Bond Implied Risks Around Macroeconomic Announcements [*]

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Abstract

Using a large panel of Treasury futures and options, I construct model-free measures of bond uncertainty and tail risk across different tenors, showing that bond tail risk works as a good indicator for recessions since it remains moderate during normal times and suddenly enlarges before financial crises. Besides the term structure and cyclicality of bond implied risks, I document three novel findings regarding their movement around announcements by the US Federal Reserve: First, measures of stock and bond uncertainty increase two days prior to the announcements and revert back upon release. Second, the pre-FOMC announcement drift also prevails in Treasury bonds, such that yields of the 5, 10 and 30 years shrink 1 bp on the day before the announcement. Third, variation in uncertainty predicts the positive stock return and bond yield change, but its jump prior to the FOMC meeting has an offsetting impact. Nevertheless, neither the global positive nor the local negative effect is large enough to fully explain the pre-FOMC announcement drift.

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[*] All errors are mine.

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The recent disruptions in global financial markets in Spring 2020 are a stark reminder of the significant uncertainty faced by investors after the default of Lehman Brothers in 2008. Option markets are particularly suited to gauge such manifestations of uncertainty because they capture market participants' future expectations. Particular attention is paid to the so-called VIX index, an implied-volatility index calculated from S&P500 options, which climbed to new heights in March 2020. A second manifestation of market panics is a so-called flight-to-safety which refers to the fact that investors tend to shift their portfolios from risky (equity) to safer (government bonds) assets. However, during the Great Financial Crisis, safe assets like US Treasuries are usually in scarce supply. While measures of uncertainty extracted from equity markets are in ubiquitous use, little is known about corresponding risks in bond markets. This is surprising given the paramount role of safe assets during periods of distress. This paper fills this gap.

In this paper, I estimate measures of bond uncertainty and tail risk from bond option prices across different tenors using a long time-series and large cross-section. I focus on the behavior of these measures around various announcements such the monetary policy announcements by the Federal Market Open Committee (FOMC) or more general macroeconomic announcements. Studying the dynamics of these measures around announcement days provides me with a unique laboratory because these events are highly anticipated and we expect significant uncertainty to be resolved upon release. Moreover, recent work in equity markets connects the heightened uncertainty prior to the announcement to the pre-announcement drift, see, e.g., Hu, Pan, Wang, and Zhu (2019). Following this literature, I explore the relationship between bond and equity uncertainty, as well as tail risk around announcements and link these measures to risk premia earned around these days. To motivate my paper, I plot in Figure 1 the dynamics of stock and bond implied volatility 15 trading days before and after FOMC meetings.[1] While it is well-known that equity market risks increase prior to announcements, I find a very similar patterns in bond option markets. In particular, I find significant increases in option-implied volatility two days before FOMC announcements and a sharp drop to their mean upon the announcement.

Lucca and Moench (2015) in their seminal paper document a substantial return in the stock market 24 hours before days when the FOMC announces its new monetary policy. Interestingly, they do not find a similar pattern in Treasury bond markets. Prima facie, this misalignment may seem puzzling: Why does the stock market move while bonds remain unchanged? Exploring daily data, I uncover the existence of a similar pattern in bond markets. Bond yields on 5-year, 10-year, and 30-year bonds sharply decline the day before monetary policy releases. For example, inline with Lucca and Moench (2015), I find cumulative stock returns increase by 29 bps prior to the announcement for my data sample, while bond yields drop by 1 bp, the huge abnormal drifts compared to 1.67 bps and -0.07 bp of daily change for equity and bonds on average.

Two things are worth highlighting. Firstly, the massive stock return on the FOMC day is consistent with Lucca and Moench (2015) since much of the stock drift takes place not 1 day ahead, but on the same day prior to 2:00 pm, as shown in their most influential figure. Secondly, the contrasting outcomes regarding the bond pre-announcement drift may result from the time division: while I

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[1] I use the terms "implied volatility" and "uncertainty", as well as "implied skewness" and "tail risk" interchangeably in my paper.

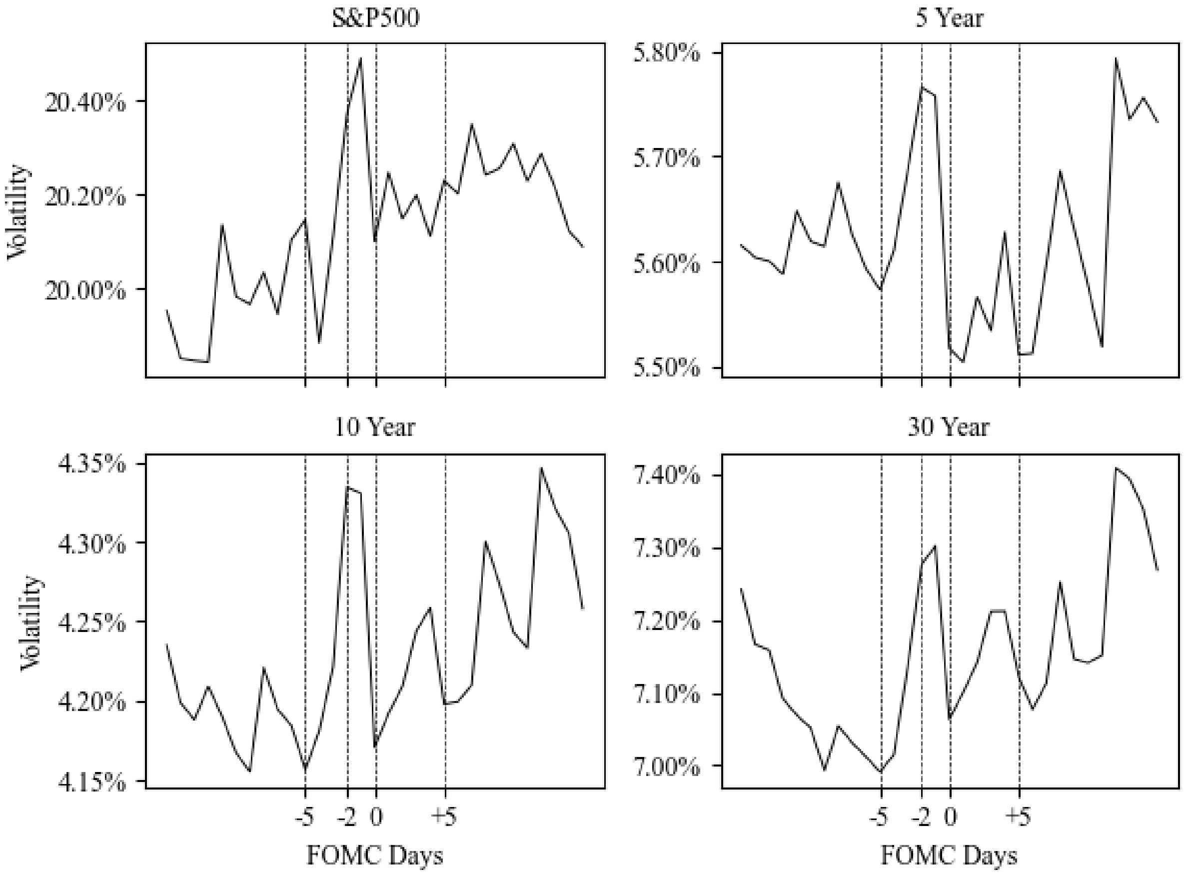

Figure 1. Stock and Bond Uncertainty Over FOMC Cycle

Note: These figures present the average uncertainty level for the stock index and Treasury bonds over the FOMC cycle, i.e., 15 trading days before and after the announcement. Stock uncertainty is akin to the VIX index, while the 5-, 10-, and 30-year bond uncertainty measures are calculated using Equation (7). Data runs from 2000 to 2018.

study simple daily changes, these authors rely on 24-hour windows. Therefore, bonds may react even earlier than stocks so that daily changes are better suited to capture the pre-drift.

The significant changes in bond yields and stock returns before the announcement are accompanied by significant increases in uncertainty in either of the two markets. Figures 1 and 2 document a significant increase of uncertainty proxies 2 days before the announcement day, followed by a positive stock return and a negative bond yield change preceding the FOMC announcement. To investigate this pre-announcement risk-return relationship, I extend two related hypotheses with bond implied risks to examine the predictive power of uncertainty for the abnormal drift.

One of them is the "Heightened Uncertainty Premium" proposed by Hu, Pan, Wang, and Zhu (2019), who argue that the extraordinary increase in VIX predicts the next-day abnormal stock return, rationalizing the stock pre-FOMC drift by the increase in uncertainty in the 3 days before the FOMC meeting. In this paper, I find that the significant increase in bond uncertainty is followed by a positive yield change, and that the sharp decrease of risk precedes a negative yield movement — together leading to a positive relationship between heightened uncertainty and next-day bond yield changes.

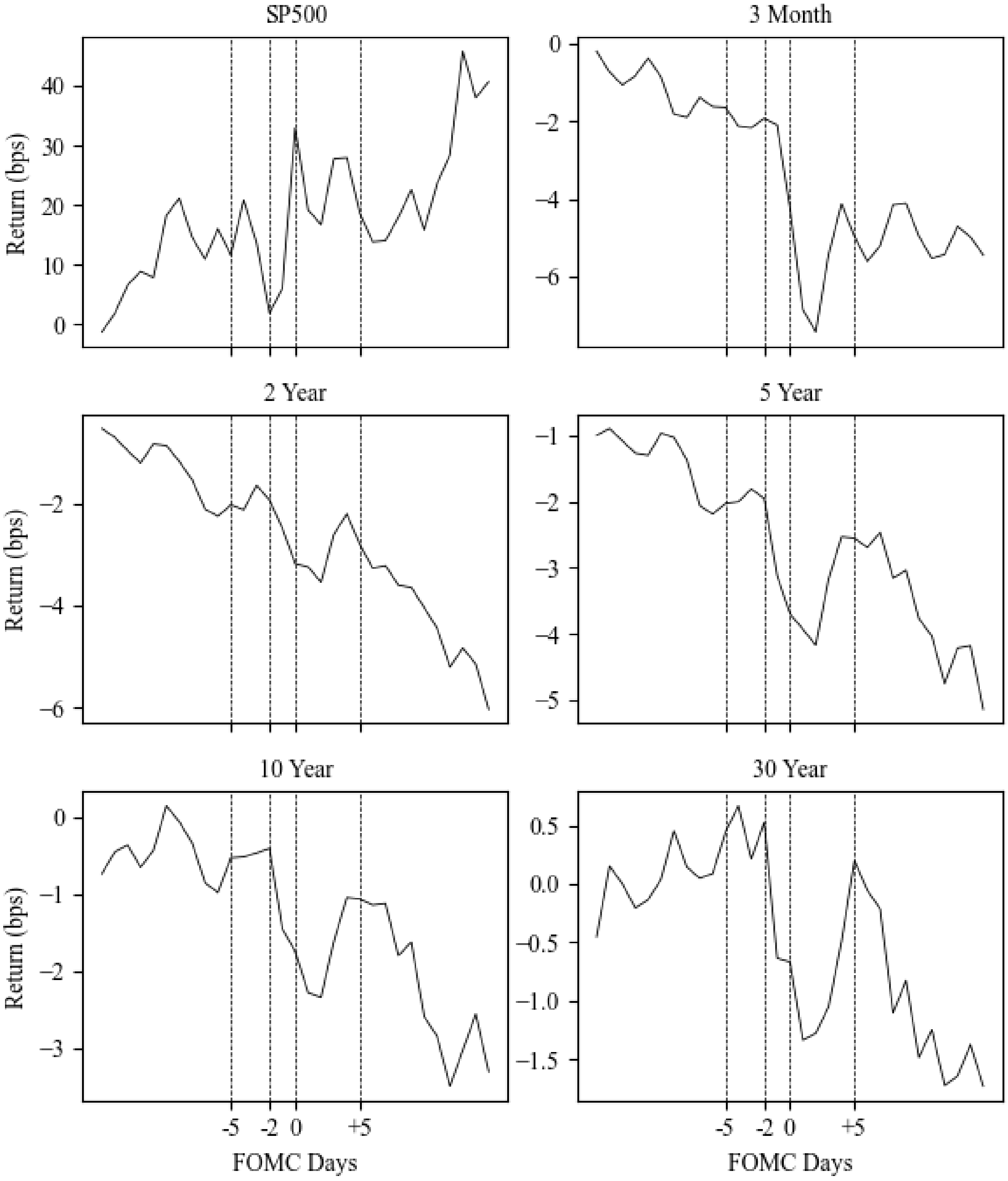

Figure 2. Stock Return and Bond Yield Drift Over FOMC Cycle

Note: These figures plot cumulative stock index returns and bond yield changes over the FOMC cycle, i.e., 15 days before and after the announcement. Cumulative stock returns are calculated from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. Data runs from 2000 to 2018.

Hence, given the reverse drift pattern observed in bond markets relative to equity markets, it is unlikely that the authors' hypothesis applies similarly to bond markets. Also, the uncertainty surge before the FOMC days is hardly ”heightened”: The average increase of stock and bond uncertainty before announcement, though significantly different from the mean zero, can only fall into the lowest cutoff bar, so that the heightened uncertainty days do not coincide with the pre-FOMC days. Looking at the distribution of pre-FOMC uncertainty and the following drift (see Table 13), the uncertainty increase before the FOMC announcement is moderate such that the FOMC days pass the cutoff on average twice per year, and these days are followed by positive stock return and negative bond yield changes, consistent with the pre-FOMC announcement drift but contrast to the bond heightened risk premium. Therefore, this hypothesis is insufficient for the pre-FOMC announcement drift, although it gives rise to the general positive relationship between the change in uncertainty and the next-day drift.

Another series of related papers investigate the effect of monetary policy uncertainty on policy transmission. For instance, Tillmann (2017) and De Pooter, Favara, Modugno, and Wu (2020) use their constructed monetary policy uncertainty and surprise measures to conclude similarly that high uncertainty mitigates the yield curve response to the post-announcement monetary policy surprise. I apply an equivalent setup for bond pre-announcement drift by making the following alterations: First, I replace the monetary policy uncertainty measure by bond implied volatility, such that for bonds of each maturity, the pre-announcement yield changes are regressed on their corresponding uncertainty risks. Second, as I focus on the pre-announcement drift rather than the reactions afterwards, the measure of monetary policy surprise derived from the high-frequency future price change around the announcement is less relevant, so I replace it by the dummy variable indicating the pre-FOMC days. Results (in Table 14) reveal that firstly, variation in uncertainty predicts the next-day stock return and bond yield change positively: 1% of the implied volatility rise can drive up the stock return, the 10-year and 30-year bond yield by 7.4 bps, 1.1 bps and 0.7 bp, correspondingly. The sudden jump in volatility before the FOMC meeting, however, has a negative impact, compatible with the uncertainty transmission hypothesis. For example, the interaction term drags down the stock and bond drifts by 21.4 bps, 1.0 bps and 2.0 bps for 1% uncertainty rise. Nevertheless, both the global positive and the local negative effect though significant, are too minimal to fully cover the huge pre-announcement drift. Taking into the average magnitude of the pre-FOMC uncertainty increase into the back-of-the-envelope calculation, I find that the overall effect from the uncertainty change is small and can be negative: It contributes to the pre-FOMC announcement drift by -13.6%, -11.7% and 23.0% for stock, 10-year and 30-year bond, respectively.

I finally confirm this inadequacy by running regressions only on the pre-announcement risk and return, such that if we observed larger coefficients than what the whole-data regressions can provide with correct signs, the uncertainty jump before the announcement would be so exceptional that it boosts a massive response. Nevertheless, as seen in Table 16, the coefficients are not even significantly different from zero, letting alone to be unusual. Therefore, although the rise of uncertainty and drift are followed one by another, and that uncertainty has the global and local predictive power for returns, it itself is not sufficient for the documented pre-FOMC announcement in stocks and bonds.

Besides the main results, the term structure and the cyclicality of uncertainty and tail risk supplement the overall assessment of bond implied risks. First, Bonds with longer maturity are associated with more substantial risks in general, except that the 5-year uncertainty and tail risk are comparable to the 30-year ones after the 2007-09 financial crisis, and that the 10-year tail risk outnumbers its 30-year peer, indicating that the maturity isn't the only determining factor for bond risk term structure. Second, I compare stock and bond risks with regard to their summary statistics (Table 1), uncovering that bond implied risks are smaller than the stock risks in mean, but the bond tail risks are more volatile than the stock counterpart. Also, uncertainty risks of stock and bond are positively correlated, yet their tail risks are little connected, which is reflected not only in statistics but also in their time series movements: bond implied volatility together with the stock peer is counter-cyclical — They enlarge during recessions and decrease afterwards. By contrast, the stock SKEW index is large and accumulating during the good times before falling down over financial crashes, whereas bond tail risks remain moderate most of the time and only augment right ahead of the crises. Readers can find these pattern in Figure 3 and 4 and the corresponding regressions in Table 2 and 3. Therefore, bond tail risk works as a better signal for financial disturbance.

Owing to the resolution of uncertainty, the average uncertainty risk on the FOMC days is not distinct from other days (Table 4). Also, on days when the Fed alters the target interest rate, whatever expansionary or contractionary, we could see a decline in uncertainty risks (Table 5). In addition, the movement of uncertainty is more profound with a cut in the target interest rate: both the pre-jump and the resolution are larger around expansionary monetary policy (Table 7). The same applies to the pre-announcement returns, as the stock and short-term bond drifts are mostly realized during recessions, or with expansionary monetary policy (Table 9). In comparison, the drop of longer-term yields comes with the unchanged target rate more significantly.

Beyond the pre-announcememt drift, I also extend Neuhierl and Weber (2018)'s paper to investigate the "monetary momentum" in the bond market. While the stock index keeps going upwards, bond yields shift down, after the significant bounce back in the week of the FOMC meeting (see Figure 2). Also, the cumulative yield drop becomes less magnificent along the tenors. The 2-year bond yield declines by 6 bps over the FOMC cycle; the decrease of 4 bps, 3 bps and 1.5 bps are assigned to the 5-year, 10-year and 30-year yields. In order to investigate the yield responses across tenors, I divide the bond yields into the expected rate and the term premia according to data provided by Adrian, Crump, and Moench (2013). Figure 6 shows that the monetary policy alters investors' beliefs about the future expected rate, such that the expected part drops near the same amount for bonds of all maturities. It's the increased term premia over the FOMC cycle that causes the overall bond yield to response differ, which is higher with longer maturities. Furthermore, stock return and bond yield shift downwards with expansionary monetary policies, and upwards with contractionary ones, yet the monetary momentum effect in bonds weakens as the maturity lengthens, consistent with the previous results.

Contribution to the Literature

Besides the most relevant research mentioned above, my paper contributes to the literature in various strands. Firstly, I apply the methodology from Bakshi, Kapadia, and Madan (2003) with Treasury futures and options to extract the term structure of bond implied volatility and skewness. Similar option-implied methods from Breeden and Litzenberger (1978), Carr and Madan (2001) and Schneider and Trojani (2015) are also used in the literature to generate pro-cyclical stock skewness risks, while some researchers point out the instability of implied skewness derived through those methods so that they proceed with others. For example Bollerslev, Todorov, and Xu (2015) and Gao, Gao, and Song (2018) provide counter-cyclical stock tail risks using the out-of-money puts only. There're also methods such as the Bali, Cakici, and Whitelaw (2014)'s approach which accesses the downside variance risk as the tail risk. For a more consistent measure for bond uncertainty and tail risk, I choose to proceed with Bakshi, Kapadia, and Madan (2003), but I apply the index calculation practice to overcome the potential issues of liquidity and instability.

Researchers employ the option-implied uncertainty and tail risk for various questions in stock markets, leaving only a few papers devoted to bond risks. My paper is mostly related to the paper of Choi, Mueller, and Vedolin (2017), who derive the implied variance for the 5, 10, and 30-year Treasury bonds using similar methods to construct the bond variance risk premium. For bonds of each maturity, they obtain the downward sloping term structure of bond implied variance across the time-to-maturity of the associated option series. To be more specific, they calculate the 5-,10- and 30-year implied variance using options maturing 1, 2, 3, 6, 9, and 12 months, yet the longer-term ones are less traded. In comparison, I implement the weighted average method from the index calculation approach over the nearest and the next option series, to provide a single 30-day implied risk for bonds of each tenor. As a result, the derived bond implied risks are comparable to the existing benchmarks with high correlation coefficients. Also, both the index and the derived bond implied volatilities jump 2 days before the FOMC meeting, further validating this approach. Consequently, this paper contributes to the literature by providing a reliable bond risk measure across different tenors. It's also the first paper to look at bond tail risk. Another paper also working on the Treasury bond implied risk is from Cremers, Fleckenstein, and Gandhi (2017), who focus only on the 5-year at-the-money implied volatility and investigate its predictability for economic activity. Similarly, Dew-Becker, Giglio, and Kelly (2019) employ the at-the-money implied volatility in various markets including bonds to discuss the cost of hedging the economic and financial uncertainties.

The bond uncertainty risk in my paper also relates to the market-based monetary policy uncertainty extracted from the derivatives of the short-term interest rates, yet I focus on the longer-term (2, 5, 10, and 30 years) implied risks from Treasury bonds. For instance, Swanson (2006) adopts the 90% width of probability distribution for the federal fund rate 1 year ahead; Bauer, Lakdawala, and Mueller (2019) use the 1-year Eurodollar futures and options to compute the risk-neutral standard deviation of the interest rate change; Kurov and Stan (2018) employ the realized volatility of the Eurodollar futures rate with 2 years to expiration. There are also other measures for monetary policy uncertainty: Husted, Rogers, and Sun (2019) have the news-based uncertainty using text searching and Istrefi and Mouabbi (2018) offer the subjective monetary policy uncertainty by gauging the disagreement among professional forecasts.

Another branch of research that this paper relates attempts to document and explain the asset price changes before monetary policy releases. When Lucca and Moench (2015) detect the pre-announcement return in the stock market, subsequent papers solving the puzzle have been split into two channels: information leaking, and uncertainty risk compensation. About the uncertainty-based theory, Hu, Pan, Wang, and Zhu (2019) introduce the premium for heightened uncertainty, claiming that the substantial increment in VIX is accompanied by the next-day unusual excess return so that the rise in uncertainty risk ahead of the FOMC meeting rationalizes the abnormal drift. Also, Bauer, Lakdawala, and Mueller (2019) points out the uncertainty resolution on the FOMC announcement days. Another statement in Lucca and Moench (2015)'s paper is that the pre-announcement drift is not discovered in the Treasury bond market, which is even more puzzling because what the Fed adjusts is the interest rate, and we cannot catch the pre-drift in the interest rate assets. Also, as papers have already validated the interest rate sensitivity to monetary shocks even for the long-term bonds (Kuttner (2001), Leombroni, Vedolin, Venter, and Whelan (2019), Gürkaynak, Sack, and Swanson (2005) and Hanson and Stein (2015)), the puzzles and possible uncertainty channel trigger me to revisit the bond pre-announcement drift. Surprisingly, the pre-FOMC announcement drift does exist in bond markets. And as the paper from Kurov, Sancetta, Strasser, and Wolfe (2019) uncovers the bond yield drift in advance of macroeconomic news, it supports my finding from a different perspective since asset prices typically react more to monetary policy than to macroeconomic indicator announcements.

Among the research about monetary policy uncertainty, some authors deploy the uncertainty measure to study its role in policy transmission. For instance, De Pooter, Favara, Modugno, and Wu (2020) apply Swanson (2006)'s uncertainty measure to understand how the shock (the 2-year Treasury yield change around the 30-min FOMC announcement window, which is originally proposed by Hanson and Stein (2015)) transmit to yields under different levels of uncertainty risk. They conclude that for a given monetary policy shock, the reaction of yields is more pronounced when uncertainty is low. Tillmann (2017) tries multiple existing monetary uncertainty measures with the daily change of 2-year Treasury yield as the policy shock to study the yield curve response. Bauer, Lakdawala, and Mueller (2019) introduce their own measure of uncertainty, as use the first principal component of daily change in Eurodollar futures for the shock. They all arrive in a similar result that the high uncertainty tempers the yield curve reactions to the monetary policy shock.

Learning from those papers, I contribute to investigating the role of bond uncertainty risk in monetary policy transmission under the context of the pre-announcement drift. In this paper, I verify the positive relationship between the change of uncertainty and the next-day stock and bond drift, and the negative effect of high uncertainty movement on the monetary policy transmission even before the announcement. In the end, I confirm the insufficiency of uncertainty risk to solve the pre-announcement puzzle.

The rest of the paper is organized as followed: Section 1 starts with the data and methodology for measuring bond implied risks. The term structure features of bond uncertainty and tail risk are discussed. Section 2 focuses on the uncertainty reactions to the market condition and the monetary policy change, starting from the exact-day performance to the dynamics over the FOMC cycle. In section 3, I document the existence of bond pre-announcement drift. The monetary momentum effect in the bond market is also investigated. Section 4 connects the uncertainty risk with the pre-announcement return, by applying the heightened uncertainty hypothesis and the uncertainty transmission mechanism. Section 5 concludes and proposes further research possibilities.

