yields to monetary policy surprises: interaction with the zero lower bound period

	Dependent Variable			
	Nominal Yields		Tips Yields	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	1.898***	1.393**	2.090***	1.680***
	(3.56)	(2.41)	(4.71)	(4.85)
$uncertainty_{d-1}$	0.012	0.019	0.020	0.025
	(0.65)	(0.97)	(1.20)	(1.46)
Δmp_d x $uncertainty_{d-1}$	-0.576**	-0.454*	-0.663***	-0.535***
	(-2.51)	(-1.82)	(-3.39)	(-3.45)
ZLB	0.027	0.027	0.007	0.034
	(0.72)	(0.65)	(0.18)	(0.90)
Δmp_d x ZLB	0.589	0.894	1.875**	1.595*
	(0.67)	(0.75)	(2.19)	(1.85)
$uncertainty_{d-1}$ x ZLB	-0.030	-0.002	-0.001	-0.003
	(-0.93)	(-0.05)	(-0.02)	(-0.11)
Δmp_d x $uncertainty_{d-1}$ x ZLB	-0.481	-0.135	-0.585	-0.487
	(-0.74)	(-0.15)	(-0.78)	(-0.73)
Observations	156	156	156	156
R-squared	0.31	0.23	0.49	0.43

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of nominal and real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. ZLB is an indicator variable that is equal one when the federal funds rate targe range is between 0% and 0.25%. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Table A4: Response of 60-minute changes of U.S. nominal and real yields to monetary policy surprises

	Dependent Variable			
	Nominal Yields		Tips Yields	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	1.683***	1.281***	2.079***	1.485***
	(7.04)	(3.81)	(7.79)	(4.03)
Δmp_d x $uncertainty_{d-1}$	-0.335***	-0.289**	-0.533***	-0.385**
	(-3.36)	(-2.06)	(-4.63)	(-2.53)
Evaluation				
Low Uncertainty	1.404***	1.044***	1.744***	1.193***
(25th perc.)	(9.18)	(4.68)	(8.87)	(4.69)
Medium Uncertainty	1.069***	0.739***	1.553***	1.008***
(50th perc.)	(17.44)	(8.71)	(9.84)	(5.54)
High Uncertainty	0.905***	0.593***	1.036***	0.673***
(75th perc.)	(24.50)	(12.29)	(15.39)	(11.46)
Observations	157	157	116	131
R-squared	0.86	0.62	0.84	0.62

NOTE: Reported coefficients denote the 60-minute changes, around FOMC dates, of nominal and real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Table A5: Response of nominal real yields to monetary policy surprises: alternative measures of policy surprises

	30-minute MP shocks		Nakamura-Steinsson shocks	
	Dependent Variable		Dependent Variable	
	TIPS Yields		TIPS Yields	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
Δmp_d	3.612***	2.886***	5.145***	3.731***
	(5.76)	(5.03)	(4.27)	(3.16)
Δmp_d x $uncertainty_{d-1}$	-1.248***	-1.023***	-1.925***	-1.426***
	(-4.91)	(-4.35)	(-3.74)	(-2.82)
Evaluation				
Low Uncertainty	2.585***	2.045***	4.060***	2.927***
(25th perc.)	(6.06)	(5.28)	(4.43)	(3.25)
Medium Uncertainty	1.276***	0.972***	1.379***	0.941***
(50th perc.)	(6.37)	(5.62)	(5.44)	(3.83)
High Uncertainty	0.638***	0.450***	0.501***	0.291*
(75th perc.)	(4.26)	(3.62)	(2.74)	(1.68)
Observations	156	156	104	104
R-squared	0.39	0.32	0.26	0.21

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises for various levels of monetary policy uncertainty. Monetary policy surprises are proxied by (i) the 30-minute change in the two-year nominal yield surrounding (10 minutes prior and 20 minutes after) FOMC announcements shown in columns 1-2, (ii) surprises proxied by the Nakamura and Steinsson (2018) measure, which is the 30-minute change surrounding FOMC announcements (15 minutes prior and 15 minutes after) of the first principle component of interest rates at different maturities spanning the first year of the term structure (columns 3-4). Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Table A6: Response of nominal and real yields to monetary policy surprises: Swanson (2019) shocks