1 Measuring Bond Implied Risks

1.1 Data

I obtain the daily trading information of 2-, 5-, 10-, and 30-year Treasury futures and options covering the year 2000 to 2018 from the CME End-of-Day dataset. The derivatives for S&P500 index are also used to construct benchmarks. As multiple contracts are listed on each date, I extract the future price by the rolling convention from Choi, Mueller, and Vedolin (2017), with the nearest and the next series of option prices after the data cleaning process.[2] The Treasury constant-maturity 3-month interest rate is employed as the risk-free rate.

1.2 Implied Volatility and Skewness

To construct the bond risk measures, I implement the formulas from Bakshi, Kapadia, and Madan (2003) to calculate the variance ($V(t,\tau) \equiv E^Q[e^{-r\tau}R(t,\tau)^2]$), cubic ($W(t,\tau) \equiv E^Q[e^{-r\tau}R(t,\tau)^3]$), and quartic ($X(t,\tau) \equiv E^Q[e^{-r\tau}R(t,\tau)^4]$) contract prices, as well as the first moment expected return ($\mu(t,\tau) \equiv E^Q[e^{-r\tau}R(t,\tau)]$), where $R(t,\tau) \equiv \ln[S(t+\tau)] - \ln[S(t)]$, and τ is the time to maturity. Since options are written on futures, the spot price $S(t)$ is the future price in this setting. One thing to be noted is that Treasury and SP500 options are American style while the methodology of Bakshi, Kapadia, and Madan (2003) is based on European options. As Choi, Mueller, and Vedolin (2017) prove that the adjustment is small for options within one year to expiration, and I only use the options maturing in 1 and 2 months, I proceed with no adjustment. According to Equation (1) to (4), the out-of-money call and put options are given different weights according to their moneyness before aggregating to approximate the risk contracts. Those equations are similar but different from the ones deployed by the CBOE indexes, in terms of the weights before the option prices, the calculation of $\mu(t,\tau)$, and one practical error adjustment, because artificial future prices from the Call-Put Parity is applied under the index calculation procedure instead of the real future prices. I choose the Bakshi, Kapadia, and Madan (2003) approach with more detailed comparisons and reasons in Appendix A.2.

$$V(t,\tau) = \int_{S(t)}^{\infty} \frac{2\left(1 - \ln\left[\frac{K}{S(t)}\right]\right)}{K^2} C(t,\tau;K)dK + \int_{0}^{S(t)} \frac{2\left(1 + \ln\left[\frac{S(t)}{K}\right]\right)}{K^2} P(t,\tau;K)dK \tag{1}$$

$$W(t,\tau) = \int_{S(t)}^{\infty} \frac{6\ln\left[\frac{K}{S(t)}\right] - 3\left(\ln\left[\frac{K}{S(t)}\right]\right)^2}{K^2} C(t,\tau;K)dK - \int_{0}^{S(t)} \frac{6\ln\left[\frac{S(t)}{K}\right] + 3\left(\ln\left[\frac{S(t)}{K}\right]\right)^2}{K^2} P(t,\tau;K)dK \tag{2}$$

$$X(t,\tau) = \int_{S(t)}^{\infty} \frac{12\left(\ln\left[\frac{K}{S(t)}\right]\right)^2 - 4\left(\ln\left[\frac{K}{S(t)}\right]\right)^3}{K^2} C(t,\tau;K)dK + \int_{0}^{S(t)} \frac{12\left(\ln\left[\frac{S(t)}{K}\right]\right)^2 + 4\left(\ln\left[\frac{S(t)}{K}\right]\right)^3}{K^2} P(t,\tau;K)dK \tag{3}$$

$$\mu(t,\tau) = e^{r\tau} - 1 - \frac{e^{r\tau}}{2}V(t,\tau) - \frac{e^{r\tau}}{6}W(t,\tau) - \frac{e^{r\tau}}{24}X(t,\tau) \tag{4}$$

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[2] Exhaustive details on data filtering are discussed in Appendix A.1.

The price of the variance contract $V(t,\tau)$ is referred as the risk-neutral implied variance. The implied skewness $S(t,\tau)$ is derived by the combination of the risk contract prices:

$$S(t,\tau) = \frac{E^Q(R((t,\tau) - E^Q[R(t,\tau)])^3}{\{E^Q(R(t,\tau) - E^Q[R(t,\tau)])^2\}^{\frac{3}{2}}} = \frac{e^{r\tau}W(t,\tau) - 3\mu(t,\tau)e^{r\tau}V(t,\tau) + 2\mu(t,\tau)^3}{[e^{r\tau}V(t,\tau) - \mu(t,\tau)^2]^{3/2}} \tag{5}$$

Using two sets of options each day, we now have both the nearest and the next implied variance and skewness labeled by $V(t,\tau_1)$, $V(t,\tau_2)$ and $S(t,\tau_1)$, $S(t,\tau_2)$, respectively. Although I use the method from Bakshi, Kapadia, and Madan (2003) instead of the index calculation approach for the underlying risk contract prices, I follow the index practices to take the weighted average of the two implied risks for the 30-day uncertainty and tail risk. In this way, the potential liquidity effect is eliminated, solving the issues that traditional skewness formulas (i.e. from Bakshi, Kapadia, and Madan (2003), Carr and Madan (2001) or Breeden and Litzenberger (1978)) cause unstable tail risks, which many authors point out so that they choose other ways to proceed. However, those other methods for example using only out-of-the-money put options or the partial downside variance risk are not as effective as the standard skewness equations since they derive the counter-cyclical tail risks, inconsistent with the existing stock SKEW index and actually still part of the variance risk.

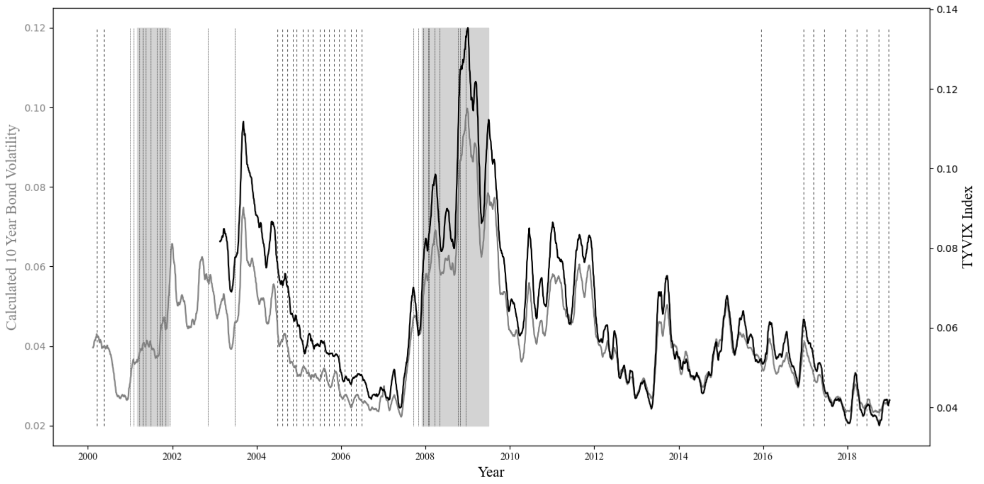
For a more comparable risk measure with the pro-cyclical stock tail risk index, the nearest and next implied risks are weighted by how close their time-to-maturity is to 30 days (see Equation (6)), so the derived implied volatility denoted by V^{iy} is provided in Equation (7) after taking the square root of the annualized risk-neutral variance, and implied skewness S^{iy} is presented in Equation (8), for Treasury bond risks of 2, 5, 10, and 30 years.

$$w_1 = \frac{\tau_2 - \frac{30}{252}}{\tau_2 - \tau_1}, w_2 = 1 - w_1 = \frac{\frac{30}{252} - \tau_1}{\tau_2 - \tau_1} \tag{6}$$

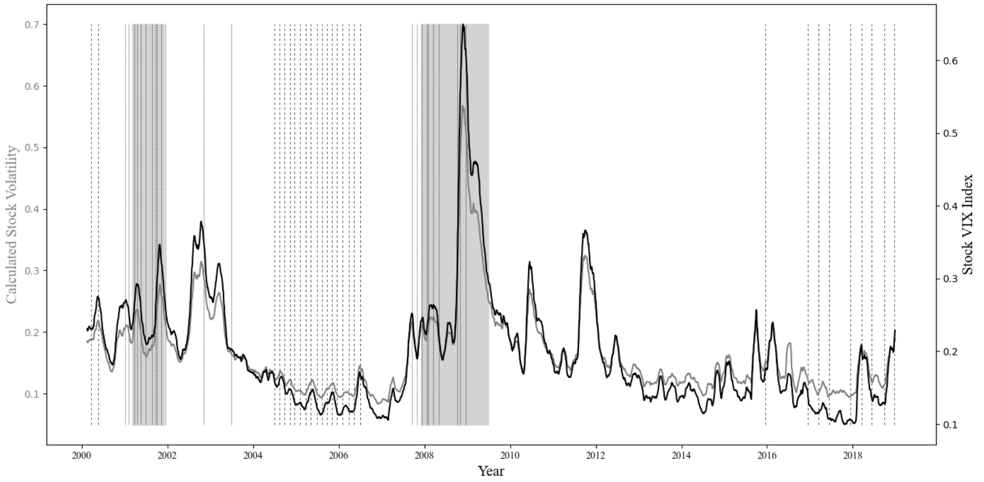
$$V^{iy} = \sqrt{\frac{252}{30}(w_1 \times V^{iy}(t,\tau_1) + w_2 \times V^{iy}(t,\tau_2))}, i = 2, 5, 10, 30 \tag{7}$$

$$S^{iy} = w_1 \times S^{iy}(t,\tau_1) + w_2 \times S^{iy}(t,\tau_2), i = 2, 5, 10, 30 \tag{8}$$

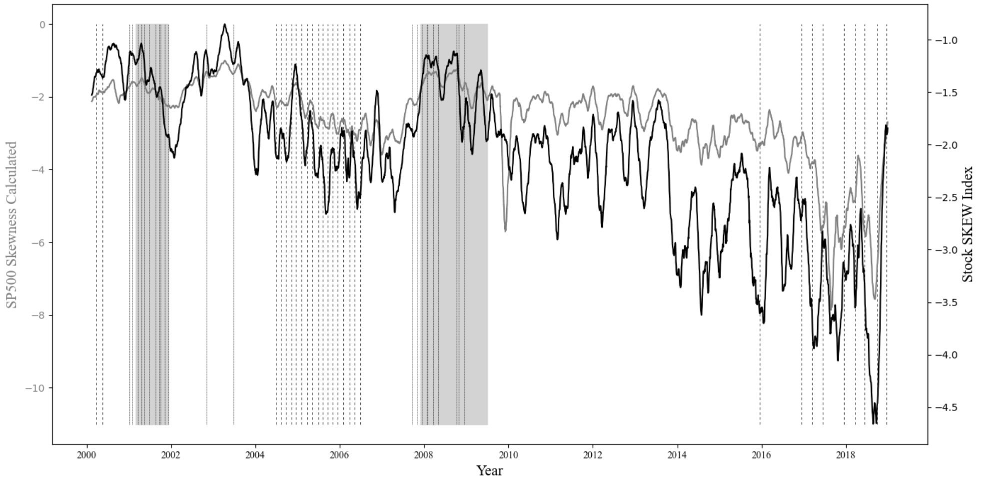
Treating the existing CBOE indexes TYVIX, VIX, and SKEW as benchmarks, which gauge the implied volatility of the 10-year Treasury note, and the S&P500 index implied volatility as well as skewness, I verify the robustness of the measure in Figure 3, where you can find the 30-day moving average of the derived risks and their corresponding indexes. Figure 3a confirms that the calculated 10-year implied volatility follows well with the TYVIX index, providing validation for bond uncertainty risks across tenors. To justify the skewness measure without a bond tail risk index, I derive the S&P500 implied risks to compare them with the VIX and SKEW indexes. We could see that the fitness of uncertainty risk is reasonably well and skewness risk is also able to capture the trend.[3] On a daily base, the correlations between the computed risks and the indexes are 0.96, 0.99 and 0.79, respectively, confirming the bond risk measure reliability.



(a) 10-Year Derived Uncertainty Risk and TYVIX Index



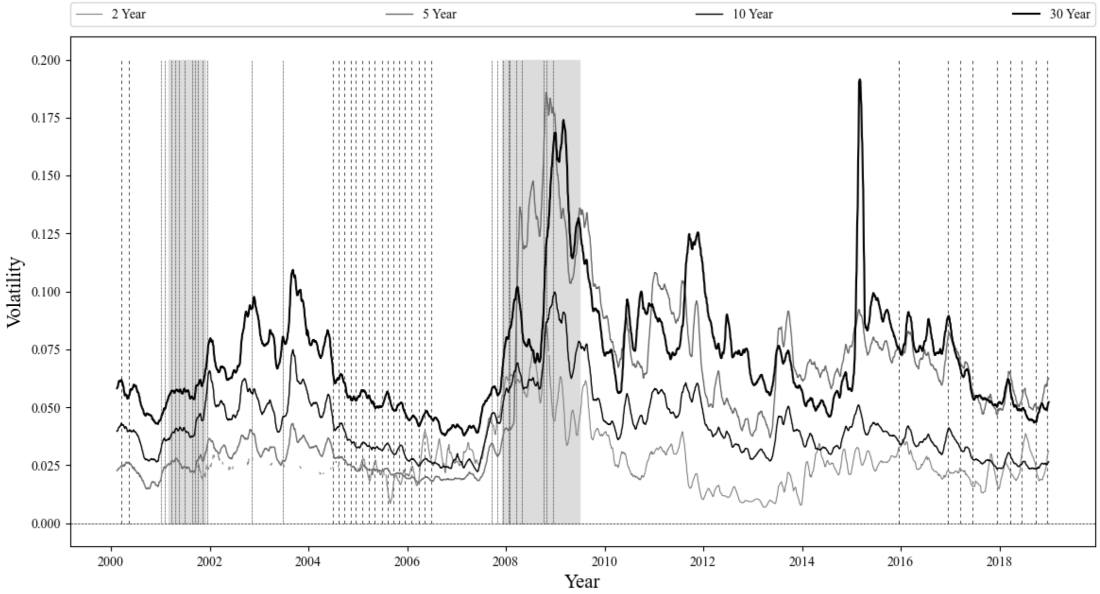
(b) Stock Derived Uncertainty Risk and VIX Index



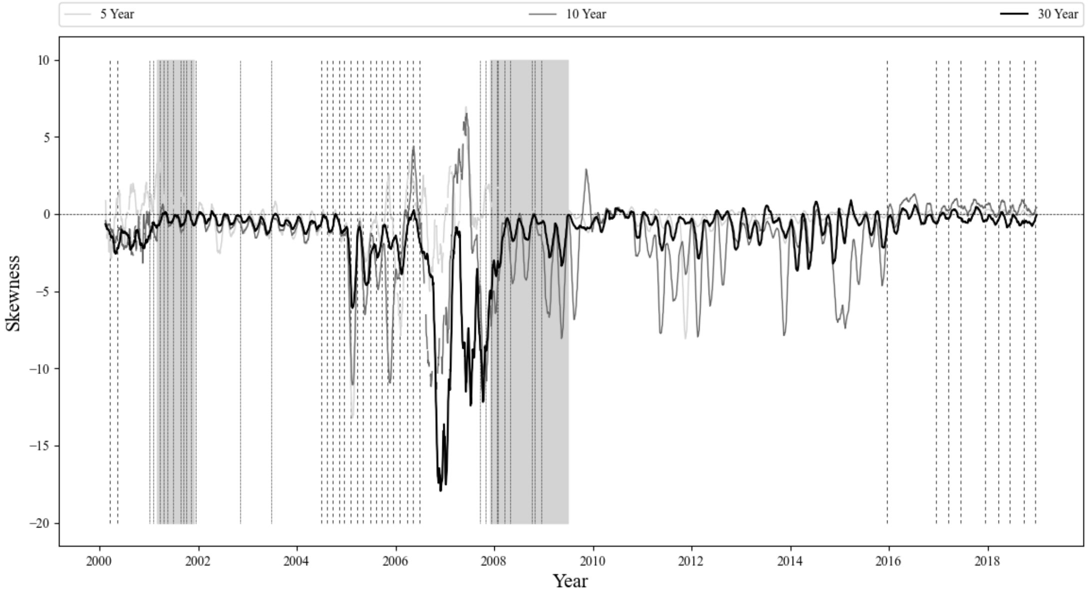
(c) Stock Derived Tail Risk and SKEW Index

Figure 3. Benchmark Comparison

Note: These figures compare derived implied risks with the corresponding indexes, where the daily data are taken the 30-day moving average to reflect the trend. $TYVIX$, VIX and $SKEW$ are available from the CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The daily correlations are 0.96, 0.99 and 0.79, respectively. Data runs from 2000 to 2018.



(a) Term Structure of Bond Uncertainty Risk



(b) Term Structure of Bond Tail Risk

Figure 4. Term Structure of Bond Implied Risk

Note: These figures present the 30-day moving average of the bond implied volatility and skewnss term structure from 2000 to 2018. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. 2 Year skewness is not graphed since the data is scarce compared to the other maturity counterparts. Grey bars represent two recessions defined by NBER Business Cycle. The dot/dash lines label the announcements of expansionary/contractionary monetary policy.

Table 1. Summary Statistics of Stock and Bond Implied Risk

	VIX	V^{2y}	V^{5y}	V^{10y}	V^{30y}	$SKEW$	S^{2y}	S^{5y}	S^{10y}	S^{30y}
Mean	19.70%	2.80%	5.61%	4.19%	7.15%	-2.14	-0.26	-0.31	-1.62	-1.38
Std	8.62%	1.53%	3.50%	1.50%	2.67%	0.82	3.04	2.97	3.71	3.13
1%	53.00%	7.72%	16.99%	9.22%	17.06%	-4.57	-13.30	-13.14	-15.29	-18.89

	VIX	V^{2y}	V^{5y}	V^{10y}	V^{30y}	$SKEW$	S^{2y}	S^{5y}	S^{10y}	S^{30y}
VIX	1									
V^{2y}	0.44	1								
V^{5y}	0.42	0.51	1							
V^{10y}	0.72	0.57	0.63	1						
V^{30y}	0.60	0.29	0.65	0.79	1					
$SKEW$	0.42	0.28	-0.12	0.37	0.15	1				
S^{2y}	-0.21	-0.12	-0.19	-0.24	-0.22	-0.08	1			
S^{5y}	0.02	0.07	0.02	-0.04	-0.04	0.001	0.10	1		
S^{10y}	-0.00	-0.09	-0.02	-0.10	-0.08	-0.08	0.20	0.20	1	
S^{30y}	0.12	-0.08	0.21	0.13	0.20	-0.09	0.05	0.06	0.40	1

Note: The upper table provides the daily mean, standard deviation and 1% quantile of stock and bond implied risks from 2000 to 2018. VIX and $SKEW$ are available from the CBOE webpage, while V^{iy} together with S^{iy} denotes the derived bond implied volatility and skewness risks for 2, 5, 10 and 30 years from Equation (7) and (8), the construction of which are provided in Chapter 1. Correlation is presented in the second table.

1.3 The Term Structure of Bond Risks

Table 1 together with Figure 4 summarizes the comparison between stock and bond risks and the term structure characteristics. Firstly, bond risks are smaller in magnitude compared to the stock counterparts. The daily average of VIX from 2000 to 2018 is 19.70%, while the largest 30-year bond volatility is 7.15%. The same applies to the skewness risk, where the stock SKEW index is -2.14 and the greatest 10-year tail risk is -1.62. Here, I compare the CBOE indexes with the calculated bond implied risks, but the derived stock risks and their matching indexes don't share the same mean values despite of the high correlation. Nevertheless, as the derived stock uncertainty and tail risk are larger than the corresponding indexes as seen in Figure 3, this comparison can only be biased towards small in terms of the difference between the stock and bond risks.

Bond skewness, on the other hand, is more volatile than the stock's. The standard deviations of bond skewness risks are 3.04, 2.97, 3.71 and 3.13, respectively, compared with only 0.82 for the SKEW index. The volatile bond tail risks can also be justified through the angle of quantile distribution, which reveals that the largest 1% tail risk of bonds are much higher than the stock's. Moreover, although the correlation between stock and bond uncertainty risk is positive,[4] there is little if not no correlation for their tail risks embedded. The correlations between uncertainty and tail risk are

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[3] More details about the benchmark comparison, the reason of the discrepancy in the skewness risk, and the at-the-money implied volatility measure used by other literature are discussed in Appendix A.3.

[4] Stock and bond uncertainty risk are positively correlated, but they diverge sometimes. See more in Appendix Figure A-2, which reveals that the correlation between 10-year bond and stock index falls below zero three times between the 2000 to 2018.

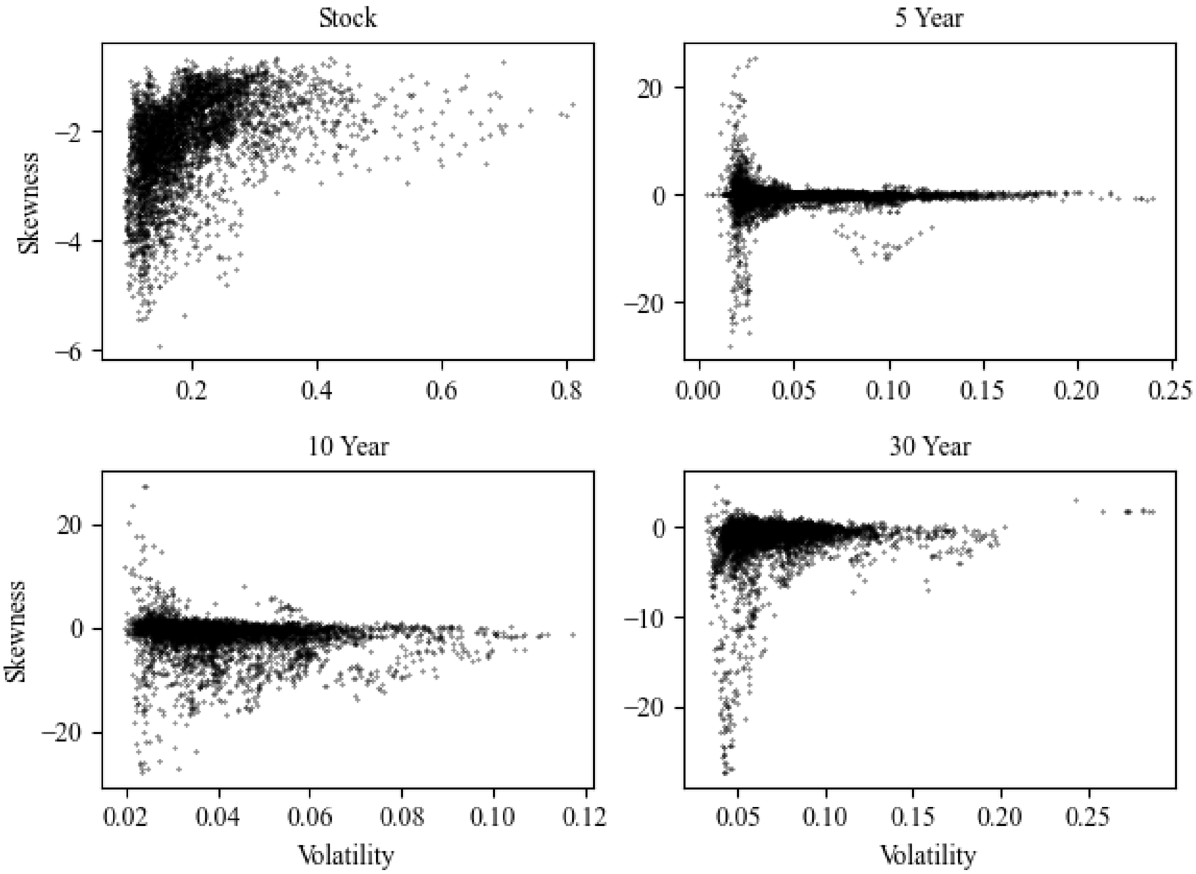

Figure 5. Uncertainty and Tail Risk in Scatter Plot

Note: These scatter plots manifest the distribution and co-movement of the uncertainty and tail risk in stock and bonds. The points reflect the implied volatility and skewness at the same day. VIX and $SKEW$ are available from the CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1.

small, too — 0.42, -0.12, 0.02, -0.10, 0.20 for stock and bonds respectively — only that tail risks are more diverse when uncertainty risks are low, as shown in the scatter plots in Figure 5. This pattern is consistent with the later finding that uncertainty is counter-cyclical while tail risk is forward-looking, such that before financial crises, uncertainty risks are moderate while tail risks already accumulate a lot. Another finding worth mentioning is that the bond implied skewness can be positive while the stock index is always negatively skewed, implying that bonds could have a longer tail for positive return in some periods.

Concerning the term structure properties, longer maturity is associated with more substantial uncertainty risk, yet the 5-year is an exception, which is larger than the 10-year counterpart (5.61% vs 4.19%). From Figure 4, we can tell that the reason lies in the changing behavior of the 5-year uncertainty after the 2007-09 financial crisis, when it became comparable to the 30-year risk, driving up the overall mean. From this perspective, maturity isn't the only determining factor for the term structure of bond risks. The same can be easily applied to the tail risk, where the 10-year implied skewness is the largest on average.

2 Bond Implied Risks in the Market

2.1 Risks Under Recessions

From 2000 to 2018, two major financial crises hit the market: the Internet bubble burst and the 2007-09 financial crisis.[5] As shown in Figure 3 and 4, implied volatilities of stocks and bonds rise during the two crashes and fall afterwards. In other words, uncertainty risk is counter-cyclical.

By contrast, tail risk acts early. From June 2004 to June 2006, for instance, when the Fed had been raising the target interest rate from 1% to 5.25%, stock tail risk fluctuated to an uplifted level yet uncertainty continued to decline (see Figure 3c). When the crisis approached, uncertainty surged and tail risk retreated to low. After the 2007-09 financial crisis, stock tail risk resumed to its accelerating pace, volatile and vast at the same time, especially in recent years when the Fed started to raise the interest rate, signaling a strong economy. In this sense, stock tail risk is pro-cyclical and forward-looking.

Bond tail risk, little correlated with the stock counterpart, remains moderate most of the time. Nonetheless, right before the 2007-09 financial crashes, it experiences enormous surge and vacillation. Take the 30-year bond tail risk as an example, which suddenly rose to nearly -20 in the beginning of 2007, when volatility was at its lowest level. When the recession arrived, it dropped back to normal. Similarly, the bond tail risk during the Internet bubble period is relatively higher than normal, although the magnitude is less evident. From this perspective, bond tail risk serves as a better signal for economic turbulence, because we don't know the threshold for the stock skewness about how much it would pile up before the crisis comes. In comparison, seeing the abrupt surge in the bond tail risk, we could forecast that the next economic recession is around the corner.

To validate the descriptive claims made above, I regress the level of stock and bond risks on dummy variables to see if the bond implied risks exhibit meaningful distinction under recessions. According to the NBER Business Cycle specification, I define the two economic contractions, from March 2001 to November 2001, and from December 2007 to June 2009, as the ”Bust” period, leaving the other time as expansions or ”Boom” periods. Displayed in Table 2, the stock and bond implied uncertainty are higher by 13.4%, 2.9%, 4.1%, 2.3% and 2.6% in the recessions. As skewness is negative in mean, the crashes witness the stock tail risk shrinking by 0.8, while the bond regression results are controversial: the 5-year and 30-year tail risk decline during the contractions while the 2-year and 10-year tail risk increase, all of which are statistically significant.

I attribute this inconsistency to the time specification of the Internet Bubble Burst recession. The Dot Com bubble burst in the year 2001, while its effect lasts in the markets until June 2003, since the S&P500 continued to go downwards. Also, we can see from the Figure 3 and 4 that the implied volatility of stocks and bonds keep rising until the mid 2003. It's justified further by the Fed that policymakers still cut the interest rate on their June 25, 2003 meeting. Following the NBER definition is distorting the tail risk results, since the stock and bond tail risk keep minimal for an extended time after the NBER-specified range. Therefore, I expand the Internet ”Bust” time to the end of June 2003, so that the 10-year bond tail risk in the recessions become positive while not significant different from

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[5] In this paper, as the data only cover up to the year 2018, the economic recession brought by the Coronavirus can not be investigated through the bond risk angle.

Table 2. Risks Under Recessions: NBER Business Cycle

	VIX_t	V_t^{2y}	V_t^{5y}	V_t^{10y}	V_t^{30y}
$1_{t,Bust}$	**13.4428*****	**2.9041*****	**4.1430*****	**2.3328*****	**2.5781*****
	(0.3266)	(0.0607)	(0.1426)	(0.0569)	(0.1124)
Intercept	**18.0404*****	**2.4532*****	**5.0996*****	**3.9038*****	**6.8308*****
	(0.1143)	(0.0210)	(0.0499)	(0.0199)	(0.0393)
R-squared	0.2631	0.3810	0.1510	0.2613	0.0997
	$SKEW_t$	S_t^{2y}	S_t^{5y}	S_t^{10y}	S_t^{30y}
$1_{t,Bust}$	**0.7662*****	**-0.8855*****	**0.7358*****	**-0.4192****	**0.3568*****
	(0.0346)	(0.1544)	(0.1319)	(0.1642)	(0.1384)
Intercept	**-2.2304*****	**-0.1525*****	**-0.4029*****	**-1.5693*****	**-1.4221*****
	(0.0121)	(0.0533)	(0.0463)	(0.0578)	(0.0485)
R-squared	0.0937	0.0086	0.0064	0.0012	0.0012

Note: The table illustrates how daily stock and bond implied risks perform under recessions, according to the NBER Business Cycle definition. The ”Bust” time is from March 2001 to November 2001, and from December 2007 to June 2009. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The units of uncertainty and tail risk are 1% and 1, respectively. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table 3. Risks Under Recessions: Internet Bubble Burst Recession Extended

	VIX_t	V_t^{2y}	V_t^{5y}	V_t^{10y}	V_t^{30y}
$1_{t,Bust}$	**12.3540*****	**2.3992*****	**1.5107*****	**2.0013*****	**1.9374*****
	(0.2512)	(0.0587)	(0.1236)	(0.0452)	(0.0919)
Intercept	**17.1479*****	**2.4475*****	**5.2965*****	**3.7782*****	**6.7483*****
	(0.1139)	(0.0225)	(0.0560)	(0.0205)	(0.0417)
R-squared	0.3376	0.3099	0.0303	0.2921	0.0855
	$SKEW_t$	S_t^{2y}	S_t^{5y}	S_t^{10y}	S_t^{30y}
$1_{t,Bust}$	**0.8970*****	**-0.6905*****	**0.3611*****	0.2056	**0.7228*****
	(0.0265)	(0.1417)	(0.1071)	(0.1334)	(0.1119)
Intercept	**-2.3211*****	**-0.1569*****	**-0.3872*****	**-1.6639*****	**-1.5270*****
	(0.0120)	(0.0542)	(0.0488)	(0.0608)	(0.0507)
R-squared	0.1952	0.0061	0.0022	0.0003	0.0085

Note: The table illustrates how daily risks perform under recessions, according to the NBER Business Cycle definition, but the Internet Bubble Burst recession is extended to June 2003, the last time the Fed cut the interest rate after the Bubble burst. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The units of uncertainty and tail risk are 1% and 1, respectively. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

other days (see Table 3). In this paper, however, I proceed with the NBER definition of recessions as the control variable as well as for the interaction terms, since it's more acceptable by the vast research.

2.2 Risks on the FOMC Days

Besides the distinct performance of bond implied volatility and skewness under financial crises, do bond risks perform uniquely on particular days, for example, days of the monetary policy announcement or the release of economic indicators? From Table 4, none of the implied volatility or skewness risks are exhibiting any exceptions on the FOMC days, and the intercepts are consistent with the average level of risks.

Table 4. Risk on the FOMC Days

	VIX_t	V_t^{2y}	V_t^{5y}	V_t^{10y}	V_t^{30y}
$1_{t,FOMC}$	0.4281	0.0588	-0.0930	-0.0193	-0.0862
	(0.6972)	(0.1404)	(0.2836)	(0.1214)	(0.2171)
Intercept	**19.6723*****	**2.7977*****	**5.6100*****	**4.1901*****	**7.1496*****
	(0.1268)	(0.0254)	(0.0516)	(0.0221)	(0.0395)
R-squared	-0.0001	-0.0002	-0.0002	-0.0002	-0.0002
	$SKEW_t$	S_t^{2y}	S_t^{5y}	S_t^{10y}	S_t^{30y}
$1_{t,FOMC}$	0.0465	-0.1806	0.1388	-0.2915	-0.1081
	(0.0668)	(0.2811)	(0.2421)	(0.3038)	(0.2538)
Intercept	**-2.1379*****	**-0.2521*****	**-0.3171*****	**-1.6116*****	**-1.3747*****
	(0.0121)	(0.0511)	(0.0442)	(0.0550)	(0.0462)
R-squared	-0.0001	-0.0002	-0.0001	-0.0000	-0.0002

Note: In this table, the level of risks are regressed on the release of monetary policy. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The units for uncertainty and tail risk are 1% and 1, respectively. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Then, I further decompose the FOMC days through two approaches, the setup of which is also utilized in the later chapters. Firstly, I add the period effect $1_{t,Bust}$ as the control variable, and include its interaction term with the FOMC days $1_{t,Bust} \times 1_{t,FOMC}$ to see if risks response to the announcement under recessions. In the second method, I divide the FOMC days into "Expansionary" days, "Contractionary" days, and "No Change" days according to how the Fed alter the target interest rate —increases, decreases or keeps the rate unchanged. In this regression, I also control the period effect but without the interaction terms $1_{t,Bust} \times 1_{t,Expand}$, $1_{t,Bust} \times 1_{t,Contract}$ and $1_{t,Bust} \times 1_{t,NoChange}$, because from the figures we can see that the expansionary monetary policy normally comes with the recessions, and $1_{t,Bust} \times 1_{t,Contract}$ equals zero. The difference between the two approaches is that the interaction term $1_{t,Bust} \times 1_{t,FOMC}$ combines some of the "Expansionary" and the "No Change" days together, focusing on the recession effect, while the latter method pays more attention to the specific monetary policies.

Results in Table 5 tell that the level of uncertainty risks do not specially response to the FOMC announcements during crashes. As for the decomposed FOMC days, the bond implied volatility is

Table 5. Uncertainty on the FOMC Days: Decomposed

	VIX_t	V_t^{2y}	V_t^{5y}	V_t^{10y}	V_t^{30y}
$1_{t,FOMC}$	-0.1047	-0.0606	-0.1339	-0.0862	-0.1610
	(0.6476)	(0.1190)	(0.2827)	(0.1129)	(0.2229)
$1_{t,Bust}$	**13.3896*** **	**2.8881*** **	**4.1609*** **	**2.3310*** **	**2.5763*** **
	(0.3331)	(0.0619)	(0.1454)	(0.0581)	(0.1146)
$1_{t,Bust} \times 1_{t,FOMC}$	1.3630	0.4268	-0.4272	0.0606	0.0753
	(1.6975)	(0.3197)	(0.7410)	(0.2960)	(0.5842)
Intercept	**18.0438*** **	**2.4551*** **	**5.1039*** **	**3.9066*** **	**6.8359*** **
	(0.1162)	(0.0213)	(0.0507)	(0.0203)	(0.0400)
R-squared	0.2629	0.3810	0.1508	0.2610	0.0995
	VIX_t	V_t^{2y}	V_t^{5y}	V_t^{10y}	V_t^{30y}
$1_{t,Expand}$	**3.0510** **	0.4929	**-2.2422*** **	-0.0334	-0.6591
	(1.5516)	(0.3497)	(0.6764)	(0.2705)	(0.5337)
$1_{t,Contract}$	**-3.6589*** **	-0.1141	**-1.7640*** **	**-0.8420*** **	**-1.6480*** **
	(1.3971)	(0.2458)	(0.6091)	(0.2435)	(0.4806)
$1_{t,NoChange}$	0.4468	-0.0386	**0.6601** **	0.1153	0.3558
	(0.7240)	(0.1309)	(0.3157)	(0.1262)	(0.2491)
$1_{t,Bust}$	**13.3445*** **	**2.8921*** **	**4.1969*** **	**2.3294*** **	**2.5882*** **
	(0.3290)	(0.0613)	(0.1434)	(0.0573)	(0.1132)
Intercept	**18.0493*** **	**2.4547*** **	**5.0995*** **	**3.9068*** **	**6.8345*** **
	(0.1159)	(0.0213)	(0.0505)	(0.0202)	(0.0399)
R-squared	0.2643	0.3809	0.1547	0.2628	0.1021

Note: In this table, the level of uncertainty risks are regressed on the decomposed FOMC days by two methods. The upper table examines if the level of risks on FOMC days are different under the recessions according to NBER US Business Cycle. The lower table decomposes the FOMC days into ”Contractionary”, ”Expansionary” and ”No Change” days according to how the Fed alters the target interest rate. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The unit for uncertainty is 1%. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

lower on the days with expansionary or contractionary policy changes, signaling the resolution of uncertainty. Stock uncertainty on the Expansionary days are still higher than usual, although the recession effect is controlled already. Regarding the skewness risks which don't react to the FOMC days, controlling the period effect and decomposing the days makes no difference so that I put the results in the Appendix Figure A-3 and Table A-2 to A-5. Besides monetary policy shocks, I also examine whether implied risks react to fundamental economic shocks. Apart from the other three risks, stock tail risk exhibits significant responses to the release of many economic indicators. I post the details in Appendix Table A-6 to A-7.

In summary, uncertainty risk on the FOMC days is indifferent from other days on average; Recessions don't affect the response of risk to the FOMC announcement, while the change in target interest rate in either directions resolve part of the uncertainty. Tail risks are not impacted by the FOMC announcements.

2.3 Risks Over the FOMC Cycle

Table 6. Uncertainty Change Around FOMC Announcement

	ΔVIX_t	ΔV_t^{2y}	ΔV_t^{5y}	ΔV_t^{10y}	ΔV_t^{30y}
Mean	-0.0023	-0.0007	0.0009	-0.0006	-0.0035
Std	1.6706	0.4681	0.5511	0.2999	0.5373

	ΔVIX_t	ΔV_t^{2y}	ΔV_t^{5y}	ΔV_t^{10y}	ΔV_t^{30y}
$1_{t,FOMCPre3}$	**0.2410***	0.0227	0.0428	**0.0467***	**0.1119****
	(0.1355)	(0.0442)	(0.0446)	(0.0242)	(0.0436)
$1_{t,FOMCPre2}$	**0.2756****	0.0221	**0.0921****	**0.1098*****	**0.1558*****
	(0.1355)	(0.0442)	(0.0446)	(0.0242)	(0.0436)
$1_{t,FOMC}$	**-0.5252*****	**-0.1678*****	**-0.2452*****	**-0.1593*****	**-0.2339*****
	(0.1359)	(0.0442)	(0.0446)	(0.0242)	(0.0435)
Intercept	-0.0021	0.0033	0.0046	-0.0005	-0.0046
	(0.0255)	(0.0083)	(0.0084)	(0.0046)	(0.0082)
R-squared	0.0042	0.0034	0.0070	0.0140	0.0099

Note: The upper table provides the mean and standard deviation of daily uncertainty change for stocks and bonds. The lower table illustrates how daily uncertainty changes around the FOMC announcement. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The unit of uncertainty is 1%. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Although bond implied risks on the FOMC days are not exceptional on average, as the VIX index rises in the 3 days preceding the FOMC meeting (Hu, Pan, Wang, and Zhu (2019)), and that uncertainty resolution is captured with monetary policy changes, I further investigate how the stock and bond implied risks move around the FOMC cycle to provide the whole picture about their dynamics. Targeting the FOMC days as the central date 0, I look into the average bond implied risks 15 trading days before and after, which represent the FOMC cycle with no overlap on the counted days, since 8 meetings are conducted every year, once one and a half month. As presented in Figure 1 and discussed in the introduction section, uncertainty risk accumulates one week before the announcement, jumps two days ahead, and falls on the FOMC days.

The movement of bond implied risks is supported by regressing the change of risks on the FOMC related days in Table 6, which manifests the notable difference: 3 Days before the FOMC meeting, uncertainty risk starts to rise; 2 Days preceding the FOMC announcement, stock, 5-,10-, and 30-year bond implied volatility upsurge by 0.28%, 0.09%, 0.11%, and 0.16% respectively. On the days upon announcement, implied volatility drops by 0.52%, 0.17%, 0.25%, 0.16%, and 0.23% on average, getting back to the normal levels. That implied volatility falls on the announcement day agrees with the insignificance of risks on the FOMC days, and the uncertainty resolution proposed by Bauer, Lakdawala, and Mueller (2019).

Moreover, I separate the FOMC days to investigate if the dramatic risk variations can be attributed to recessions or to any specific policy change. According to Table 7, the uncertainty resolution on the FOMC days universally persist: both the upper and lower tables manifest the decline of implied

Table 7. Uncertainty Change Around FOMC Announcement: Decomposed

	ΔVIX_t	ΔV_t^{2y}	ΔV_t^{5y}	ΔV_t^{10y}	ΔV_t^{30y}
$1_{t,FOMCPre3}$	0.1975	0.0412	0.0466	0.0530**	0.1462***
	(0.1466)	(0.0473)	(0.0482)	(0.0262)	(0.0472)
$1_{t,FOMCPre2}$	0.1615	-0.0017	0.0870*	0.0889***	0.1558***
	(0.1466)	(0.0473)	(0.0482)	(0.0262)	(0.0472)
$1_{t,FOMC}$	-0.5375***	-0.1818***	-0.1872***	-0.1366***	-0.2323***
	(0.1466)	(0.0475)	(0.0482)	(0.0262)	(0.0470)
$1_{t,Bust}$	-0.0460	0.0066	0.0395	0.0034	0.0178
	(0.0785)	(0.0259)	(0.0259)	(0.0140)	(0.0252)
$1_{t,Bust} \times 1_{t,FOMCPre3}$	0.3056	-0.1436	-0.0333	-0.0439	-0.2358*
	(0.3843)	(0.1319)	(0.1265)	(0.0686)	(0.1234)
$1_{t,Bust} \times 1_{t,FOMCPre2}$	0.7872**	0.1836	0.0278	0.1423**	-0.0029
	(0.3843)	(0.1319)	(0.1265)	(0.0686)	(0.1234)
$1_{t,Bust} \times 1_{t,FOMC}$	0.0938	0.1002	-0.4025***	-0.1558**	-0.0142
	(0.3914)	(0.1285)	(0.1265)	(0.0686)	(0.1233)
Intercept	0.0034	0.0025	-0.0001	-0.0009	-0.0067
	(0.0272)	(0.0088)	(0.0090)	(0.0049)	(0.0087)
R-squared	0.0044	0.0035	0.0085	0.0153	0.0098

	ΔVIX_t	ΔV_t^{2y}	ΔV_t^{5y}	ΔV_t^{10y}	ΔV_t^{30y}
$1_{t,ExpandPre3}$	0.1692	-0.1970	-0.0349	-0.0480	-0.0959
	(0.3514)	(0.1490)	(0.1157)	(0.0626)	(0.1126)
$1_{t,ExpandPre2}$	0.8461**	0.2247	0.2449**	0.3558***	0.3421***
	(0.3514)	(0.1420)	(0.1157)	(0.0626)	(0.1126)
$1_{t,Expand}$	-0.5493	-0.2166	-0.3253***	-0.2502***	-0.2839**
	(0.3590)	(0.1422)	(0.1157)	(0.0626)	(0.1126)
$1_{t,ContractPre3}$	0.1640	0.1269	-0.0239	0.0200	0.0575
	(0.3163)	(0.1000)	(0.1042)	(0.0564)	(0.1014)
$1_{t,ContractPre2}$	0.0568	-0.0113	0.1514	0.1034*	0.2095**
	(0.3163)	(0.1024)	(0.1042)	(0.0564)	(0.1014)
$1_{t,Contract}$	-0.3918	-0.1694*	-0.2570**	-0.1132**	-0.3571***
	(0.3163)	(0.1000)	(0.1042)	(0.0564)	(0.1014)
$1_{t,NoChangePre3}$	0.2776*	0.0213	0.0763	0.0743**	0.1716***
	(0.1640)	(0.0517)	(0.0540)	(0.0292)	(0.0528)
$1_{t,NoChangePre2}$	0.2102	0.0036	0.0424	0.0582**	0.1003*
	(0.1640)	(0.0517)	(0.0540)	(0.0292)	(0.0528)
$1_{t,NoChange}$	-0.5551***	-0.1614***	-0.2256***	-0.1517***	-0.1909***
	(0.1640)	(0.0520)	(0.0540)	(0.0292)	(0.0526)
$1_{t,Bust}$	-0.0145	0.0136	0.0238	-0.0005	0.0096
	(0.0758)	(0.0250)	(0.0250)	(0.0135)	(0.0243)
Intercept	-0.0004	0.0017	0.0017	-0.0004	-0.0057
	(0.0271)	(0.0088)	(0.0089)	(0.0048)	(0.0087)
R-squared	0.0035	0.0032	0.0068	0.0178	0.0109

Note: The table illustrates how daily uncertainty changes around the FOMC announcement by two decomposing methods. The upper table examines if the uncertainty change around the FOMC days is different under the recessions, according to NBER US Business Cycle. The lower table decomposes the FOMC days into ”Contractionary”, ”Expansionary” and ”No Change” days according to how the Fed alters the target interest rate. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The unit of uncertainty is 1%. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

volatility risk on FOMC days. Also, the recessions boost response of risks to some degree: During the ”Bust” periods, uncertainty jumps and drops more than ordinary days. Similarly, around the expansionary policy change, the stock and bond implied volatility surge higher and drop deeper.

Combined with the previous regressions, the magnitude of implied volatility on FOMC announcemnet days are on average not different from other days, but days when the Fed make policy changes can witness the significant resolution in uncertainty. The implied volatility risk jumps 2 days before and drops back on the announcement days, the extent of which is the most under recessions or if a reduction in the target interest rate comes.

I further verify this argument through the risk dynamics over the FOMC cycle, by rearranging the time series data into different groups denoting their position relative to the FOMC announcement days. Then I regress each group on whether it's under economic recessions and also whether it's around expansionary or contractionary monetary policy, so that the coefficients reflect the different responses compared to other FOMC days only. I put the results in Appendix Table A-8 and A-9, which are robust and reinforce the above statements.

3 Return Around the FOMC Announcement

3.1 Bond Pre-FOMC Announcement Drift

The influential paper by Lucca and Moench (2015) uncovers the pre-announcement drift in the stock markets but not bonds, while monetary policy targets the interest rate. Puzzled by the ill-matched responses, I revisit the pre-FOMC announcement drift for stocks and bonds. I gather the daily stock returns from CRSP S&P500 value-weighted portfolio and the bond yield changes from Treasury yield curve, analogous to the S&P500 index return and Treasury yield change Lucca and Moench (2015) use, except that they work on the intraday data instead of the daily ones. Accordingly, we define the ”pre-announcement” time differently: They confine to the 24-hour interval ahead of 2 pm, the time for the FOMC announcement, while I utilize the simple 1-day change.

Figure 2 provides the average accumulated stock return and bond yield change starting from 15 trading days before the FOMC meeting. We can see that S&P500 stock return enlarges on the FOMC days, seemingly contradictory to the pre-drift argument. A closer look into the most cited figure in their paper, one can notice that the pre-drift takes place mostly on the announcement days, just before 2 pm. Therefore, the more than 25 bps' surge of stock return on FOMC days is equivalent to their pre-announcement drift. Since I study a more recent period (2000-2018) compared to the original paper (1994-2013), the size of the drift is different from theirs (49 bps). My result is more comparable to what Hu, Pan, Wang, and Zhu (2019) obtain (27bps) from the year 1994 to 2018.

Unexpectedly, the pre-announcement drift also exists in bonds: The 3-month Treasury yield falls on the FOMC days, and the 5-,10-, and 30-year bond yields go down one day earlier, as manifested in Figure 2. 3 Days after, bond yields have a significant restoration. And then they followed the downward trend to decline further. In Table 8, I regress the daily stock returns and bond yield change R_t specifying whether it is around the FOMC meetings. On the announcement days, stock collects 27 bps of return, and the 3-month yield shrinks by 2 bps. One day before the meeting, the 5, 10, and

30-year yields decline around 1 bp. The rebound of bond yields 3 days after is most notable for the 3-month, 2-year, and 5-year interest rates, but the coefficients for the 10-year and 30-year bond are also positive. The different conclusions regarding the bond pre-announcement drift may attribute to how we define the pre-announcement period. Bonds may react even earlier than stocks so that the simple end-of-day yield change catches the movement better than the 24-hour interval.