	Dependent Variable			
	Nominal Yields		Tips Yields	
	5-year	10-year	5-year	10-year
	(1)	(2)	(3)	(4)
Coefficients				
$uncertainty_{d-1}$	0.01	0.019	0.030*	0.022
	(0.73)	(1.09)	(1.85)	(1.51)
$\Delta fedfunds_{d}$	0.126*	0.212***	0.248***	0.214**
	(1.71)	(3.06)	(2.92)	(2.55)
$\Delta fedfunds_{d}$ x $uncertainty_{d-1}$	-0.048*	-0.087***	-0.090***	-0.081**
	(-1.69)	(-3.11)	(-2.63)	(-2.41)
ΔFG_{d}	0.071***	0.054**	0.138***	0.102***
	(3.72)	(2.05)	(5.8)	(4.45)
ΔFG_{d} x $uncertainty_{d-1}$	-0.017*	-0.012	-0.048***	-0.034***
	(-1.90)	(-1.04)	(-4.16)	(-3.19)
$\Delta LSAP_{d}$	-0.068***	-0.093***	-0.046*	-0.077***
	(-4.13)	(-3.76)	(-1.70)	(-3.18)
$\Delta LSAP_{d}$ x $uncertainty_{d-1}$	0.026**	0.033*	0.008	0.025*
	(2.15)	(1.87)	(0.52)	(1.85)
Observations	155	155	155	155
R-squared	0.36	0.37	0.51	0.51

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of nominal and real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises interacting with our measure of monetary policy uncertainty. Monetary policy surprises included are the fed funds target rate shock, forward guidance shock, and large-scale asset purchase shocks, denoted by Δfedfunds, ΔFG, and ΔLSAP, respectively. Uncertainty refers to the level of our measure of monetary policy uncertainty prevailing the day before the FOMC meeting, as implied by derivative prices for the federal funds rate one-year ahead. Low/Medium/High uncertainty corresponds to the lower, median and upper quartile of the monetary policy uncertainty historical distribution. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.

Table A7: Response of nominal and real yields to monetary policy surprises: interaction of different uncertainty measures to surprises

	Dependent Variable					
	TIPS Yields					
	5-year			10-year		
	(1)	(2)	(3)	(4)	(5)	(6)
Coefficients						
Δmp_d	3.423***	-0.495	-0.443	2.816***	-0.593	-0.573
	(7.05)	(-1.01)	(-0.86)	(5.57)	(-1.43)	(-1.56)
$uncertainty_{d-1}$	0.019			0.016		
	(1.28)			(1.09)		
Δmp_d x $uncertainty_{d-1}$	-1.201***			-0.998***		
	(-5.99)			(-4.75)		
EPU_{d-1}	0	0	0	0	0	0
	(0.34)	(0.66)	(0.34)	(0.61)	(0.95)	(0.6)
Δmp_d x EPU_{d-1}		0.014**			0.014***	
		(2.40)			(2.7)	
VIX_{d-1}	-0.002	-0.003	-0.002	-0.003	-0.003	-0.002
	(-1.37)	(-1.48)	(-1.33)	(-1.31)	(-1.59)	(-1.36)
Δmp_d x VIX_{d-1}			0.055**			0.053***
			(2.43)			(3.24)
Observations	156	157	157	156	157	157
R-squared	0.46	0.34	0.34	0.4	0.32	0.32

NOTE: Reported coefficients denote the two-day response, around FOMC dates, of nominal and real U.S. Treasury yields (with five- and ten-year maturity) to monetary policy surprises interacting with different measures of uncertainty. Monetary policy surprises are proxied by the 60-minute change in the two-year nominal yield surrounding (15 minutes prior and 45 minutes after) FOMC announcements. Uncertainty refers to our measure of monetary policy uncertainty as implied by derivative prices for the federal funds rate one-year ahead; EPU is the economic policy uncertainty measures of Baker, Bloom and David (2009); VIX is the stock market volatility index constructed by the Chicago Board of Options Exchange. Sample period is May 1999 to January 2018. ***, ** and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *t*-ratios, based on robust standard errors, are shown in parenthesis below the estimated coefficients.