Table 8. Pre-FOMC Announcement Drift in Stock and Bond

	R_t^{stock}	R_t^{3m}	R_t^{2y}	R_t^{5y}	R_t^{10y}	R_t^{30y}
Mean	1.6691	-0.0517	-0.0702	-0.0730	-0.0747	-0.0694
Std	119.5645	4.8450	5.1577	6.0151	5.7784	5.3426
	R_t^{stock}	R_t^{3m}	R_t^{2y}	R_t^{5y}	R_t^{10y}	R_t^{30y}
$1_{t,FOMCPre1}$	4.4201	-0.0352	-0.4082	__-0.9924**__	__-0.9193*__	__-1.0595**__
	(9.7110)	(0.3915)	(0.4188)	(0.4884)	(0.4694)	(0.4865)
$1_{t,FOMC}$	__26.5385***__	__-2.0734***__	-0.6247	-0.5211	-0.2123	0.0125
	(9.7110)	(0.3915)	(0.4188)	(0.4884)	(0.4694)	(0.4865)
$1_{t,FOMCPost3}$	5.6412	__1.9963***__	__1.0122**__	__1.0776**__	0.7367	0.3005
	(9.7110)	(0.3928)	(0.4188)	(0.4884)	(0.4694)	(0.4865)
Intercept	0.4581	-0.0476	-0.0695	-0.0585	-0.0616	-0.0445
	(1.8280)	(0.0738)	(0.0789)	(0.0920)	(0.0884)	(0.0920)
R-squared	0.0010	0.0110	0.0013	0.0016	0.0008	0.0006
	$R_{t,t+1}^{stock}$	$R_{t,t+1}^{3m}$	$R_{t,t+1}^{2y}$	$R_{t,t+1}^{5y}$	$R_{t,t+1}^{10y}$	$R_{t,t+1}^{30y}$
$1_{t,FOMCPre1}$	__29.1537**__	__-2.1715***__	__-1.0696*__	__-1.5396**__	__-1.1455*__	-1.0327
	(13.1915)	(0.5948)	(0.5844)	(0.6872)	(0.6611)	(0.6836)
Intercept	2.2711	-0.0324	-0.1023	-0.0910	-0.1093	-0.1033
	(2.3998)	(0.1084)	(0.1064)	(0.1251)	(0.1203)	(0.1249)
R-squared	0.0008	0.0026	0.0005	0.0008	0.0004	0.0003

Note: The top table provides the mean and standard deviation of daily stock return and bond yield change. The following table regresses daily changes on dummy variables denoting the FOMC days. To capture the pre-FOMC announcement drift at the same time, 2-day rolling returns $R_{t,t+1}$ are extracted by $R_{t,t+1}^{stock} = (1 + R_t^{stock}) \times (1 + R_{t+1}^{stock}) - 1$ and $R_{t,t+1}^{bond} = R_t^{bond} + R_{t+1}^{bond}$ for stock and bonds respectively. Stock return is from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. The unit is bp. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

To capture both the stock and bond pre-announcement drift at the same time since they locate on different days, I transform the daily drift to the rolling 2-day returns $R_{t,t+1}$, where $R_{t,t+1}^{stock} = (1 + R_t^{stock}) \times (1 + R_{t+1}^{stock}) - 1$ and $R_{t,t+1}^{bond} = R_t^{bond} + R_{t+1}^{bond}$. The lower table in 8 shows that this method successfully merges the pre-drift: 1 day earlier and on the day of the FOMC announcement, stock return enlarges 29 bps more than other days, and bond yields lessen 2.2 bps, 1.0 bps, 1.5 bps, 1.1 bps, and 1 bp respectively.

When dividing the FOMC days further, we could see in Table 9 that most of the pre-announcement return are obtained during the financial crisis, since the coefficients before $1_{t,FOMCPre1}$ become insignificant and all the drifts move to the interaction terms. More specifically, the stock index accumulates 97 bps pre-announcement return during the Bust time, and the bond yields decrease 10,

Table 9. Pre-FOMC Annoucement Drift in Stock and Bond: Decomposed

	$R^{stock}_{t,t+1}$	$R^{3m}_{t,t+1}$	$R^{2y}_{t,t+1}$	$R^{5y}_{t,t+1}$	$R^{10y}_{t,t+1}$	$R^{30y}_{t,t+1}$
$1_{t,Bust}$	**-28.2461*****	**-1.5943*****	**-0.8038****	-0.0943	0.1184	0.1667
	(7.3289)	(0.3311)	(0.3248)	(0.3824)	(0.3680)	(0.3460)
$1_{t,FOMCPre1}$	15.6793	-0.7336	-0.4806	-1.0250	-0.8912	-0.9298
	(14.2476)	(0.6390)	(0.6315)	(0.7434)	(0.7154)	(0.7565)
$1_{t,Bust} \times 1_{t,FOMCPre1}$	**96.7687*****	**-9.5267*****	**-3.8851****	**-3.4968***	-1.7556	-0.5861
	(37.3465)	(1.6754)	(1.6552)	(1.9485)	(1.8751)	(1.7690)
Intercept	**5.7071****	0.1590	-0.0045	-0.0795	-0.1237	-0.1290
	(2.5562)	(0.1147)	(0.1133)	(0.1334)	(0.1284)	(0.1358)
R-squared	0.0043	0.0165	0.0031	0.0012	0.0002	-0.0001

	$R^{stock}_{t,t+1}$	$R^{3m}_{t,t+1}$	$R^{2y}_{t,t+1}$	$R^{5y}_{t,t+1}$	$R^{10y}_{t,t+1}$	$R^{30y}_{t,t+1}$
$1_{t,ExpandPre1}$	**69.7917****	**-10.3249*****	**-2.9966****	-2.1845	-0.1219	-0.7401
	(34.1922)	(1.5325)	(1.5146)	(1.7831)	(1.7158)	(1.6582)
$1_{t,ContractPre1}$	30.8810	0.3972	1.6370	0.8521	-0.4592	-1.6617
	(30.7882)	(1.3798)	(1.3638)	(1.6056)	(1.5450)	(2.0135)
$1_{t,NoChangePre1}$	20.8239	-1.0134	**-1.3340***	**-2.0240****	**-1.5497***	-1.0086
	(15.9555)	(0.7150)	(0.7068)	(0.8321)	(0.8007)	(0.8026)
$1_{t,Bust}$	**-25.6520*****	**-1.7209*****	**-0.8883*****	-0.2019	0.0241	0.1342
	(7.2496)	(0.3272)	(0.3211)	(0.3781)	(0.3638)	(0.3423)
Intercept	**5.3916****	0.1742	0.0058	-0.0664	-0.1123	-0.1240
	(2.5543)	(0.1145)	(0.1132)	(0.1333)	(0.1282)	(0.1356)
R-squared	0.0030	0.0168	0.0030	0.0009	-0.0000	-0.0004

Note: The upper table is designed to see if the pre-FOMC announcement drift is related to recessions. In the lower table, FOMC days are divided into ”Expansionary”, ”Contractionary” and ”No Change” Days to investigate the relationship between the drift and specific monetary policy change. The 2-day rolling returns $R_{t,t+1}$ are extracted by $R^{stock}_{t,t+1} = (1 + R^{stock}_t) \times (1 + R^{stock}_{t+1}) - 1$ and $R^{bond}_{t,t+1} = R^{bond}_t + R^{bond}_{t+1}$ for stock and bonds respectively. Stock return is from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. The unit is bp. Data runs from 2000 to 2018.
Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

4, 3, 2 and 1 bp accordingly. As the crashes are often accompanied with expansionary policy changes, we can also discover similar pattern that the pre-FOMC announcement drifts for stock and bonds are most significant with the cut in interest rate. Days when the Fed keeps the target unchanged are accompanied with significant 2-year, 5-year and 10-year bond yield decline before the FOMC meeting.

3.2 Bond Monetary Momentum

What presented in Figure 2 is related to the recent paper by Neuhierl and Weber (2018), who document that the stock market return continues to grow after the FOMC announcement, and call it “monetary momentum”. Here, my result is consistent with theirs, and I also add bond yields into consideration, which keep decreasing after the FOMC announcement. Besides the downward trend, bond yields shift up 3 days after the meeting, the up-bound unobserved for the stock index.

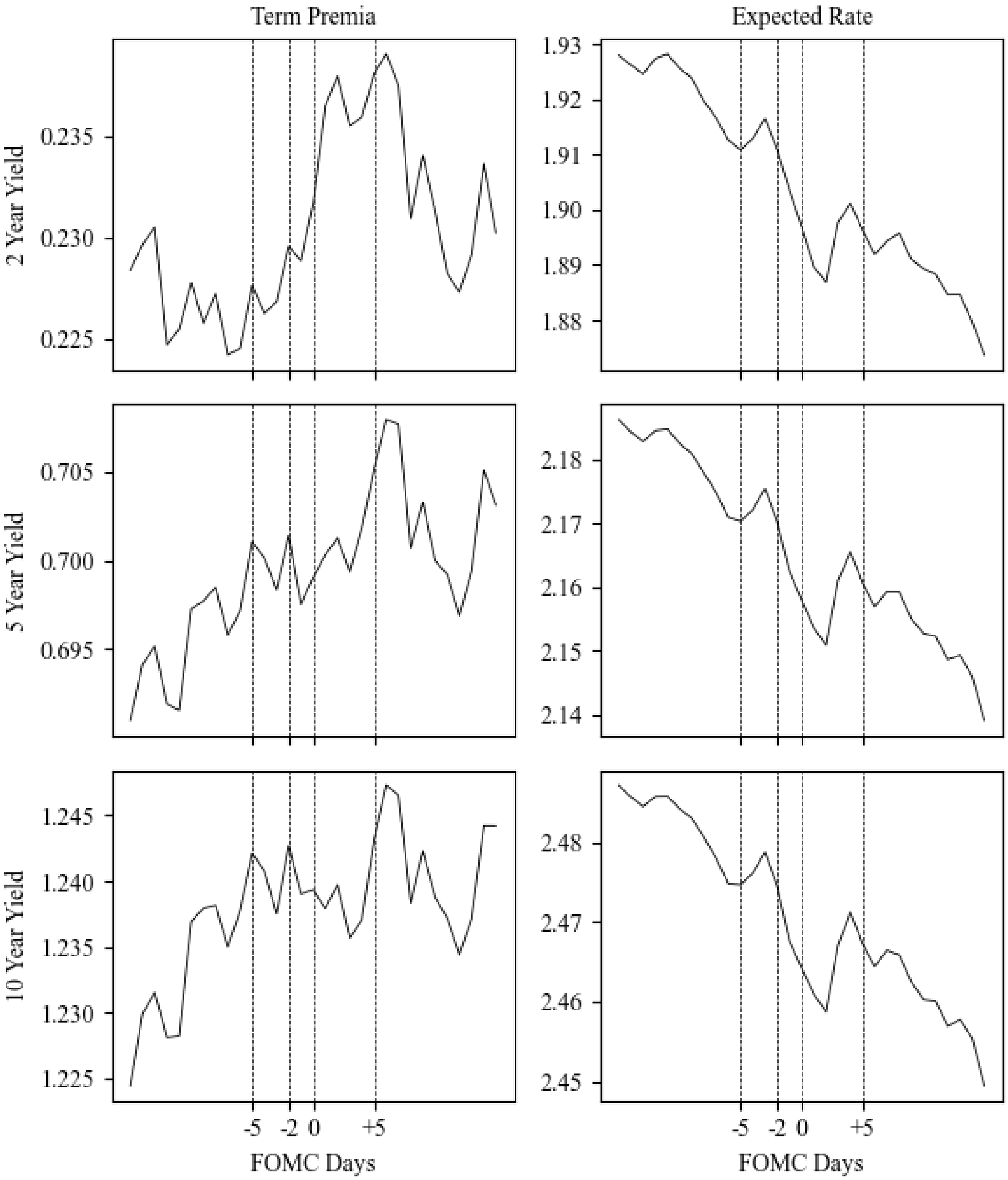

Figure 6. Term Premia and Expected Return Over FOMC Cycle

Note: These figures decompose the 2-year, 5-year and 10-year bond yield changes into the term premia and expected rate by Adrian, Crump, and Moench (2013) to see their dynamics over the FOMC cycle, i.e., 15 trading days before and after the announcement. The data is available from New York Fed webpage. The unit of bond yield is 1%. Data runs from 2000 to 2018.

According to Adrian, Crump, and Moench (2013), bond yields can be decomposed into two parts: the expected rate and the term premia, so that I download the data from New York Fed to see their corresponding dynamics over the FOMC cycle, investigating which part the FOMC announcement alters. From the Figure 6, it's the expected rate that mainly decides the movement of the bond yields.

Moreover, after subtracting the term premia from the bond yields, the patterns for 2-year, 5-year and 10-year expected rate looks extremely similar: they basically decrease the same amount over the FOMC cycle by around 5 bps. Compared with the Figure 2, the differenr response of bond yields attributes to the their increased term premia around the FOMC cycle, which is higher with longer maturities.

Moreover, they discover that the stock return drifts upwards with expansionary monetary surprises and downwards on other FOMC days, where the surprise measure is the 30-minute window price change of the 30-day Fed Fund futures around the announcement. As I replicate their results and also extend to bonds with the daily and 1-hour monetary policy surprise,[6] as well as the actual monetary policy change, the results are similar to what they get. Monetary policy change and monetary policy surprise produce the opposite effect: Days with actual expansionary policy lead to the negative accumulated stock return and 10-year bond yield change, while expansionary surprises are driving up the drifts. Readers can find the pattern in the Appendix Table A-1.

In this paper, I focus on the actual monetary policy change instead of the surprise measure for the following reasons. Firstly, the shock measure could easily change signs when different approaches are adopted. I summarize the existing measures for monetary policy surprises in Appendix A.4, and demonstrate how they provide different results for the same day. Whether it's an expansionary or contractionary surprise could easily be switched just because a different window is chosen. Secondly, the monetary surprises even on a daily basis may be attributed to the reversal trading behavior. For example, as investors expect an expansionary policy to come, the prices may already move ahead. After the announcement, some reversed trading may be followed, so that the actual change and surprise offer the opposite trend. Thirdly, my main focus of this paper is the pre-announcement drift. As the shock occurs after, it's not related. And finally, the bond yield drop is more consistent with the expansionary policy change as the Fed decreases the target rate.

Figure 7 provides an overall assessment about how the bond yields change around the monetary policy changes. Days around an expansionary monetary policy have witnessed the drop in yields, the magnitude of which becomes smaller as the maturity extends. The 3-month Treasury yield decreases by 50 bps over the FOMC cycle, followed by 35 bps, 20 bps, 10 bps, and 8 bps for longer-term bonds. Also, a noticeable bounce back happens in the week after the announcement, and the relative level of the rally becomes stronger with longer tenors. For example, there is a moderate increase for the 5-year yield. However, the upsurge is more magnificent for the 10-year and 30-year bonds. To the contrary, Days with a contractionary monetary policy are accompanied by the increase in stock return and bond yields, the change of which is less prominent than what the cut in interest rate can cause. Similarly, despite the upward movement, the bond yields also modify after the announcement, and the reversal becomes more noticeable with longer maturity bonds.

As shown in Table 10, the cumulative stock return and the short-term bond yield around the expansionary monetary policy become significantly lower than other FOMC days 2 weeks before the

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[6] The reason to choose the daily and the 1-hour future price change instead of the 30-min window is the data availability. Without access to the tick data from CME which the authors obtain, I extract the data from Thomson Reuters DataScope, but their high-frequency trading dataset for 30-day Treasury future price is not ample, resulting in a lot of NaNs if I use the 30-min window. So I proceed with 1-hour and daily change.

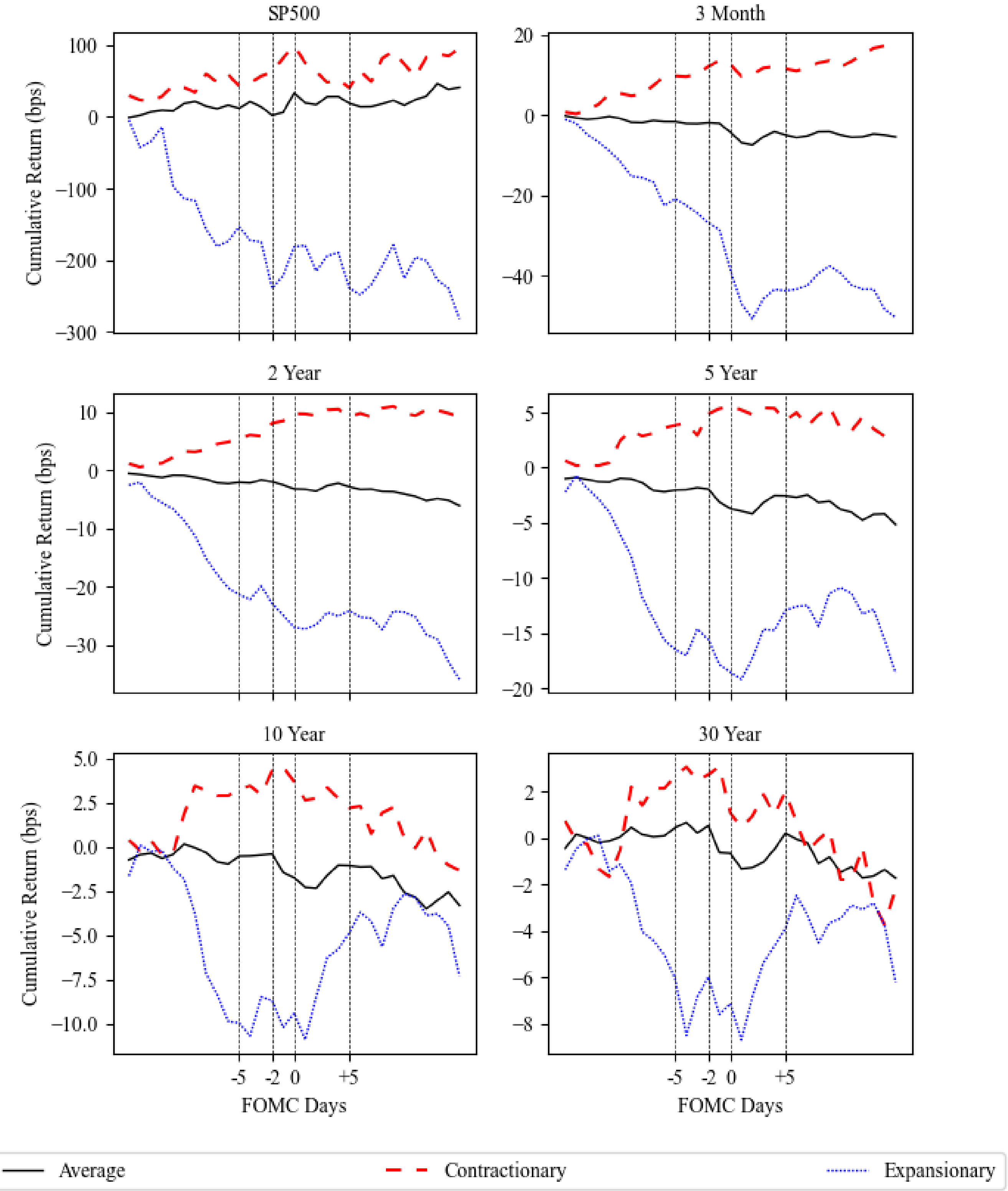


Figure 7. Bond Monetary Momentum: Decomposed by Monetary Policy Change

Note: These figure presents the diverging movement of cumulative bond yields with monetary policy change. The solid black line represents the average level; The blue dotted line provides the yield change around expansionary monetary policy; The red dash line denotes contractionary policy change. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. Data runs from 2000 to 2018.

announcement, by 215 bps, 9 bps and 6 bps for stock, 3-month and 2-year bond respectively. This disparity enlarges further into the FOMC announcement until 3 weeks after, to reach 437 bps, 42 bps and 24 bps in the end. As the maturity lengthens, the yield drop is less notable. The yields of the 5-year, 10-year, and 30-year bonds are only 14 bps, 10 bps, and 7 bps lower than other FOMC days, shown in Table 11. Also, because of the rebound, cumulative changes of the long-term bond yields on Expansionary days are not distinctive from other FOMC days. On Contractionary days, the 3-month and 2-year bond yield increase significantly through the FOMC cycle, to the largest 14 bps of the positive yield change.

Table 10. Cumulative Return Over FOMC Cycle: Stock and Short Term Bond

Stock	Pre15	Pre10	Pre5	Pre1	FOMC	Post1	Post5	Post10	Post15
1_{Expand}	-9.8717	**-214.9670*** **	**-251.5294*** **	**-318.8184*** **	**-304.3030*** **	**-289.6418** **	**-356.7478*** **	**-323.7747** **	**-436.5160*** **
	(31.3489)	(66.7877)	(82.3929)	(97.9273)	(103.1977)	(112.2070)	(118.4200)	(131.2210)	(147.2544)
$1_{Contract}$	44.4780	1.0913	5.0558	48.0968	38.3129	28.8675	-29.5914	9.4672	-6.3221
	(28.9578)	(61.6934)	(76.1083)	(90.4579)	(95.3263)	(103.6484)	(109.3875)	(122.9748)	(138.0007)
Intercept	-15.1544	39.4139	37.5216	33.6718	60.2431	45.8302	66.7415	52.6095	89.8558
	(13.2371)	(28.2011)	(34.7903)	(41.3498)	(43.5752)	(47.3793)	(50.0028)	(55.4080)	(62.1781)
R-squared	0.0048	0.0533	0.0474	0.0602	0.0469	0.0328	0.0440	0.0276	0.0436
3 Month									
1_{Expand}	-0.3823	**-8.9303*** **	**-17.5943*** **	**-22.9856*** **	**-32.4180*** **	**-39.5997*** **	**-37.9729*** **	**-32.4779*** **	**-41.9139*** **
	(1.8482)	(2.0035)	(2.9595)	(3.3791)	(3.7604)	(5.0313)	(3.9975)	(5.1328)	(4.7664)
$1_{Contract}$	0.9407	**5.5061*** **	**10.1199*** **	**13.9771*** **	**13.7466*** **	**11.8336** **	**12.2150*** **	**14.1904*** **	19.0571***
	(1.7072)	(1.8506)	(2.7337)	(3.1213)	(3.4736)	(4.6476)	(3.6926)	(4.8103)	(4.4674)
Intercept	-0.2264	-0.1132	-0.4057	-0.4057	-1.1038	-2.2264	-0.6792	-1.7830	-1.3905
	(0.7804)	(0.8460)	(1.2496)	(1.4268)	(1.5878)	(2.1245)	(1.6879)	(2.1673)	(2.0205)
R-squared	-0.0103	0.1753	0.2702	0.3365	0.4026	0.3308	0.4258	0.2652	0.4213
2 Year									
1_{Expand}	-1.6645	**-5.7301* **	**-18.6272*** **	**-19.3450*** **	**-20.5263*** **	**-20.7588*** **	**-17.7322*** **	**-16.0591*** **	**-24.1081*** **
	(1.2314)	(3.0642)	(3.8165)	(4.5110)	(4.4598)	(4.7497)	(4.8018)	(5.9790)	(6.0476)
$1_{Contract}$	1.6523	3.5121	5.2284	**8.9811** **	**11.1368*** **	**11.1294** **	**10.4899** **	**14.6157*** **	**14.1608** **
	(1.1375)	(2.8305)	(3.5254)	(4.1669)	(4.1197)	(4.3875)	(4.4355)	(5.6033)	(5.6683)
Intercept	-0.5094	-0.2264	0.2358	-0.4811	-1.3868	-1.4151	-1.3113	-3.2453	-3.4571
	(0.5200)	(1.2939)	(1.6115)	(1.9048)	(1.8832)	(2.0056)	(2.0276)	(2.5246)	(2.5636)
R-squared	0.0181	0.0260	0.1518	0.1411	0.1728	0.1566	0.1210	0.0899	0.1394

Note: This table regresses the stock and short-term bond (3-month and 2-year) cumulative return and yield change starting from 15 days beforehand to 15 days after the FOMC announcement, on whether it's related to the expansionary/contractionary monetary policy. The intercept represents the average level of cumulative return on days with no change in target interest rate. Cumulative stock returns are calculated from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table 11. Cumulative Return Over FOMC Cycle: Longer Term Bonds

5 Year	Pre15	Pre10	Pre5	Pre1	FOMC	Post1	Post5	Post10	Post15
1_{Expand}	-0.7543	-3.3659	**-14.0968*** **	**-12.2777** **	**-12.2092** **	**-12.7482** **	-7.4212	-3.3306	-8.7776
	(1.4099)	(3.5390)	(4.1976)	(4.8683)	(5.1308)	(5.4932)	(5.4117)	(6.3948)	(6.5970)
$1_{Contract}$	1.5640	2.8329	3.7075	7.1105	8.0889*	7.6664	5.6611	8.5535	7.2868
	(1.3024)	(3.2690)	(3.8775)	(4.4970)	(4.7394)	(5.0742)	(4.9990)	(5.9930)	(6.1831)
Intercept	**-1.0283** *	-0.5472	-0.2075	-1.8962	-2.6604	-2.7736	-1.8396	-3.8868	-3.6571
	(0.5953)	(1.4943)	(1.7725)	(2.0556)	(2.1665)	(2.3195)	(2.2851)	(2.7002)	(2.7964)
R-squared	0.0003	0.0003	0.0712	0.0534	0.0519	0.0451	0.0121	0.0044	0.0122
10 Year									
1_{Expand}	-0.6591	-0.7592	**-9.5390** **	-7.5025	-6.3084	-7.6415	-2.0886	2.2609	-1.0605
	(1.3337)	(3.3196)	(4.0096)	(4.6513)	(5.0284)	(5.6057)	(5.5363)	(6.1256)	(6.3234)
$1_{Contract}$	0.9387	1.0964	1.9704	4.6590	4.2055	3.5013	1.9394	4.2963	2.4677
	(1.2320)	(3.0664)	(3.7038)	(4.2965)	(4.6449)	(5.1782)	(5.1140)	(5.7406)	(5.9267)
Intercept	-0.6887	0.3679	0.8868	-0.8019	-1.1698	-1.3585	-0.8679	-3.0000	-2.5048
	(0.5632)	(1.4017)	(1.6930)	(1.9640)	(2.1232)	(2.3670)	(2.3377)	(2.5865)	(2.6804)
R-squared	-0.0064	-0.0115	0.0291	0.0165	0.0060	0.0049	-0.0107	-0.0090	-0.0116
30 Year									
1_{Expand}	-0.9159	-1.2190	**-7.4556** **	**-7.8048** *	-7.5063	-8.6111	-4.6460	-2.3508	-4.1829
	(1.2752)	(2.8953)	(3.5990)	(4.4556)	(4.8605)	(5.5471)	(5.5072)	(5.9031)	(6.1866)
$1_{Contract}$	1.1079	-1.1714	1.0683	2.7190	0.3984	0.2222	1.0206	0.8159	-0.0162
	(1.5117)	(3.4324)	(4.2667)	(5.2821)	(5.7621)	(6.5761)	(6.5288)	(6.9981)	(7.3297)
Intercept	-0.3222	0.6000	1.7889	0.5667	0.7444	0.2778	1.1222	-0.7444	-0.3409
	(0.5546)	(1.2594)	(1.5654)	(1.9380)	(2.1141)	(2.4128)	(2.3954)	(2.5676)	(2.7155)
R-squared	-0.0061	-0.0143	0.0208	0.0136	0.0039	0.0039	-0.0098	-0.0148	-0.0127

Note: This table regresses long term bond (5-, 10- and 30-year) yield change starting from 15 days beforehand to 15 days after the FOMC announcement, on whether it's related to the expansionary/contractionary monetary policy. The intercept represents the average level of return on days with no change in target interest rate. Cumulative stock returns are calculated from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

4 Risk Return Relationship for the Pre-FOMC Announcement Drift

4.1 Premium for Heightened Uncertainty

Many researchers are exploring the reasons for the pre-announcemnt drift. They're divided by two channels: information leaking, and uncertainty. As for the uncertainty channel, Hu, Pan, Wang, and Zhu (2019) discover that the VIX index increases in the 3 days before the announcements, followed by the pre-FOMC stock return. Therefore, they propose the premium for the heightened uncertainty and extend this phenomenon to any day with a sharp increment in uncertainty risk. In their paper, they select the heightened uncertainty days by the cutoff, indicating that risk today is higher than the previous average by a certain benchmark. Results reveal that those days are followed by a significant stock return.

I implement this approach to the bond implied risks and yield changes, and days with risk reduction are also checked. Here, the positive cutoff implies that risks on these days are greater than the previous exponential moving average μ_{t-1} by the cutoff rate (Equation 9), and the negative cutoff indicates that the magnitude of the risk drop is larger than the threshold (Equation 10). η In μ_{t-1} is the decay factor. When $\eta = 0$, μ_{t-1} is set to be the previous risk $Risk_{t-1}$, so the left hand side converts to the daily change (see formula 12). As the implied skewness is negative most of the time, the enlargement in tail risk associates with the negative cutoff. The cutoff unit is 1% for volatility and 1 for skewness. I calculated the average number of days in one year within the range of highlighted risks and their next-day average return, with t-statistics comparing the mean to the ordinary days.

$$Risk_t - \mu_{t-1} > +cutoff \tag{9}$$

$$Risk_t - \mu_{t-1} < -cutoff \tag{10}$$

$$\mu_{t-1} = (1-\eta) \sum_{\tau=0}^{\tau=t-1} \eta^{\tau} VIX_{t-\tau-1} \tag{11}$$

$$Risk_t - Risk_{t-1} = \Delta Risk_t > +cutoff(< -cutoff), \text{Where } \eta = 0, \mu_{t-1} = Risk_{t-1} \tag{12}$$

After checking the consistency with Hu, Pan, Wang, and Zhu (2019)'s paper for the stock market, I show in Table 12 that heightened increment in 10-year uncertainty is joined by the next-day lift in yield, and heightened risk reduction depresses the yield so that not only the rise matters. I put the robust results for stock, 2-, 5-, and 30-year risks in Appendix Table A-10 to A-13. Stock and bond heightened tail risk are not triggering distinctive stock return or bond yield adjustment.

However, the highlighted uncertainty premium is not adequate to explain the pre-FOMC announcement drift. First of all, the surge of implied volatility is followed by the upward drift for both stocks and bonds. However, the bond yields fall before the announcement instead of rising. Therefore, the uncertainty rise cannot be utilized to explain the bond pre-drift due to the opposite sign. Secondly, the uncertainty surging preceding the FOMC meetings is not large enough to be ”heightened.” Hu, Pan, Wang, and Zhu (2019) document the average 0.22% growth of VIX before

Table 12. 10-Year Bond Yield Change After Heightened Risk Days

Cutoff Vol (%)	N Days (/year)	Return (bps)	T-stat	N Days (/year)	Return (bps)	T-stat	N Days (/year)	Return (bps)	T-stat
	$\eta = 0$			$\eta = 0.15$			$\eta = 0.30$		
+0.7	4.5	0.98	1.70	4.5	0.53	0.97	5.1	**1.72**	3.07
+0.6	6.8	0.41	0.96	6.7	**1.20**	2.54	7.4	**1.30**	2.86
+0.5	10.9	0.57	1.64	11.2	**1.15**	3.16	11.1	**1.01**	2.80
+0.4	17.6	0.20	0.89	17.6	**0.62**	2.28	16.7	**0.77**	2.68
+0.3	28.2	0.20	1.20	28.5	0.34	1.78	27.8	**0.40**	2.00
+0.2	46.8	0.12	1.14	46.5	**0.31**	2.21	45.4	**0.58**	3.66
+0.1	73.3	0.12	1.51	73.3	**0.18**	1.96	74.1	0.15	1.73
+0	116.6	0.08	1.75	115.4	**0.15**	2.43	115.7	**0.14**	2.34
-0	132.3	-0.22	1.78	134.1	**-0.26**	2.43	133.8	**-0.26**	2.34
-0.1	81.7	**-0.32**	2.03	82.0	**-0.33**	2.17	82.7	**-0.42**	2.86
-0.2	47.4	-0.33	1.45	46.1	**-0.46**	2.16	47.1	**-0.52**	2.55
-0.3	26.8	-0.52	1.82	25.7	-0.55	1.91	25.6	**-0.63**	2.25
-0.4	15.4	**-0.88**	2.46	14.3	**-0.92**	2.47	13.6	**-1.05**	2.80
-0.5	8.8	-0.9	1.89	8.7	**-1.04**	2.18	8.2	**-0.97**	1.96
-0.6	5.9	**-1.21**	2.10	5.9	-0.99	1.70	5.6	-0.27	0.35
-0.7	3.4	-0.19	0.16	3.2	-0.92	1.14	3.5	-0.4	0.46

Cutoff Skew	N Days (/year)	Return (bps)	T-stat	N Days (/year)	Return (bps)	T-stat	N Days (/year)	Return (bps)	T-stat
	$\eta = 0$			$\eta = 0.15$			$\eta = 0.30$		
+5.0	4.2	-0.42	0.54	2.3	-0.32	0.28	2.2	-0.52	0.51
+4.0	5.6	-0.27	0.35	3.7	-0.55	0.69	3.5	-0.32	0.34
+3.0	7.9	-0.47	0.85	5.6	-0.77	1.26	5.2	-0.44	0.63
+2.0	14.1	-0.35	0.80	11.1	-0.13	0.15	10.8	0.1	0.44
+1.5	20.6	-0.38	1.10	17.3	-0.39	1.03	17.5	-0.39	1.02
+1.0	35.7	-0.17	0.44	31.5	-0.05	0.13	30.4	-0.07	0.02
+0.5	62.4	0.02	0.65	59.5	0.03	0.72	60.1	0.01	0.56
+0	117.6	-0.02	0.6	115.7	0.03	1.11	117.4	0.03	1.13
-0	126.8	-0.12	0.58	122.4	-0.16	0.94	120.7	-0.16	0.96
-0.5	67.3	-0.18	0.75	62.9	-0.16	0.58	61.2	-0.22	1.02
-1.0	35.1	-0.32	1.17	30.6	-0.35	1.22	30.5	-0.35	1.22
-1.5	19.5	-0.36	0.99	16.4	-0.3	0.71	16.9	-0.36	0.91
-2.0	12.5	-0.21	0.36	9.6	-0.03	0.1	10.2	-0.22	0.36
-3.0	6.9	-0.09	0.03	4.5	0.73	1.31	4.4	0.29	0.58
-4.0	4.8	-0.17	0.17	3.1	0.67	0.99	2.8	0.48	0.71
-5.0	3.7	0.03	0.15	1.9	0.16	0.25	2.0	0.03	0.11

Note: This table presents the 10-year bond yield change after heightened risk days, which are determined by Equation (9) and (10), so that risk is higher than the previous exponential moving average μ_{t-1} (Equation (11)) by the cutoff bar. ”N Days” represents how many days in one year on average belong to the heightened risk days. ”Return” gives the next-day bond yield change. ”T-stat” compares the mean of yield change to ordinary days. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. Data runs from 2000 to 2018.

Table 13. Distribution of Pre-FOMC Uncertainty Change and Drift

Cutoff VIX(%)	N Days (/year)	Return (bps)	T-stat	Cutoff V^{5y}(%)	N Days (/year)	Return (bps)	T-stat
+1.00	1.8	7.87	0.16	+0.40	1.4	-0.96	0.49
+0.75	2.5	26.49	0.99	+0.30	1.9	-0.72	0.41
+0.50	3.0	29.25	1.21	+0.20	2.6	-1.02	0.73
+0.25	3.6	33.86	1.57	+0.10	3.5	-1.14	0.96
+0	4.7	35.44	1.89	+0	4.5	-1.40	1.38
V^{10y}(%)				V^{30y}(%)			
+0.40	1.0	2.26	1.29	+0.60	1.3	-2.29	1.44
+0.30	1.7	-1.34	0.83	+0.45	1.7	-1.57	1.08
+0.20	2.2	-2.6	1.96	+0.30	2.2	-2.39	1.95
+0.10	3.4	-1.48	1.32	+0.15	3.1	-2.02	1.94
+0	4.5	-1.22	1.23	+0	4.7	-1.45	1.66

Note: This table provides the distribution of uncertainty increase 2 days before the FOMC announcement, and their corresponding pre-FOMC announcement drift. There are total 157 FOMC meetings from 2000 to 2018, 8 meetings per year. ”N Days” presents how many FOMC meetings are preceded with certain level of uncertainty increase.

FOMC meetings, and my corresponding number is 0.28%, both of which hardly qualify for the most relaxed cutoff bar. The average volatility increments for the 5-year, 10-year, and 30-year bonds are 0.09%, 0.11%, and 0.16%, falling into the loosest threshold and predicting insignificant next-day return.

Although the average uncertainty changes before the FOMC meeting are moderate, there could be days with extreme upsurge, leading to significant next-day return. Therefore, I summaries the distribution of uncertainty increase 2 days before the meeting and their followed pre-announcement drift in Table 13. We could see that on average only 2 days out of 8 FOMC meetings are with “heightened” risks. Also, they’re followed by negative bond yield change, consistent with the pre-announcement drift, but contrary to the heightened uncertainty premium hypothesis. Therefore, although the hypothesis works for general cases, it cannot be used to explain the drift prior to the FOMC announcement.

4.2 Uncertainty Effect on Monetary Policy Transmission

Even though the heightened uncertainty premium is inadequate to explain the pre-FOMC announcement drift, it is still possible that risk variation can predict the next-day return. Moreover, instead of investigating the direct risk-return relationship, Bauer, Lakdawala, and Mueller (2019), De Pooter, Favara, Modugno, and Wu (2020) and Tillmann (2017) use their constructed monetary policy uncertainty measure to research its role in policy transmission, namely the yield curve response to the monetary policy surprise, which is obtained from the short-term interest rate (Federal Fund rate or Eurodollar) future price change around the announcement, either in the 30-min window or the daily change. In their regressions, the response of bond yields is regressed on the level of

Table 14. Pre-FOMC Risk-Return Relationship

	$R^{stock}_{t,t+1}$	$R^{2y}_{t,t+1}$	$R^{5y}_{t,t+1}$	$R^{10y}_{t,t+1}$	$R^{30y}_{t,t+1}$
$\Delta V^{stock/2y/5y/10y/30y}_{t-1}$	**7.4325*** **	0.2025	0.2870	**1.1230*** **	**0.7241*** **
	(1.4296)	(0.2317)	(0.2267)	(0.4062)	(0.2340)
$1_{t,FOMCPre1}$	**32.6191** **	**-1.0610***	**-1.6804** **	**-1.1535***	-0.7120
	(13.3571)	(0.6017)	(0.6941)	(0.6838)	(0.7028)
$1_{t,FOMCPre1} \times \Delta V^{stock/2y/5y/10y/30y}_{t-1}$	**-21.3812** **	1.2447	1.2371	-0.9756	**-2.0215***
	(8.7783)	(1.4326)	(1.2139)	(1.7301)	(1.1498)
Intercept	2.6207	-0.0103	-0.0975	-0.1174	-0.1124
	(2.3947)	(0.1088)	(0.1248)	(0.1201)	(0.1248)
R-squared	0.0066	0.0005	0.0011	0.0016	0.0026

Note: This table regresses 2-day stock return and bond yield changes on the corresponding lagged uncertainty change, indicators denoting the pre-FOMC announcement drift and their interaction terms. Stock return is available from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. The 2-day rolling returns $R_{t,t+1}$ are extracted by $R^{stock}_{t,t+1} = (1 + R^{stock}_{t}) \times (1 + R^{stock}_{t+1}) - 1$ and $R^{bond}_{t,t+1} = R^{bond}_{t} + R^{bond}_{t+1}$ for stock and bonds respectively. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The units of uncertainty and return are 1% and 1 bp, respectively. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

uncertainty risk and an interaction term with the monetary policy surprise. They reach a similar conclusion that high uncertainty depresses the yield curve response to the monetary policy shocks. In this paper, I applied a similar setup to the pre-announcement risk and return with three major variations.

Firstly, I focus on the pre-announcement drift, not the bond yield performance after the FOMC meeting, so the different regressors are applied. I regress the 2-day rolling return on lagged risks and indicators showing that it's the pre-announcement drift. Secondly, instead of the market-based monetary policy uncertainty measures constructed from the interest rate futures and options by various methods, I use the corresponding bond implied risks for the term structure of the yield curve change. Thirdly, I use the dummy variable indicating the pre-FOMC days to replace monetary policy surprise measure, since the surprise components derived from the post price change of short-term interest rate futures are not related to the pre-announcement drift. In summary, the 2-day stock return and bond yield change are regressed on the lagged change of the corresponding uncertainty risk, the indicator denoting the pre-FOMC days, and their interaction terms.

As I regress the 2-day return on the lagged change of uncertainty, Table 14 shows that 1% of the volatility rise can drive up the stock return, 10-year and 30-year bond yield by 7.4 bps, 1.1 bps and 0.7 bp. Hence, variation in uncertainty can predict the next-day return positively, which also helps verify the heightened uncertainty results. However, the average uncertainty changes before the FOMC meeting are 0.28%, 0.11% and 0.16% for stock and long-term bonds respectively, far from sufficient for explaining the pre-announcement drift. Also, as the bond yield decreases instead of rising before the announcement, the variation in uncertainty is not the reason for bond abnormal drift.

Table 15. Pre-FOMC Risk-Return Relationship: Decomposed

	$R_{t,t+1}^{stock}$	$R_{t,t+1}^{2y}$	$R_{t,t+1}^{5y}$	$R_{t,t+1}^{10y}$	$R_{t,t+1}^{30y}$
$\Delta V_{t-1}^{stock/2y/5y/10y/30y}$	**7.3978*** **	0.2040	0.2883	**1.1235*** **	**0.7239*** **
	(1.4270)	(0.2312)	(0.2267)	(0.4062)	(0.2340)
$1_{t,FOMCPre1}$	18.2132	-0.4188	-1.1706	-0.9208	-0.5925
	(14.2697)	(0.6422)	(0.7475)	(0.7281)	(0.7735)
$1_{t,FOMCPre1} \times \Delta V_{t-1}^{stock/2y/5y/10y/30y}$	**-24.7323*** **	1.9648	1.3336	-0.7686	**-2.0150* **
	(8.8968)	(1.4460)	(1.2147)	(1.7452)	(1.1503)
$1_{t,Bust}$	**-28.0178*** **	**-0.8627** **	-0.1869	0.0656	0.1289
	(7.3092)	(0.3382)	(0.3815)	(0.3672)	(0.3456)
$1_{t,FOMCPre1} \times 1_{t,Bust}$	**109.3880*** **	**-5.0229*** **	**-3.5134* **	-1.7546	-0.6707
	(37.7758)	(1.8094)	(1.9422)	(1.8843)	(1.7662)
Intercept	**6.0322** **	0.0903	-0.0747	-0.1254	-0.1322
	(2.5506)	(0.1155)	(0.1331)	(0.1282)	(0.1357)
R-squared	0.0103	0.0048	0.0015	0.0014	0.0021

	$R_{t,t+1}^{stock}$	$R_{t,t+1}^{2y}$	$R_{t,t+1}^{5y}$	$R_{t,t+1}^{10y}$	$R_{t,t+1}^{30y}$
$\Delta V_{t-1}^{stock/2y/5y/10y/30y}$	**7.4013*** **	0.2042	0.2891	**1.1228*** **	**0.7240*** **
	(1.4261)	(0.2312)	(0.2267)	(0.4062)	(0.2341)
$1_{t,ExpandPre1}$	**126.3325*** **	**-4.2832** **	**-3.0532* **	-1.4246	-0.6703
	(36.7733)	(2.0217)	(1.8297)	(2.0038)	(1.8006)
$1_{t,ContractPre1}$	31.5843	2.1403	1.1058	-0.1505	-1.7550
	(30.6706)	(1.3906)	(1.7131)	(1.5774)	(2.1526)
$1_{t,NoChangePre1}$	18.4873	**-1.5574** **	**-2.0029** **	**-1.4338* **	-0.6369
	(16.0500)	(0.7013)	(0.8331)	(0.8141)	(0.8135)
$1_{t,ExpandPre1} \times \Delta V_{t-1}^{stock/2y/5y/10y/30y}$	**-75.8095*** **	**5.9004** **	**3.2584* **	2.6626	-0.8132
	(16.8083)	(2.5972)	(1.7022)	(2.9771)	(2.0006)
$1_{t,ContractPre1} \times \Delta V_{t-1}^{stock/2y/5y/10y/30y}$	-25.0885	0.5537	-1.9844	-4.1105	-0.3113
	(25.5479)	(3.7682)	(4.0247)	(3.3845)	(3.3742)
$1_{t,NoChangePre1} \times \Delta V_{t-1}^{stock/2y/5y/10y/30y}$	2.2247	-0.3409	-0.7334	-3.0474	**-3.1690** **
	(11.3077)	(1.9424)	(1.9178)	(2.8630)	(1.5595)
$1_{t,Bust}$	**-25.1778*** **	**-0.9886*** **	-0.3039	-0.0334	0.0866
	(7.2218)	(0.3341)	(0.3773)	(0.3631)	(0.3421)
Intercept	**5.6863** **	0.1050	-0.0605	-0.1133	-0.1257
	(2.5455)	(0.1153)	(0.1330)	(0.1280)	(0.1355)
R-squared	0.0115	0.0049	0.0014	0.0013	0.0016
	0.0132	0.0072	0.0031	0.0030	0.0038

Note: This table regresses daily stock return and bond yields change on the corresponding lagged uncertainty change, indicators denoting the decomposed pre-FOMC announcement drift and their interaction terms, after the period effect is controlled. Stock return is available from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. The 2-day rolling returns $R_{t,t+1}$ are extracted by $R_{t,t+1}^{stock} = (1 + R_t^{stock}) \times (1 + R_{t+1}^{stock}) - 1$ and $R_{t,t+1}^{bond} = R_t^{bond} + R_{t+1}^{bond}$ for stock and bonds respectively. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The units of uncertainty and return are 1% and 1 bp, respectively. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Through the interaction terms, the regression results shed light on the role of bond uncertainty risk in monetary policy transmission even before the FOMC announcement: The uncertainty surge before the FOMC days has the negative effect on stock return and the bond yield changes: The increase in pre-announcement uncertainty brings down the drift by 21.4 bps, 1.0 bp and 2.0 bps for stock, 10-year and 30-year bond. We can do the end-of-the-envelope calculation using the regression coefficients. For stock index which accumulates 32.6 bps before the announcement, the uncertainty change tempers the return by 3.9 bps,$((7.4-21.4)*0.28\%/1\% = 3.9)$ so that the overall pre-announcement drift is 28.7 bps, consistent with the 29.2 bps results in the previous regression. For 10-year bonds, the surge in uncertainty increases the bond yield by 0.12 bp $(1.1 * 0.11\%/1\% = 0.12)$, causing bond yield decline by 1 bp $(-1.15 + 0.12 = -1.03)$. For 30-year bond yield, uncertainty gives rise to 0.2 bps decline in yields $((0.7 - 2.0) * 0.16\%/1\% = -0.21)$, together the 0.7 bps yield decline on the pre-FOMC days, constituting the overall 1 bps bond yield drop. From the calculation, we could see that the large part of the drift is not explained by risk. By contract, uncertainty risk for stock and bonds before the FOMC meeting has a small or even opposite effect. It contributes to the stock, 10-year and 30-year pre-announcement drift by $-3.9/28.7 = -13.6\%$ and $0.12/-1.03 = -11.7\%$ and $-0.21/-0.91 = 23\%$ respectively. Consequently, uncertainty itself is insufficient for the pre-announcement drift.

Similarly, I also do the FOMC days decomposition for the pre-announcement risk-return relationship, the results of which are consistent with the previous arguments about the predictability of uncertainty and the accumulated pre-FOMC announcement drift during recessions or with expansionary monetary policy, as shown in Table 15 . Also, the interaction terms provide the offsetting effect: In the upper table, the increase of pre-FOMC uncertainty drags down the stock return and 30-year bond yield by 25 bps and 2 bps; In the lower table, while the expected interest rate cut pushes up the pre-FOMC stock return by 126 bps and push down the 2- and 5-year bond yield by 4 bps and 3 bps, the pre-FOMC uncertainty has an opposite effect, by decreasing the stock return by 76 bps and increasing the bond yields by 6 bps and 3 bps, respectively.

4.3 Not Special Pre-FOMC Risk-Return Relationship

Readers may argue that I regress with all the time series data, not just the pre-FOMC announcement drifts, which may dilute the uncertainty effect such that regressing only the pre-announcement drift on the lagged risk change might provide much larger coefficient for stock and negative relationship for bonds, suggesting that the special uncertainty increase before the FOMC days give rise to the abnormal drifts. To tackle this argument, I confine to the pre-announcement risk and return, shrinking the data size from 4745 trading days from 2000 to 2018 to 157 FOMC meetings, while it's still large enough for a reliable result. Under this context, the previous dummy variables all become 1 so that the regressors transfer to the ones listed in the Table 16. Here the term ΔV_{t-1} reflect the overall effect the uncertiancy can bring to the pre-announcement drift. As we can see that pre-FOMC uncertainty overall has an insignificant effect on the drift afterwards, letting alone the more substantial influence than other days.

This setup is also applied by Hu, Pan, Wang, and Zhu (2019), and similar to their results, much of

Table 16. Pre-FOMC Risk-Return Relationship: FOMC Days Only

	$R^{Pre,Stock}_{t,t+1}$	$R^{Pre,2y}_{t,t+1}$	$R^{Pre,5y}_{t,t+1}$	$R^{Pre,10y}_{t,t+1}$	$R^{Pre,30y}_{t,t+1}$
$\Delta V^{stock/2y/5y/10y/30y}_{t-1}$	-13.9487	1.4472	1.5241	0.1475	-1.2973
	(9.6454)	(1.7486)	(1.3700)	(1.9467)	(1.1704)
Intercept	__35.2398**__	-1.0712	__-1.7779**__	-1.2709	-0.8243
	(14.6341)	(0.7320)	(0.7844)	(0.7792)	(0.7190)
R-squared	0.0069	-0.0027	0.0015	-0.0064	0.0019
	0.0133	0.0060	0.0079	0.0000	0.0100

	$R^{Pre,Stock}_{t,t+1}$	$R^{Pre,2y}_{t,t+1}$	$R^{Pre,5y}_{t,t+1}$	$R^{Pre,10y}_{t,t+1}$	$R^{Pre,30y}_{t,t+1}$
$\Delta V^{stock/2y/5y/10y/30y}_{t-1}$	__-17.3345*__	2.1687	1.6219	0.3549	-1.2911
	(9.7059)	(1.7206)	(1.3630)	(1.9668)	(1.1749)
$1_{t,Bust}$	__81.3702**__	__-5.8856***__	__-3.7004*__	-1.6889	-0.5419
	(40.9629)	(2.1427)	(2.1750)	(2.1417)	(1.8070)
Intercept	24.2454	-0.3285	-1.2453	-1.0461	-0.7247
	(15.5176)	(0.7615)	(0.8401)	(0.8306)	(0.7945)
R-squared	0.0255	0.0517	0.0136	-0.0089	-0.0056

	$R^{Pre,Stock}_{t,t+1}$	$R^{Pre,2y}_{t,t+1}$	$R^{Pre,5y}_{t,t+1}$	$R^{Pre,10y}_{t,t+1}$	$R^{Pre,30y}_{t,t+1}$
$\Delta V^{stock/2y/5y/10y/30y}_{t-1}$	-15.3544	1.8524	1.4837	-0.2091	-1.3362
	(9.8034)	(1.7456)	(1.3838)	(2.0296)	(1.1989)
$1_{t,Contract}$	9.4105	__3.8041**__	2.7312	1.0991	-0.6361
	(38.4740)	(1.8908)	(2.0634)	(2.0066)	(2.2639)
$1_{t,Expand}$	42.4409	-2.3438	-0.6105	1.5041	0.5571
	(42.0706)	(2.5169)	(2.2482)	(2.2524)	(1.9333)
Intercept	27.7285	__-1.5486*__	__-2.1723**__	__-1.6485*__	-0.8417
	(17.6927)	(0.8456)	(0.9429)	(0.9237)	(0.8370)
R-squared	0.0006	0.0279	0.0018	-0.0154	-0.0131

Note: In this table, only the pre-announcement drift and its associated previous uncertainty risk are regressed together. The results after controlling the period effect and decomposing the FOMC days are posted in the lower tables. Stock return is available from daily returns on the CRSP S&P500 value-weighted portfolio. Bond yield changes are computed from the daily Treasury yield curve available from the Federal Reserve Board webpage. The 2-day rolling returns $R_{t,t+1}$ are extracted by $R^{stock}_{t,t+1} = (1 + R^{stock}_{t}) \times (1 + R^{stock}_{t+1}) - 1$ and $R^{bond}_{t,t+1} = R^{bond}_{t} + R^{bond}_{t+1}$ for stock and bonds respectively. VIX and $SKEW$ are available from CBOE webpage. The derived uncertainty and tail risk are from Equation (7) and (8), the construction of which are provided in Chapter 1. The units of uncertainty and return are 1% and 1 bp, respectively. Data runs from 2000 to 2018. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

the pre-announcement drift are located on the intercepts, showing that uncertainty cannot explain large portion of the return. In my paper, the coefficient before the stock uncertainty is not positively and significantly different from zero. To the contrary, it gives a negative coefficient compared to the positive one in their paper. Also, the results are robust when I try $\Delta V_{t-3,t-1}$, the setup in their paper.

Investigating the risk-return relationship through the above three angles — heightened uncertainty premium, the uncertainty effect on monetary policy transmission, and the special pre-FOMC risk-return relationship — I conclude that the early upsurge in stock and bond uncertainty cannot fully justify the pre-announcement return.

5 Future Extensions

In this paper, I construct the term structure of bond implied volatility and skewness to explore the characteristics of risks across different tenors and investigate how bond implied risks move under financial conditions and change over monetary policy announcements. The first important finding is that stock and bond uncertainty jump 2 days before the announcement and drop back on the FOMC day. Also, I look at the pre-announcement drift in bonds and validate that bond yields drop 1 bps before the announcements. Thirdly, I examine the uncertainty increase and the pre-announcement drift through three approaches, validating that although the change in uncertainty risk can predict the next-day return and that the upsurge before the FOMC meeting dampens the effect, the pre-2-day uncertainty increase cannot fully explain the pre-announcement drift due to its minimal impact.

An extension of this paper could focus on explaining the monthly return instead of the daily pre-FOMC drift. As Adrian, Crump, and Vogt (2019) discover the non-linearity between the stock return and VIX, and Martin (2017) offers the theoretical foundation, a similar relationship might also be found in bonds portfolios with the corresponding implied risks. In this way, we can also look at the risk-return relationship between stocks and bonds and investigate their return correlation with stock and bond risks.

Also, an increasing number of papers build up connections between risk premium and tail risk in the stock market, theoretically and empirically, by adding stock tail risk as a factor and construct the tail risk portfolio to examine the abnormal alphas. For example, Schneider, Wagner, and Zechner (2017) relate the stock tail risk to explain the betting against beta as well as the low variance risk abnormality, and Borochin and Zhao (2020) link the stock tail risk to explain momentum effect. Also, Borochin, Chang, and Wu (2020) explore the short-term and long-term risk neutral skewness, which have different impacts to the cross-section stock returns. Very recent paper by Rubin and Ruzzi (2020) investigate stock tail risk's effect on Treasury bond market, which can be also extended to use the bond tail risks instead.

References

Adrian, T., R. K. Crump, and E. Moench (2013): "Pricing the term structure with linear regressions," *Journal of Financial Economics*, 110(1), 110–138.

Adrian, T., R. K. Crump, and E. Vogt (2019): "Nonlinearity and Flight-to-Safety in the Risk-Return Trade-Off for Stocks and Bonds," *The Journal of Finance*, 74(4), 1931–1973.

Adrian, T., and J. Rosenberg (2008): "Stock returns and volatility: Pricing the short-run and long-run components of market risk," *The journal of Finance*, 63(6), 2997–3030.

Ai, H., and R. Bansal (2018): "Risk preferences and the macroeconomic announcement premium," *Econometrica*, 86(4), 1383–1430.

Amaya, D., P. Christoffersen, K. Jacobs, and A. Vasquez (2015): "Does realized skewness predict the cross-section of equity returns?," *Journal of Financial Economics*, 118(1), 135–167.

Amengual, D., and D. Xiu (2018): "Resolution of policy uncertainty and sudden declines in volatility," *Journal of Econometrics*, 203(2), 297–315.

An, B.-J., A. Ang, T. G. Bali, and N. Cakici (2014): "The joint cross section of stocks and options," *The Journal of Finance*, 69(5), 2279–2337.

Andersen, T. G., N. Fusari, and V. Todorov (2015): "The risk premia embedded in index options," *Journal of Financial Economics*, 117(3), 558–584.

——— (2017): "Short-term market risks implied by weekly options," *The Journal of Finance*, 72(3), 1335–1386.

——— (2019): "The pricing of tail risk and the equity premium: evidence from international option markets," *Journal of Business & Economic Statistics*, pp. 1–28.

Andersen, T. G., V. Todorov, and M. Ubukata (2019): "Tail risk and return predictability for the japanese equity market," *Journal of Econometrics, forthcoming*.

Ang, A., R. J. Hodrick, Y. Xing, and X. Zhang (2006): "The cross-section of volatility and expected returns," *The Journal of Finance*, 61(1), 259–299.

Baele, L., G. Bekaert, K. Inghelbrecht, and M. Wei (2020): "Flights to safety," *The Review of Financial Studies*, 33(2), 689–746.

Bai, J., T. G. Bali, and Q. Wen (2019): "Common risk factors in the cross-section of corporate bond returns," *Journal of Financial Economics*, 131(3), 619–642.

Bakshi, G., N. Kapadia, and D. Madan (2003): "Stock return characteristics, skew laws, and the differential pricing of individual equity options," *The Review of Financial Studies*, 16(1), 101–143.

Bali, T. G., N. Cakici, and R. F. Whitelaw (2014): "Hybrid tail risk and expected stock returns: When does the tail wag the dog?," *The Review of Asset Pricing Studies*, 4(2), 206–246.

BARBERIS, N. (2013): "The psychology of tail events: Progress and challenges," *American Economic Review*, 103(3), 611–16.

BARRAS, L., AND A. MALKHOZOV (2016): "Does variance risk have two prices? Evidence from the equity and option markets," *Journal of Financial Economics*, 121(1), 79–92.

BAUER, M. D., A. LAKDAWALA, AND P. MUELLER (2019): "Market-based monetary policy uncertainty," *Available at SSRN*.

BEKAERT, G., E. ENGSTROM, AND S. R. GRENADIER (2010): "Stock and bond returns with moody investors," *Journal of Empirical Finance*, 17(5), 867–894.

BERGER, D., I. DEW-BECKER, AND S. GIGLIO (2020): "Uncertainty shocks as second-moment news shocks," *The Review of Economic Studies*, 87(1), 40–76.

BERNILE, G., J. HU, AND Y. TANG (2016): "Can information be locked up? Informed trading ahead of macro-news announcements," *Journal of Financial Economics*, 121(3), 496–520.

BOLLERSLEV, T., G. TAUCHEN, AND H. ZHOU (2009): "Expected stock returns and variance risk premia," *The Review of Financial Studies*, 22(11), 4463–4492.

BOLLERSLEV, T., AND V. TODOROV (2011): "Tails, fears, and risk premia," *The Journal of Finance*, 66(6), 2165–2211.

BOLLERSLEV, T., V. TODOROV, AND L. XU (2015): "Tail risk premia and return predictability," *Journal of Financial Economics*, 118(1), 113–134.

BOROCHIN, P., H. CHANG, AND Y. WU (2020): "The information content of the term structure of risk-neutral skewness," *Journal of Empirical Finance*.

BOROCHIN, P., AND Y. ZHAO (2020): "Risk Neutral Skewness Predicts Price Rebounds and so can Improve Momentum Performance," .

BREEDEN, D. T., AND R. H. LITZENBERGER (1978): "Prices of state-contingent claims implicit in option prices," *Journal of business*, pp. 621–651.

CARR, P., AND D. MADAN (2001): "Towards a theory of volatility trading," *Option Pricing, Interest Rates and Risk Management, Handbooks in Mathematical Finance*, pp. 458–476.

CHANG, B. Y., P. CHRISTOFFERSEN, AND K. JACOBS (2013): "Market skewness risk and the cross section of stock returns," *Journal of Financial Economics*, 107(1), 46–68.

CHOI, H., P. MUELLER, AND A. VEDOLIN (2017): "Bond variance risk premiums," *Review of Finance*, 21(3), 987–1022.

COCHRANE, J. H., AND M. PIAZZESI (2005): "Bond risk premia," *American Economic Review*, 95(1), 138–160.

CONNOLLY, R., C. STIVERS, AND L. SUN (2005): "Stock market uncertainty and the stock-bond return relation," *Journal of Financial and Quantitative Analysis*, 40(1), 161–194.

CREMERS, M., M. FLECKENSTEIN, AND P. GANDHI (2017): "Treasury yield implied volatility and real activity," *Matthias and Gandhi, Priyank, Treasury Yield Implied Volatility and Real Activity (July 21, 2017)*.

DE POOTER, M., G. FAVARA, M. MODUGNO, AND J. WU (2020): "Monetary Policy Uncertainty and Monetary Policy Surprises," .

DEW-BECKER, I., AND S. GIGLIO (2019): "Cross-sectional uncertainty and the business cycle: evidence from 40 years of options data," .

DEW-BECKER, I., S. GIGLIO, AND B. T. KELLY (2019): "Hedging macroeconomic and financial uncertainty and volatility," Discussion paper, National Bureau of Economic Research.

DEW-BECKER, I., S. GIGLIO, A. LE, AND M. RODRIGUEZ (2017): "The price of variance risk," *Journal of Financial Economics*, 123(2), 225–250.

GABAIX, X. (2012): "Variable rare disasters: An exactly solved framework for ten puzzles in macro-finance," *The Quarterly journal of economics*, 127(2), 645–700.

GAO, G. P., P. GAO, AND Z. SONG (2018): "Do hedge funds exploit rare disaster concerns?," *The Review of Financial Studies*, 31(7), 2650–2692.

GERTLER, M., AND P. KARADI (2015): "Monetary policy surprises, credit costs, and economic activity," *American Economic Journal: Macroeconomics*, 7(1), 44–76.

GHYSELS, E., P. GUÉRIN, AND M. MARCELLINO (2014): "Regime switches in the risk–return trade-off," *Journal of Empirical Finance*, 28, 118–138.

GORMSEN, N. J., AND C. S. JENSEN (2018): "Higher-moment risk," *Available at SSRN 3069617*.

GÜRKAYNAK, R. S., B. SACK, AND E. SWANSON (2005): "The sensitivity of long-term interest rates to economic news: Evidence and implications for macroeconomic models," *American economic review*, 95(1), 425–436.

HANSON, S. G., AND J. C. STEIN (2015): "Monetary policy and long-term real rates," *Journal of Financial Economics*, 115(3), 429–448.

HU, G. X., J. PAN, AND J. WANG (2016): "Early peek advantage? efficient price discovery with tiered information disclosure," *Second Annual Volatility Institute at NYU Shanghai (VINS)*.

HU, G. X., J. PAN, J. WANG, AND H. ZHU (2019): "Premium for heightened uncertainty: Solving the fomc puzzle," Discussion paper, National Bureau of Economic Research.

HUSTED, L., J. ROGERS, AND B. SUN (2019): "Monetary policy uncertainty," *Journal of Monetary Economics*.

ISTREFI, K., AND S. MOUABBI (2018): "Subjective interest rate uncertainty and the macroeconomy: A cross-country analysis," *Journal of International Money and Finance*, 88, 296–313.

KELLY, B., AND H. JIANG (2014): "Tail risk and asset prices," *The Review of Financial Studies*, 27(10), 2841–2871.

KOIJEN, R. S., H. LUSTIG, AND S. VAN NIEUWERBURGH (2017): "The cross-section and time series of stock and bond returns," *Journal of Monetary Economics*, 88, 50–69.

KOZHAN, R., A. NEUBERGER, AND P. SCHNEIDER (2013): "The skew risk premium in the equity index market," *The Review of Financial Studies*, 26(9), 2174–2203.

KUROV, A., A. SANCETTA, G. STRASSER, AND M. H. WOLFE (2019): "Price drift before US macroeconomic news: Private information about public announcements?," *Journal of Financial and Quantitative Analysis*, 54(1), 449–479.

KUROV, A., AND R. STAN (2018): "Monetary policy uncertainty and the market reaction to macroeconomic news," *Journal of Banking & Finance*, 86, 127–142.

KUTTNER, K. N. (2001): "Monetary policy surprises and interest rates: Evidence from the Fed funds futures market," *Journal of monetary economics*, 47(3), 523–544.

LEOMBRONI, M., A. VEDOLIN, G. VENTER, AND P. WHELAN (2019): "Central bank communication and the yield curve," *Available at SSRN 2873091*.

LUCCA, D. O., AND E. MOENCH (2015): "The pre-FOMC announcement drift," *The Journal of Finance*, 70(1), 329–371.

MARTIN, I. (2017): "What is the Expected Return on the Market?," *The Quarterly Journal of Economics*, 132(1), 367–433.

MARTIN, I. W., AND C. WAGNER (2019): "What is the Expected Return on a Stock?," *The Journal of Finance*, 74(4), 1887–1929.

NAKAMURA, E., AND J. STEINSSON (2018): "High-frequency identification of monetary non-neutrality: the information effect," *The Quarterly Journal of Economics*, 133(3), 1283–1330.

NEUHIERL, A., AND M. WEBER (2018): "Monetary momentum," Discussion paper, National Bureau of Economic Research.

RUBIN, M., AND D. RUZZI (2020): "Equity Tail Risk in the Treasury Bond Market," *arXiv preprint arXiv:2007.05933*.

SCHNEIDER, P., AND F. TROJANI (2015): "Fear trading," *Swiss Finance Institute Research Paper*, (15-03).

SCHNEIDER, P., C. WAGNER, AND J. ZECHNER (2017): "Low-Risk Anomalies?," *The Journal of Finance*.

SWANSON, E. T. (2006): "Have increases in Federal Reserve transparency improved private sector interest rate forecasts?," *Journal of Money, Credit and Banking*, pp. 791–819.

TILLMANN, P. (2017): "Monetary policy uncertainty and the response of the yield curve to policy shocks," *Journal of Money, Credit and Banking*.

WACHTER, J. A. (2013): "Can time-varying risk of rare disasters explain aggregate stock market volatility?," *The Journal of Finance*, 68(3), 987–1035.

Appendix A Data

Appendix A.1 Data Cleaning

The CBOE End-of-Day dataset provides the daily trading information for S&P500 and Treasury futures and options. As options are written on futures, the spot price $S(t)$ here is the future price. Futures are quarterly listed and rolled. On average, two future contracts are in the market. To get the most liquid future price, I apply the convention from Choi, Mueller, and Vedolin (2017) to roll the future on the 28th of the month preceding the maturity month. Compared to futures, options are more diverse. Typically, there are 2 to 3 monthly serial options, 1 to 2 quarterly ones, sometimes with the additional 1 to 2 options maturing half a year or one year later. On average, options with 4 different maturity dates are listed in a day, but not all are traded in a large amount. The two options with the shortest time-to-maturity are most actively traded based on trading volume, so I use them separately to calculate risks before merging into one risk measure. Since the actual traded price rather than all listed prices should be the one to use, I clean the data by deleting the ones with zero open interest, settlement price, or trading volume. Next, option prices are matched with the same- day future price, and out-of-money options are selected for the risk contracts calculation.

Appendix A.2 Procedure Comparison With Index Calculation Approach

There are several differences between Bakshi, Kapadia, and Madan (2003) method and the index calculation approach from CBOE. For indexes, the same weights are offered on the call and put, while Bakshi and et al. employ more weights to the put options since the out-of-money puts are what investors use more to hedge for risks. Also, for calculating indexes, the actual future price is not used at all. Instead, Call-Put parity is utilized for constructing an artificial one, then the closest strike price to the artificial future price is denoted as the ”at-the-money” option price, and both of the ”at-the-money” call and put options are included in the deviation. In contrast, only the out-of-money options are utilized in the paper. Since the artificial future price and the at-the-money strike price is not the same, an error-correcting term is introduced. Finally, they differ in how to calculate $\mu(t,\tau)$, the expectation of the first-moment return. I choose Bakshi, Kapadia, and Madan (2003) methodology rather than the index calculation approach since it is more reasonable for putting different weights and using actual future prices.

Appendix A.3 Data Robustness

To verify that this calculation procedure captures the risks implied in the market, I compare the computed 10-year volatility with TYVIX, the CBOT 10-year U.S. Treasury note volatility index. I adjust the indexes (see Equation A.1) to reflect the real risks. Plotted together in Figure 3a, they share a similar pattern along the time. The daily correlation is 0.97. Since the same method is applied to calculate risks across maturities, the comparison with TYVIX as the benchmark justifies the term structure of bond uncertainty risk.

$$TYVIX = TYVIX_{index}/100 \tag{A.1}$$

$$VIX = VIX_{index}/100 \tag{A.2}$$

$$SKEW = (100 - SKEW_{index})/10 \tag{A.3}$$

As there's no bond skewness index, I calculate the implied volatility and skewness of S&P500 using the same approach, to compare them with the stock indexes VIX and SKEW (after transforming them by A.2 and A.3), so that the term structure of bond implied skewness is valid if this method captures both the dynamics of VIX and SKEW. Displayed in Figure 3b, the derived stock implied volatility replicates VIX index well, with a substantial daily correlation of 0.99. The corresponding correlation for stock skewness is 0.79, but the derived skewness measure could catch up with the movement.

The reason for the relatively lower correlation between the stock SKEW index and the calculated implied skewness is the different formulas applied for the underlying risk contract prices, and the additional error-correcting term, as mentioned above. Those differences cause a small divergence for implied volatility, but when I use the underlying contracts to calculate skewness further, this discrepancy enlarges.

There is also one paper from Dew-Becker, Giglio, and Kelly (2019) who only use the "at-the-money" implied volatility, the average implied volatility of two out-of-money call and put option prices whose strike prices are nearest to the future price. When I apply their approach and use the implied volatility provided by the dataset, it matches TYVIX considerably well with the correlation of 0.95. The reason behind could be that unlike the stock option markets which are traded more intensively, the bond options that close to the spot prices are the mostly traded ones, so that they could represent much of the risks. However, the implied volatility data in CME started in 2010 and began stable to be used from 2011, limiting the data range and the later regression construction. When I try to calculate implied volatility by myself through the Black-Scholes formula and root-finding approach to supplement the data, the results are quite volatile and incompatible with the existing ones. Besides, even if I proceed with the at-the-money method, the methodology from Bakshi, Kapadia, and Madan (2003) is still needed for tail risk. After examining and replicating the three procedures, I find that method from Bakshi et al. is the most reliable one. With the most extensive data possibility and available tail risk calculation formula, so I choose to proceed with it in this paper.

Appendix A.4 Monetary Policy Surprise

Literature has mainly two approaches to constructing the monetary policy shocks. Kuttner (2001) as a pioneer, uses the Treasury future daily price change on the FOMC days. Followers such as Neuhierl and Weber (2018) adopt this method and extend it using high-frequency identification: the 30-min window around the announcement. Nakamura and Steinsson (2018) expand it further to aggregate 5 elements of interest rate future prices, including the current and the next Treasury fund rate futures, and 3 Eurodollar futures. Hanson and Stein (2015) and Gertler and Karadi (2015), instead, use the 2-year Treasury yield change, and Tillmann (2017) follows to the narrow 30-min window.

Table A-1. Summary Statistics of Monetary Policy Change and Surprise

Times	Actual Change	Daily Surprise	1-Hour Surprise
Expansionary	23	46	37
Contractionary	28	37	27

Correlation		Actural Change		1 Day Surprise		1 Hour Surprise	
		Expand	Contract	Expand	Contract	Expand	Contract
Actual Change	Expand	1	-0.19	0.33	0.07	0.19	0.05
	Contract		1	-0.12	0.13	0.09	0.14
1 Day Surprise	Expand			1	-0.36	0.33	-0.11
	Contract				1	-0.20	0.34
1 Hour Surprise	Expand					1	-0.25
	Contract						1

Note: The summary statistics illustrate how different monetary policy shock measures separate each other by comparing the Kuttner (2001) measure of daily and 1-hour versions, with the actual monetary policy change. The upper table gives how many days are denoted as expansionary or contractionary, and the lower table calculates the correlations.

In this paper, I try the daily and 1-hour change of Federal Fund Future around the announcement as the monetary policy surprise. The reason that I do not deploy the 30-minute window is because of the data scarcity. Instead of the tick data from CME that other authors use, I extract prices from Thomson Reuters DataScope, which provides infrequent data points with a lot NaNs. It becomes better when I extend the time range to 1 hour, which is the 30-min before and after the announcement, while there are still empty data for some FOMC meetings. Therefore, I use the daily future prices and the 1-hour version. Then following Kuttner (2001), the surprise measure is constructed by:

$$\text{Monetary Policy Surprise} = \frac{M}{M-D} * (ff_{post} - ff_{pre}) \tag{A.4}$$

where ff_{post} and ff_{pre} denote Fed Fund future prices before and after the announcement, M represents how many days in the month of FOMC announcement, and D denotes the day of the month, so that adjustment $\frac{M}{M-D}$ is put to extract the surprise component because the federal funds futures settle on the average funds rate over the month. Readers can find the deviation of this formula from Kuttner (2001) and Nakamura and Steinsson (2018).

Various approaches could lead to different results for each announcement. As shown in A-1, with 157 times of FOMC meeting, 23 of them are with the expansionary monetary policy change, and the expansionary surprises do not coincide with them. As I check the summary statistics of monetary policy change and surprises, their correlations are low. Also, monetary policy surprise and the actual change gives the opposite pattern for the cumulative returns. Shown in Figure 7, stock return and bond yield shifts downwards with expansionary policy. In Figure A-1, however, stock and 10-year bond yield shift upwards with expansionary surprises. For reasons listed in the main paper, I choose to proceed with the actual change.

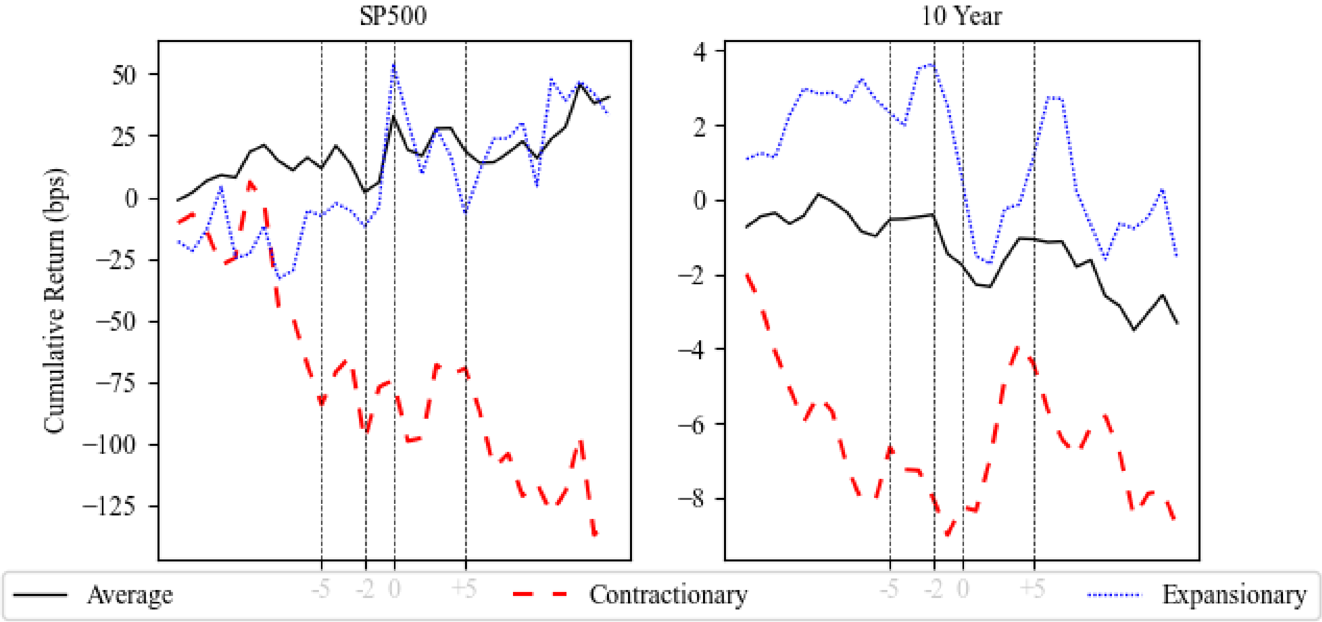
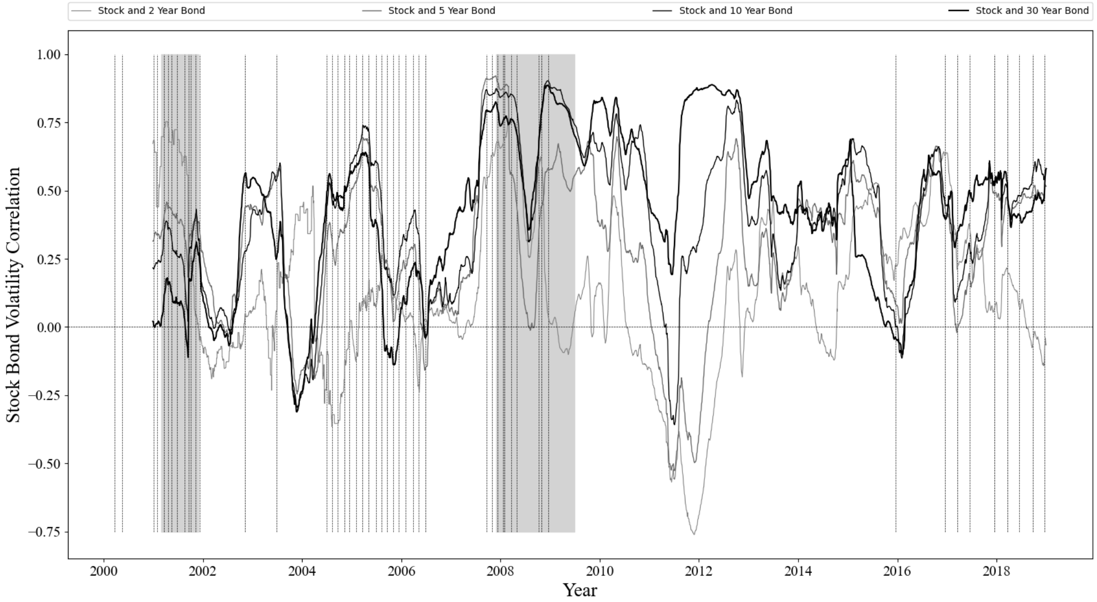


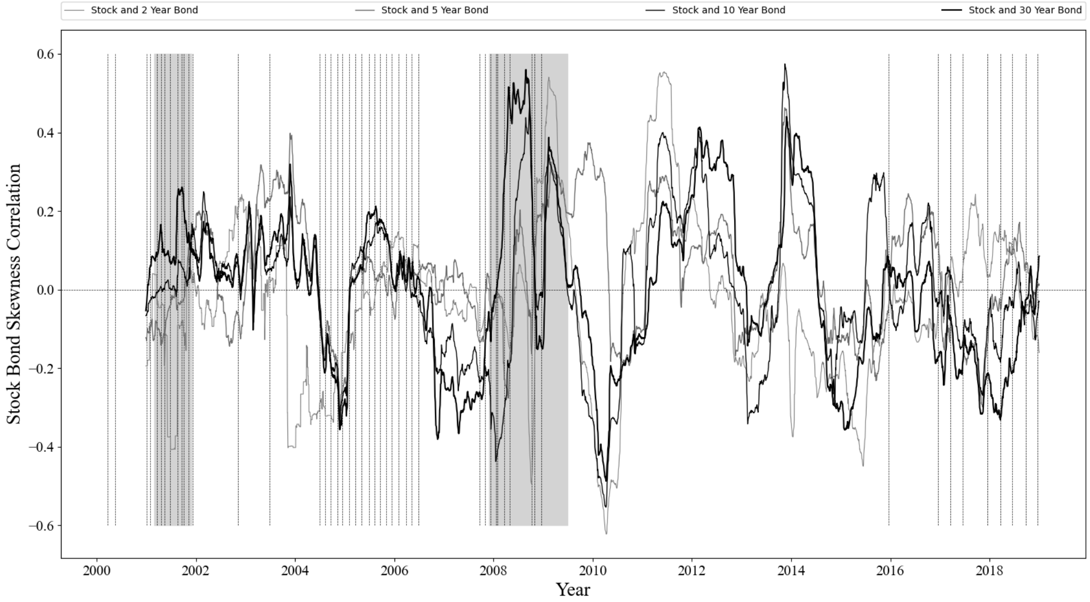
Figure A-1. Cumulative FOMC Days Return: Under Monetary Policy Surprise

Note: This figure provides the different behavior of the cumulative stock return and 10-year bond yield change over the FOMC cycle with monetary policy surprise measure using Kuttner (2001) method on daily federal fund future prices. We can compare it with Figure 7 to see that monetary policy change and surprise provide the opposite pattern.

Appendix B Supplement Tables and Figures



(a) 1 Year Rolling Correlation of Stock Bond Uncertainty Risk



(b) 1 Year Rolling Correlation of Stock Bond Tail Risk

Figure A-2. Correlation Between Stock Bond Risks

Note: The figures show the dynamics of 1-year rolling correlation between daily stock and bond risks across different maturities. Stock and bond implied volatilities are positively correlated with a lot of fluctuation, while tail risks are little connected.

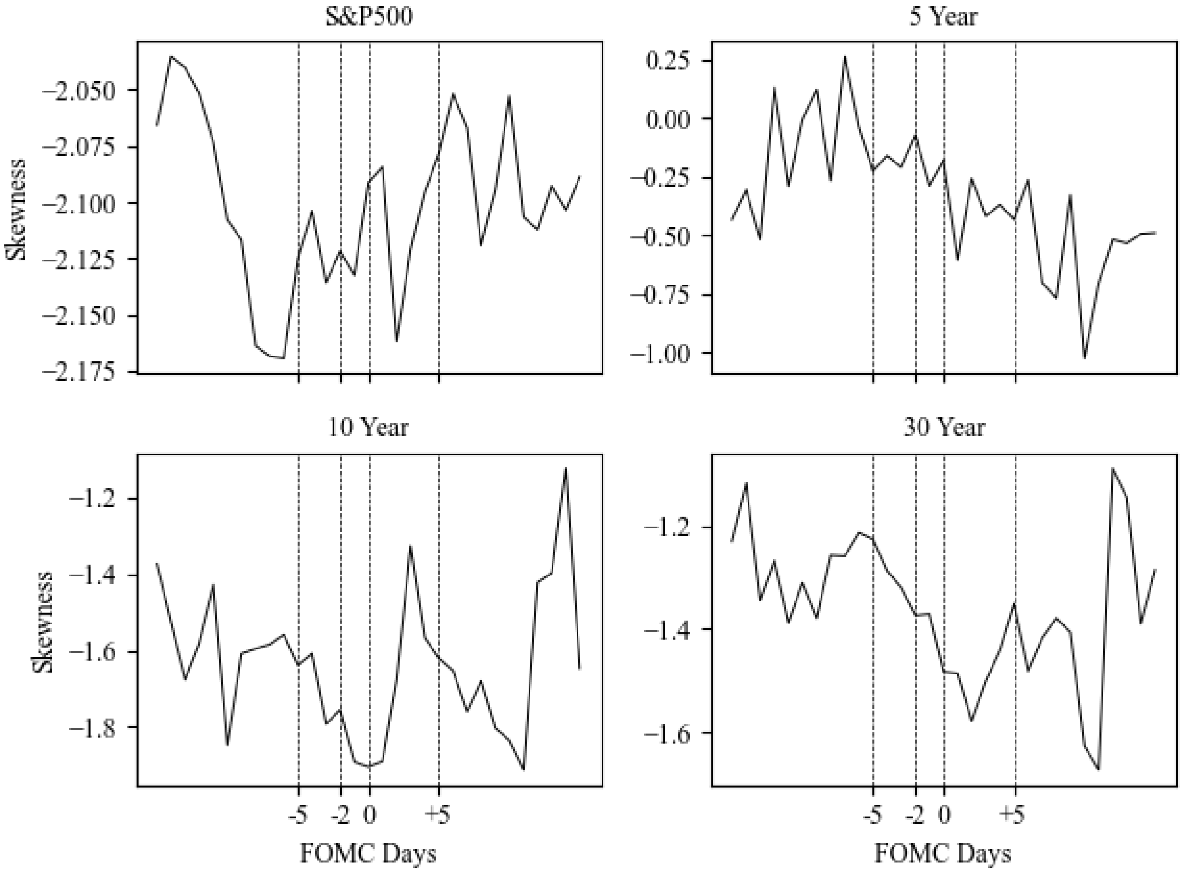


Figure A-3. Stock and Bond Tail Risk Over FOMC Cycle

Note: These figures present the average tail risk level for the stock index and Treasury bonds over the FOMC cycle, i.e., 15 trading days before and after the announcement. Stock tail risk is from the SKEW index, while the 5, 10 and 30 years bond tail risk are calculated by Equation (8). The construction of bond implied risks are in Chapter 1.

Table A-2. Tail Risk on FOMC Days: Decomposed

	$SKEW_t$	S_t^{2y}	S_t^{5y}	S_t^{10y}	S_t^{30y}
$1_{t,FOMC}$	0.0142	-0.1219	0.1600	-0.4436	-0.1530
	(0.0683)	(0.3036)	(0.2756)	(0.3468)	(0.2877)
$1_{t,Bust}$	**0.8954*****	**-0.6774*****	**0.3652*****	0.1846	**0.7191*****
	(0.0270)	(0.1441)	(0.1091)	(0.1358)	(0.1140)
$1_{t,Bust} \times 1_{t,FOMC}$	0.0406	-0.3933	-0.1305	0.6294	0.1195
	(0.1425)	(0.7904)	(0.5748)	(0.7188)	(0.6020)
Intercept	**-2.3215*****	**-0.1528*****	**-0.3924*****	**-1.6498*****	**-1.5221*****
	(0.0122)	(0.0552)	(0.0496)	(0.0618)	(0.0516)
R-squared	0.1949	0.0058	0.0019	0.0002	0.0082
	$SKEW_t$	S_t^{2y}	S_t^{5y}	S_t^{10y}	S_t^{30y}
$1_{t,Expand}$	0.1835	0.5591	0.5842	-0.0501	-0.6791
	(0.1548)	(0.8857)	(0.6387)	(0.7795)	(0.6546)
$1_{t,Contract}$	-0.1833	0.2744	0.3929	-0.4066	0.1789
	(0.1397)	(0.6238)	(0.5634)	(0.7034)	(0.5907)
$1_{t,NoChange}$	0.0438	-0.4099	-0.0334	-0.3221	-0.0866
	(0.0727)	(0.3323)	(0.2919)	(0.3695)	(0.3059)
$1_{t,Bust}$	**0.8925*****	**-0.7025*****	**0.3529*****	0.2016	**0.7361*****
	(0.0266)	(0.1427)	(0.1079)	(0.1343)	(0.1126)
Intercept	**-2.3209*****	**-0.1492*****	**-0.3899*****	**-1.6533*****	**-1.5256*****
	(0.0122)	(0.0551)	(0.0495)	(0.0617)	(0.0515)
R-squared	0.1953	0.0059	0.0019	-0.0001	0.0082

Note: In this table, the level of tail risks are regressed on the decomposed FOMC days by two methods. The upper table examines if the level of risks on FOMC days are different under the recessions according to NBER US Business Cycle. The lower table decomposes the FOMC days into ”Contractionary”, ”Expansionary” and ”No Change” days according to how the Fed alters the target interest rate. The unit of tail risk is 1.
Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-3. Tail Risk Change Around the FOMC Announcement

	$\Delta SKEW_t$	ΔS_t^{2y}	ΔS_t^{5y}	ΔS_t^{10y}	ΔS_t^{30y}
$1_{t,FOMCPre3}$	-0.0298	0.1659	-0.0260	-0.1641	-0.0285
	(0.0253)	(0.1887)	(0.2335)	(0.1930)	(0.1205)
$1_{t,FOMCPre2}$	0.0154	-0.1191	0.1279	0.0385	-0.0862
	(0.0253)	(0.1895)	(0.2357)	(0.1912)	(0.1205)
$1_{t,FOMCPre1}$	-0.0158	0.1041	-0.2159	-0.0302	-0.0070
	(0.0253)	(0.1911)	(0.2364)	(0.1912)	(0.1201)
$1_{t,FOMC}$	0.0393	-0.0641	0.1127	-0.2308	-0.1307
	(0.0254)	(0.1895)	(0.2357)	(0.1924)	(0.1201)
Intercept	-0.0010	-0.0036	0.0175	0.0156	0.0187
	(0.0049)	(0.0361)	(0.0452)	(0.0367)	(0.0231)
R-squared	0.0001	-0.0007	-0.0006	-0.0004	-0.0005

Note: The table illustrates how daily tail risk change before the FOMC announcement. The unit of tail risk is 1.
Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-4. Tail Risk Change Around FOMC Days: Decomposed

	$\Delta SKEW_t$	ΔS_t^{2y}	ΔS_t^{5y}	ΔS_t^{10y}	ΔS_t^{30y}
$1_{t,FOMCPre3}$	-0.0287	0.1886	-0.0706	-0.1948	-0.0010
	(0.0274)	(0.2023)	(0.2528)	(0.2096)	(0.1305)
$1_{t,FOMCPre2}$	0.0039	-0.1610	0.2335	0.0275	-0.0775
	(0.0274)	(0.2033)	(0.2556)	(0.2073)	(0.1305)
$1_{t,FOMCPre1}$	-0.0025	0.1463	-0.3578	-0.0363	-0.0476
	(0.0274)	(0.2063)	(0.2565)	(0.2073)	(0.1300)
$1_{t,FOMC}$	0.0402	-0.0202	0.1189	-0.2752	-0.1554
	(0.0274)	(0.2043)	(0.2556)	(0.2088)	(0.1300)
$1_{t,Bust}$	-0.0018	-0.0192	-0.0540	0.0008	-0.0046
	(0.0150)	(0.1134)	(0.1399)	(0.1126)	(0.0713)
$1_{t,Bust} \times 1_{t,FOMCPre3}$	-0.0073	-0.1731	0.3132	0.2019	-0.1855
	(0.0717)	(0.5639)	(0.6612)	(0.5395)	(0.3413)
$1_{t,Bust} \times 1_{t,FOMCPre2}$	0.0786	0.3232	-0.6914	0.0734	-0.0584
	(0.0717)	(0.5642)	(0.6623)	(0.5386)	(0.3413)
$1_{t,Bust} \times 1_{t,FOMCPre1}$	-0.0896	-0.2947	0.9494	0.0409	0.2784
	(0.0717)	(0.5504)	(0.6626)	(0.5386)	(0.3411)
$1_{t,Bust} \times 1_{t,FOMC}$	-0.0065	-0.3121	-0.0302	0.2935	0.1695
	(0.0730)	(0.5497)	(0.6623)	(0.5392)	(0.3411)
Intercept	-0.0007	-0.0014	0.0239	0.0155	0.0192
	(0.0052)	(0.0384)	(0.0482)	(0.0391)	(0.0246)
R-squared	-0.0003	-0.0018	-0.0009	-0.0014	-0.0013

	$\Delta SKEW_t$	ΔS_t^{2y}	ΔS_t^{5y}	ΔS_t^{10y}	ΔS_t^{30y}
$1_{t,ExpandPre3}$	-0.0214	0.0034	0.1542	-0.1634	-0.1703
	(0.0654)	(0.6354)	(0.6033)	(0.4908)	(0.3114)
$1_{t,ExpandPre2}$	0.0586	-0.0544	-0.2308	0.5280	0.0148
	(0.0654)	(0.6354)	(0.6033)	(0.4908)	(0.3114)
$1_{t,Expand}$	0.0384	-0.9701	0.4840	0.0028	-0.1723
	(0.0668)	(0.6065)	(0.6171)	(0.4908)	(0.3114)
$1_{t,ContractPre3}$	-0.0031	**1.1057*****	0.5218	-0.1568	-0.1608
	(0.0589)	(0.4265)	(0.5529)	(0.4418)	(0.2803)
$1_{t,ContractPre2}$	-0.0439	**-1.0085****	0.6296	-0.5841	0.0302
	(0.0589)	(0.4365)	(0.5744)	(0.4418)	(0.2803)
$1_{t,Contract}$	-0.0454	0.3610	0.1686	0.0409	-0.2918
	(0.0589)	(0.4265)	(0.5529)	(0.4418)	(0.2803)
$1_{t,NoChangePre3}$	-0.0377	-0.0658	-0.1915	-0.1647	0.0380
	(0.0307)	(0.2203)	(0.2816)	(0.2357)	(0.1460)
$1_{t,NoChangePre2}$	0.0228	0.0907	0.1001	0.1000	-0.1392
	(0.0307)	(0.2203)	(0.2829)	(0.2324)	(0.1460)
$1_{t,NoChange}$	**0.0631****	-0.0614	0.0328	-0.3577	-0.0790
	(0.0307)	(0.2229)	(0.2843)	(0.2346)	(0.1454)
$1_{t,Bust}$	-0.0047	-0.0114	-0.0359	0.0023	0.0050
	(0.0141)	(0.1069)	(0.1318)	(0.1061)	(0.0672)
Intercept	-0.0010	0.0014	0.0139	0.0142	0.0178
	(0.0051)	(0.0375)	(0.0471)	(0.0382)	(0.0241)
R-squared	-0.0002	0.0017	-0.0014	-0.0008	-0.0014

Note: The table illustrates how daily tail risk change before the FOMC announcement by two decomposing methods. The upper table examines if the tail risk change around the FOMC days is different under the recessions, according to NBER US Business Cycle. The lower table decomposes the FOMC days into ”Contractionary”, ”Expansionary” and ”No Change” days according to how the Fed alters the target interest rate. The unit of tail risk is 1%.

Table A-5. Tail Risk Change Over FOMC Cycle

$\Delta SKEW$	Pre5	Pre3	Pre2	Pre1	FOMC	Post1	Post2	Post3	Post5
1_{Expand}	-0.0929	0.0134	0.0328	-0.0587	-0.0276	-0.0298	0.0225	-0.0108	-0.0141
	(0.0647)	(0.0875)	(0.0712)	(0.0651)	(0.0740)	(0.0749)	(0.0790)	(0.0674)	(0.0588)
$1_{Contract}$	-0.0263	0.0349	-0.0664	0.0475	-0.1081	0.0921	-0.0564	**0.1409****	0.0351
	(0.0598)	(0.0809)	(0.0658)	(0.0601)	(0.0671)	(0.0692)	(0.0729)	(0.0623)	(0.0543)
Intercept	**0.0678****	-0.0390	0.0216	-0.0166	**0.0618****	-0.0097	**-0.0685****	0.0172	0.0189
	(0.0275)	(0.0371)	(0.0302)	(0.0276)	(0.0308)	(0.0318)	(0.0333)	(0.0286)	(0.0248)
R-squared	0.0006	-0.0118	-0.0034	-0.0014	0.0039	0.0014	-0.0078	0.0221	-0.0093
ΔS^{5y}									
1_{Expand}	**-1.4766****	0.3232	-0.3534	0.3463	0.4275	-0.7896	0.3865	**1.1691*****	**0.6451****
	(0.7145)	(0.5333)	(0.5568)	(0.3470)	(0.4216)	(0.7313)	(0.5112)	(0.4200)	(0.2808)
$1_{Contract}$	-0.8066	0.7157	0.5319	-0.0804	0.1382	**-1.6501****	0.0789	-0.2805	0.1785
	(0.6482)	(0.4998)	(0.5382)	(0.3355)	(0.3880)	(0.6729)	(0.4792)	(0.3850)	(0.2623)
Intercept	0.0709	-0.1800	0.1116	-0.2375	0.0443	-0.0481	0.1359	-0.0839	-0.0718
	(0.2974)	(0.2252)	(0.2360)	(0.1477)	(0.1762)	(0.3032)	(0.2175)	(0.1722)	(0.1169)
R-squared	0.0192	0.0011	-0.0022	-0.0054	-0.0062	0.0279	-0.0094	0.0466	0.0215
ΔS^{10y}									
1_{Expand}	-0.0841	0.0027	0.4295	-0.2718	0.3619	0.0873	-0.9705	0.2242	-0.0638
	(0.2475)	(0.4315)	(0.5988)	(0.4439)	(0.3224)	(0.5307)	(0.6059)	(0.7746)	(0.5254)
$1_{Contract}$	0.1566	0.0077	-0.6842	0.3325	0.3984	0.5897	-0.5742	-1.0901	-0.2459
	(0.2288)	(0.3989)	(0.5533)	(0.4102)	(0.2980)	(0.4975)	(0.5599)	(0.7028)	(0.4854)
Intercept	-0.0815	-0.1503	0.1143	-0.0345	**-0.3433****	-0.0313	0.4715*	0.4990	-0.0086
	(0.1066)	(0.1866)	(0.2558)	(0.1897)	(0.1388)	(0.2267)	(0.2579)	(0.3237)	(0.2227)
R-squared	-0.0086	-0.0135	0.0032	-0.0047	0.0036	-0.0039	0.0070	0.0050	-0.0114
ΔS^{30y}									
1_{Expand}	0.1847	-0.2052	0.1571	0.2266	-0.0902	-0.0521	0.1458	0.0471	0.0649
	(0.1750)	(0.2676)	(0.3164)	(0.1977)	(0.1911)	(0.1651)	(0.2241)	(0.4136)	(0.2538)
$1_{Contract}$	-0.1518	-0.1992	0.1690	0.1399	-0.2132	0.2098	-0.2998	-0.3987	0.1627
	(0.1616)	(0.2472)	(0.2923)	(0.1826)	(0.1765)	(0.1548)	(0.2070)	(0.3752)	(0.2345)
Intercept	-0.0139	0.0562	-0.1210	-0.0464	-0.0608	-0.0460	-0.0693	0.1689	0.0476
	(0.0739)	(0.1134)	(0.1341)	(0.0835)	(0.0807)	(0.0697)	(0.0946)	(0.1721)	(0.1072)
R-squared	0.0030	-0.0063	-0.0099	-0.0024	-0.0031	0.0012	0.0063	-0.0050	-0.0097

Note: This table regresses change of tail risk over the FOMC cycle on dummy variables indicating the monetary policy change. For example, the coefficients on 1_{Expand} manifest how much the risk will change more or less with an expansionary policy compared with no change in the target interest rate. The unit of tail risk is 1. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-6. Tail Risk Response to Economic Fundamentals

	$SKEW$	S^{2y}	S^{5y}	S^{10y}	S^{30y}
GDP	0.0107	0.4846	**0.6181***	**0.9731****	**0.6977***
	(0.0962)	(0.3872)	(0.3505)	(0.4312)	(0.3660)
CPI	**-0.1129****	-0.0427	-0.2466	-0.0489	0.1400
	(0.0558)	(0.2341)	(0.2039)	(0.2510)	(0.2125)
PPI	**-0.8931*****	0.4267	0.2835	**0.9925****	**1.0812*****
	(0.1067)	(0.4000)	(0.3894)	(0.4822)	(0.4091)
Unemployment	**0.0970***	0.2792	0.2244	-0.3939	-0.2985
	(0.0562)	(0.2347)	(0.2044)	(0.2536)	(0.2139)
Initial Jobless Claim	0.0049	0.1075	-0.0591	-0.1058	-0.1328
	(0.0293)	(0.1227)	(0.1070)	(0.1325)	(0.1117)
Change Nonfarm Payroll	**0.0970***	0.2792	0.2244	-0.3939	-0.2985
	(0.0562)	(0.2347)	(0.2044)	(0.2536)	(0.2139)
ADP Employment	**-0.1590****	-0.2198	0.2815	-0.0643	**-0.4402***
	(0.0685)	(0.2557)	(0.2482)	(0.3106)	(0.2609)
Industrial Production	**-0.1463*****	-0.1119	-0.1390	0.0518	0.1246
	(0.0559)	(0.2354)	(0.2053)	(0.2510)	(0.2130)
Factory Orders	**0.1158****	0.1993	0.1315	-0.0628	-0.1588
	(0.0557)	(0.2348)	(0.2022)	(0.2516)	(0.2121)
Durable Goods Orders	0.0017	-0.0881	-0.0805	-0.4009	0.1338
	(0.0561)	(0.2373)	(0.2048)	(0.2515)	(0.2139)
Wholesale Inventory	**0.1222****	0.0207	0.1898	-0.1983	-0.2059
	(0.0558)	(0.2342)	(0.2039)	(0.2515)	(0.2125)
ISM Manufacturing	0.0520	0.0636	0.1539	0.0678	-0.1550
	(0.0558)	(0.2341)	(0.2022)	(0.2532)	(0.2130)
Empire Manufacturing	**-0.2503*****	0.0807	-0.3368	-0.1921	0.0463
	(0.0601)	(0.2400)	(0.2207)	(0.2706)	(0.2291)
Chicago PMI	0.0790	-0.0126	0.0214	0.0413	-0.1132
	(0.0558)	(0.2305)	(0.2031)	(0.2521)	(0.2126)
Leading Index	**-0.1040***	0.2346	**-0.3992***	0.3019	0.2914
	(0.0557)	(0.2341)	(0.2039)	(0.2510)	(0.2125)
Housing Start	**-0.1571*****	-0.2207	-0.2175	0.0239	0.1805
	(0.0557)	(0.2360)	(0.2031)	(0.2505)	(0.2121)
New Home Sales	-0.0205	0.0074	0.0172	0.0978	-0.0256
	(0.0559)	(0.2400)	(0.2057)	(0.2521)	(0.2130)
Existing Home Sales	**-0.3318*****	-0.2320	0.3152	-0.1626	-0.0917
	(0.0649)	(0.2427)	(0.2355)	(0.2926)	(0.2469)
Board Consumer	0.0236	-0.2489	0.1231	-0.1560	-0.0276
	(0.0559)	(0.2354)	(0.2035)	(0.2515)	(0.2130)
Michigan Confidence	0.0019	-0.0819	0.0199	-0.0411	-0.1070
	(0.0559)	(0.2323)	(0.2040)	(0.2516)	(0.2139)
Personal Income	0.0295	0.1752	-0.1449	-0.0229	-0.0505
	(0.0562)	(0.2341)	(0.2048)	(0.2537)	(0.2144)
Personal Expenditure	0.0295	0.1752	-0.1449	-0.0229	-0.0505
	(0.0562)	(0.2341)	(0.2048)	(0.2537)	(0.2144)
Trade Balance	0.0746	0.0565	-0.2447	-0.3986	-0.2222
	(0.0558)	(0.2348)	(0.2026)	(0.2520)	(0.2130)
Retail Sales	**-0.0983***	0.0032	-0.1386	-0.3114	-0.1877
	(0.0582)	(0.2348)	(0.2128)	(0.2623)	(0.2216)
MBA Mortgage Change	**-0.2055*****	-0.0229	-0.1157	**-0.3023****	**-0.3402*****
	(0.0322)	(0.1262)	(0.1177)	(0.1460)	(0.1231)

Note: Here the regression result for $Risk_t = \alpha_0 + \alpha_1 \times 1_{t,ReleaseDate} + \epsilon_t$ is presented. Only one indicator is regressed at one time.

Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-7. Uncertainty Risk Response to Economic Fundamentals

	VIX	V^{2y}	V^{5y}	V^{10y}	V^{30y}
GDP	-0.2884	0.0003	0.0001	-0.0009	-0.0029
	(1.0106)	(0.0019)	(0.0041)	(0.0018)	(0.0031)
CPI	0.1081	0.0003	0.0017	**0.0019***	0.0030*
	(0.5867)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
PPI	**-4.3317*****	**-0.0035***	**0.0112****	**-0.0082*****	-0.0007
	(1.1283)	(0.0020)	(0.0046)	(0.0020)	(0.0035)
Unemployment	-0.1814	-0.0006	-0.0021	-0.0015	**-0.0032***
	(0.5904)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Initial Jobless Claim	-0.0675	-0.0003	-0.0007	-0.0004	-0.0009
	(0.3083)	(0.0006)	(0.0013)	(0.0005)	(0.0010)
Change Nonfarm Payroll	-0.1814	-0.0006	-0.0021	-0.0015	**-0.0032***
	(0.5904)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
ADP Employment	-0.5278	0.0008	**0.0159*****	0.0001	**0.0037***
	(0.7203)	(0.0013)	(0.0029)	(0.0013)	(0.0022)
Industrial Production	-0.0359	-0.0002	0.0030	**0.0021****	0.0038**
	(0.5879)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Factory Orders	-0.1644	-0.0004	-0.0012	-0.0007	-0.0015
	(0.5855)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Durable Goods Orders	-0.2549	0.0002	-0.0007	-0.0005	-0.0007
	(0.5892)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Wholesale Inventory	0.2531	-0.0017	-0.0019	-0.0012	-0.0021
	(0.5867)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
ISM Manufacturing	0.0010	0.0007	-0.0006	-0.0000	-0.0002
	(0.5867)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Empire Manufacturing	-0.7186	0.0000	**0.0079*****	0.0016	**0.0054*****
	(0.6322)	(0.0012)	(0.0026)	(0.0011)	(0.0020)
Chicago PMI	0.0019	0.0002	-0.0010	-0.0004	-0.0005
	(0.5867)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Leading Index	-0.0679	0.0001	0.0014	0.0009	0.0017
	(0.5855)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Housing Start	-0.0854	0.0001	0.0022	0.0015	**0.0030***
	(0.5855)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
New Home Sales	-0.3580	0.0001	-0.0009	-0.0006	-0.0007
	(0.5879)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Existing Home Sales	**-1.2098***	0.0006	**0.0115*****	-0.0010	0.0025
	(0.6813)	(0.0012)	(0.0028)	(0.0012)	(0.0021)
Board Consumer	0.1150	0.0004	0.0008	0.0004	0.0006
	(0.5879)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Michigan Confidence	-0.3393	0.0002	-0.0012	-0.0011	-0.0013
	(0.5879)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Personal Income	0.0399	0.0004	-0.0004	-0.0002	-0.0007
	(0.5904)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Personal Expenditure	0.0399	0.0004	-0.0004	-0.0002	-0.0007
	(0.5904)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Trade Balance	-0.0750	-0.0003	-0.0004	0.0000	-0.0004
	(0.5867)	(0.0012)	(0.0024)	(0.0010)	(0.0018)
Retail Sales	-0.3669	-0.0012	0.0028	0.0007	0.0022
	(0.6116)	(0.0012)	(0.0025)	(0.0011)	(0.0019)
MBA Mortgage Change	**-1.5907*****	0.0001	**0.0080*****	**-0.0016*****	0.0005
	(0.3391)	(0.0006)	(0.0014)	(0.0006)	(0.0011)

Note: The regression result for $Risk_t = \alpha_0 + \alpha_1 \times 1_{t,ReleaseDate} + \epsilon_t$ is presented. Only one indicator is regressed at one time. Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-8. Uncertainty Change Over FOMC Cycle: Under Recessions

ΔVIX_t	Pre5	Pre3	Pre2	Pre1	FOMC	Post1	Post2	Post3	Post5
$1_{t,Bust}$	-0.2386	0.2595	**0.7412****	-0.6166	0.0477	-0.1492	-0.0745	-0.5672	0.0914
	(0.4432)	(0.4023)	(0.3337)	(0.4870)	(0.4131)	(0.4350)	(0.3129)	(0.4911)	(0.3544)
Intercept	0.0782	0.2009	0.1649	0.2122	**-0.5341*****	0.1701	-0.1111	0.2080	0.0060
	(0.1696)	(0.1540)	(0.1277)	(0.1864)	(0.1551)	(0.1665)	(0.1197)	(0.1886)	(0.1356)
R-squared	-0.0046	-0.0038	0.0246	0.0038	-0.0064	-0.0057	-0.0061	0.0021	-0.0060
ΔV_t^{2y}									
$1_{t,Bust}$	-0.0371	-0.1371	0.1901	-0.0374	0.1067	-0.1605	0.0447	-0.0059	-0.0714
	(0.1194)	(0.0983)	(0.1153)	(0.1255)	(0.1430)	(0.1111)	(0.1568)	(0.1221)	(0.1245)
Intercept	0.0612	0.0437	0.0008	0.0438	**-0.1792*****	-0.0320	-0.0187	-0.0671	0.0014
	(0.0429)	(0.0354)	(0.0414)	(0.0468)	(0.0531)	(0.0411)	(0.0566)	(0.0439)	(0.0458)
R-squared	-0.0079	0.0081	0.0147	-0.0081	-0.0039	0.0093	-0.0081	-0.0088	-0.0058
ΔV_t^{5y}									
$1_{t,Bust}$	-0.0061	0.0062	0.0673	-0.1040	**-0.3630*****	-0.1247	0.0094	0.0028	0.1102
	(0.1072)	(0.1174)	(0.1281)	(0.1148)	(0.1366)	(0.1241)	(0.1262)	(0.1150)	(0.1024)
Intercept	-0.0209	0.0465	0.0868*	0.0075	**-0.1874*****	-0.0151	**0.0803***	-0.0430	-0.0562
	(0.0410)	(0.0449)	(0.0490)	(0.0439)	(0.0523)	(0.0476)	(0.0483)	(0.0442)	(0.0392)
R-squared	-0.0064	-0.0064	-0.0047	-0.0012	0.0374	0.0001	-0.0064	-0.0065	0.0010
ΔV_t^{10y}									
$1_{t,Bust}$	**0.1234****	-0.0405	**0.1456***	0.0282	**-0.1525*****	**-0.1694****	0.0281	0.0378	0.0640
	(0.0554)	(0.0605)	(0.0867)	(0.0805)	(0.0572)	(0.0690)	(0.0601)	(0.0716)	(0.0519)
Intercept	**-0.0445****	**0.0521****	**0.0880*****	-0.0187	**-0.1375*****	0.0398	0.0199	0.0349	**-0.0622*****
	(0.0212)	(0.0231)	(0.0332)	(0.0308)	(0.0219)	(0.0265)	(0.0230)	(0.0275)	(0.0199)
R-squared	0.0248	-0.0035	0.0115	-0.0057	0.0376	0.0314	-0.0050	-0.0047	0.0033
ΔV_t^{30y}									
$1_{t,Bust}$	0.0904	**-0.2180****	0.0149	0.0923	0.0036	**-0.3578*****	0.0992	-0.0582	-0.0934
	(0.0713)	(0.1011)	(0.1295)	(0.1065)	(0.0993)	(0.1306)	(0.1077)	(0.1230)	(0.0672)
Intercept	-0.0335	**0.1395*****	**0.1491*****	0.0039	**-0.2390*****	0.0668	0.0413	**0.0808***	**-0.0469***
	(0.0273)	(0.0388)	(0.0497)	(0.0408)	(0.0380)	(0.0501)	(0.0412)	(0.0474)	(0.0257)
R-squared	0.0039	0.0230	-0.0064	-0.0016	-0.0064	0.0403	-0.0010	-0.0051	0.0059

Note: This table regresses change of uncertainty around FOMC cycle on dummy variables indicating the economic recessions, so that the coefficients on 1_{Bust} manifest how much the risk will change more or less over the FOMC cycle under financial contractions. The unit of uncertainty is 1%.

Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-9. Uncertainty Change Over FOMC Cycle: Decomposed FOMC Days

ΔVIX_t	Pre5	Pre3	Pre2	Pre1	FOMC	Post1	Post2	Post3	Post5
$1_{t,Expand}$	0.1137	-0.1175	**0.6268***	-0.1890	-0.0031	-0.5997	0.0579	-0.3823	-0.1944
	(0.4534)	(0.4117)	(0.3421)	(0.5001)	(0.4218)	(0.4421)	(0.3179)	(0.5035)	(0.3621)
$1_{t,Contract}$	0.1332	-0.1127	-0.1524	-0.1895	0.1643	0.0139	0.4144	-0.0810	-0.0513
	(0.4188)	(0.3803)	(0.3160)	(0.4620)	(0.3826)	(0.4084)	(0.2936)	(0.4652)	(0.3345)
Intercept	0.0028	0.2762	0.2089	0.1834	**-0.5564*****	0.2336	-0.2044	0.1953	0.0570
	(0.1914)	(0.1738)	(0.1445)	(0.2112)	(0.1749)	(0.1867)	(0.1342)	(0.2134)	(0.1529)
R-squared	-0.0121	-0.0121	0.0132	-0.0113	-0.0118	-0.0004	0.0000	-0.0093	-0.0111
ΔV_t^{5y}									
$1_{t,Expand}$	-0.0049	-0.0963	**0.2176***	-0.1126	-0.0848	-0.1577	0.0162	0.0834	0.2055**
	(0.1095)	(0.1196)	(0.1297)	(0.1173)	(0.1427)	(0.1266)	(0.1287)	(0.1195)	(0.1033)
$1_{t,Contract}$	-0.0208	-0.1018	0.1074	-0.0625	-0.0329	-0.0242	0.1057	-0.0236	0.1506
	(0.1012)	(0.1104)	(0.1198)	(0.1083)	(0.1318)	(0.1186)	(0.1189)	(0.1084)	(0.0954)
Intercept	-0.0173	0.0796	0.0457	0.0200	**-0.2223*****	-0.0060	0.0605	-0.0501	**-0.0970****
	(0.0463)	(0.0505)	(0.0548)	(0.0495)	(0.0602)	(0.0534)	(0.0543)	(0.0495)	(0.0436)
R-squared	-0.0127	-0.0048	0.0073	-0.0059	-0.0105	-0.0029	-0.0078	-0.0090	0.0215
ΔV_t^{10y}									
$1_{t,Expand}$	0.0419	**-0.1226****	**0.2973*****	-0.0852	**-0.0988***	-0.1374*	0.0252	0.1150	0.0108
	(0.0574)	(0.0610)	(0.0862)	(0.0815)	(0.0591)	(0.0710)	(0.0613)	(0.0739)	(0.0532)
$1_{t,Contract}$	0.0040	-0.0542	0.0453	-0.1243	0.0385	-0.0372	0.0593	-0.0340	0.0481
	(0.0530)	(0.0564)	(0.0796)	(0.0753)	(0.0546)	(0.0666)	(0.0566)	(0.0670)	(0.0491)
Intercept	-0.0333	**0.0738*****	0.0577	0.0201	**-0.1522*****	0.0415	0.0097	0.0304	**-0.0630*****
	(0.0242)	(0.0258)	(0.0364)	(0.0344)	(0.0250)	(0.0300)	(0.0259)	(0.0306)	(0.0224)
R-squared	-0.0095	0.0150	0.0598	0.0081	0.0120	0.0114	-0.0055	0.0070	-0.0067
ΔV_t^{30y}									
$1_{t,Expand}$	0.0534	**-0.2614****	**0.2478***	0.0596	-0.0870	**-0.2641***	0.0717	0.0139	-0.0311
	(0.0730)	(0.1027)	(0.1308)	(0.1081)	(0.1004)	(0.1348)	(0.1099)	(0.1279)	(0.0684)
$1_{t,Contract}$	0.0622	-0.1147	0.1085	-0.1559	-0.1669*	0.0187	0.1065	-0.0929	0.0995
	(0.0674)	(0.0949)	(0.1209)	(0.0998)	(0.0927)	(0.1264)	(0.1016)	(0.1160)	(0.0632)
Intercept	-0.0391	**0.1665*****	**0.0952***	0.0365	**-0.1960*****	0.0497	0.0263	0.0870	**-0.0737****
	(0.0308)	(0.0435)	(0.0555)	(0.0456)	(0.0424)	(0.0569)	(0.0464)	(0.0532)	(0.0289)
R-squared	-0.0054	0.0313	0.0120	0.0076	0.0097	0.0135	-0.0044	-0.0084	0.0068

Note: This table regresses change of uncertainty risk over the FOMC cycle on dummy variables indicating the monetary policy change. For example, the coefficients on 1_{Expand} manifest how much the risk will change more or less with an Expansionary policy compared with no change in the target interest rate. The unit of uncertainty is 1%.

Standard errors in parentheses. *p: 0.1, **p: 0.05, ***p: 0.01

Table A-10. Stock Return After Highlighted Risk Days

Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat
Vol	$\eta = 0$			Vol	$\eta = 0.15$			Vol	$\eta = 0.30$		
+4.0	4.5	**42.76**	3.20	+4.0	4.8	**32.54**	2.48	+4.0	5.2	**51.42**	4.16
+3.5	6.3	22.45	1.92	+3.5	6.3	**38.33**	3.39	+3.5	6.8	**44.41**	4.14
+3.0	8.4	**33.67**	3.44	+3.0	8.6	**44.59**	4.69	+3.0	9.2	**52.82**	5.76
+2.5	11.7	**27.61**	3.32	+2.5	12.1	**35.10**	4.34	+2.5	12.7	**26.32**	3.29
+2.0	16.7	**23.20**	3.32	+2.0	17.2	**25.39**	3.72	+2.0	17.7	**23.44**	3.47
+1.5	25.9	**17.51**	3.11	+1.5	25.8	**15.54**	2.72	+1.5	26.6	**18.48**	3.35
+1.0	40.4	**10.14**	2.14	+1.0	40.1	**11.15**	2.39	+1.0	41.8	**12.81**	2.88
+0.5	67.3	**8.09**	2.25	+0.5	67.4	**7.99**	2.22	+0.5	67.6	**7.41**	2.02
+0	114.7	3.90	1.18	+0.0	113.9	4.57	1.53	+0.0	112.3	**6.37**	2.45
-0	133.1	0.05	0.99	-0	135.6	-0.74	1.51	-0	137.2	**-2.15**	2.43
-0.5	77.7	1.93	0.10	-0.5	78.3	-0.45	0.82	-0.5	80.6	-0.87	1.01
-1.0	43.4	1.72	0.01	-1.0	44.3	-0.63	0.61	-1.0	44.8	0.31	0.37
-1.5	25.0	-2.34	0.77	-1.5	24.7	1.06	0.12	-1.5	25.5	-4.85	1.26
-2.0	15.1	-3.40	0.74	-2.0	14.7	-10.69	1.78	-2.0	15.2	**-13.87**	2.27
-2.5	9.3	0.55	0.13	-2.5	8.8	-6.40	0.89	-2.5	9.2	-13.07	1.65
-3.0	5.8	18.99	1.54	-3.0	5.8	-0.62	0.20	-3.0	6.0	0.04	0.15
-3.5	3.8	16.05	1.04	-3.5	3.9	9.13	0.54	-3.5	4.2	-20.81	1.68
Cutoff	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat
Skew	$\eta = 0$			Skew	$\eta = 0.15$			Skew	$\eta = 0.30$		
+0.7	4.8	12.49	0.88	0.7	4.1	19.01	1.28	0.7	3.6	14.11	0.86
+0.6	6.8	14.66	1.25	0.6	6.5	14.18	1.18	0.6	6.2	21.68	1.83
+0.5	11.2	**19.97**	2.29	0.5	10.3	16.37	1.76	0.5	9.8	11.58	1.15
+0.4	17.3	10.88	1.45	0.4	16.4	**21.81**	3.08	0.4	15.9	**16.93**	2.29
+0.3	26.3	6.31	0.92	0.3	25.6	**12.21**	2.05	0.3	25.0	**15.7**	2.72
+0.2	44.7	7.38	1.54	0.2	43.3	9.02	1.94	0.2	43.3	**11.56**	2.61
+0.1	75.8	6.55	1.86	0.1	76.4	**8.06**	2.45	0.1	77.2	**7.45**	2.23
+0	123.9	4.10	1.39	0	124.5	**5.23**	2.04	0	124.7	4.12	1.41
-0	123.1	-0.22	1.07	-0	122.6	-1.75	1.93	-0	122.4	-0.64	1.30
-0.1	75.7	1.05	0.23	-0.1	74.3	0.63	0.39	-0.1	74.8	0.46	0.46
-0.2	45.3	-1.58	0.88	-0.2	43.9	-3.32	1.33	-0.2	43.6	-2.21	1.03
-0.3	26.7	-6.36	1.60	-0.3	25.9	-4.55	1.22	-0.3	25.8	-1.55	0.63
-0.4	16.5	-1.12	0.43	-0.4	15.9	-8.02	1.46	-0.4	15.6	-8.45	1.51
-0.5	10.5	-6.52	0.99	-0.5	10.3	-13.88	1.86	-0.5	10.3	-13.43	1.80
-0.6	7	**-18.81**	2.00	-0.6	6.5	-6.20	0.74	-0.6	6.4	-5.17	0.64
-0.7	4.8	-10.75	1.00	-0.7	4.1	12.26	1.03	-0.7	3.9	-13.78	1.12

Note: This table presents the stock return after highlighted risk days, which are determined by Equation 9 and 10, so that risk is higher than the previous exponential moving average μ_{t-1} (see Equation 11) by the cutoff. ”N Days” represents how many days in one year (on average) belong to the heightened risk days. ”Return” gives the next-day bond yield change. ”T-stat” compares the mean of return to ordinary days.

Table A-11. 2 Year Bond Yield Change After Highlighted Risk Days

Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat
Vol	$\eta = 0$			Vol	$\eta = 0.15$			Vol	$\eta = 0.30$		
+1.1	4.2	-0.75	1.18	+1.1	3.2	-1.15	1.64	+1.1	3.5	**-1.83**	2.80
+0.9	6.2	-0.39	0.69	+0.9	5.1	-0.71	1.22	+0.9	5.2	-0.07	0.00
+0.7	8.9	-0.34	0.68	+0.7	7.7	-0.06	0.02	+0.7	7.9	-0.17	0.25
+0.5	13.4	-0.30	0.73	+0.5	12.3	-0.18	0.33	+0.5	12.9	-0.23	0.51
+0.3	22.7	0.17	1.03	+0.3	20.9	0.25	1.29	+0.3	22.9	0.17	1.04
+0.1	50.6	0.15	1.49	+0.1	48.5	0.09	1.07	+0.1	50.1	0.08	1.00
+0	88.4	**0.14**	2.04	+0	84.6	0.12	1.84	+0	84.3	0.10	1.65
-0	97.2	-0.18	1.16	-0	97.8	-0.17	1.03	-0	95.2	-0.15	0.85
-0.1	54.9	**-0.39**	2.26	-0.1	54.5	**-0.41**	2.38	-0.1	55.7	**-0.35**	2.02
-0.3	20.6	-0.39	1.29	-0.3	19.9	-0.53	1.82	-0.3	20.7	**-0.59**	2.09
-0.5	11.8	-0.48	1.23	-0.5	10.1	-0.33	0.71	-0.5	11.2	**-0.83**	2.21
-0.7	8.3	-0.58	1.27	-0.7	6.9	-0.66	1.32	-0.7	6.6	-0.72	1.43
-0.9	5.9	**-1.37**	2.70	-0.9	4.8	-0.76	1.29	-0.9	4.6	-0.92	1.56
-1.1	4.2	-0.9	1.45	-1.1	3.3	-0.77	1.09	-1.1	2.9	-1.04	1.41
Cutoff	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat
Skew	$\eta = 0$			Skew	$\eta = 0.15$			Skew	$\eta = 0.30$		
+2.0	5.1	0.44	0.98	+2.0	4.1	0.4	0.82	+2.0	4.2	0.46	0.92
+1.5	7.1	0.28	0.79	+1.5	5.9	0.08	0.31	+1.5	6.0	0.18	0.52
+1.0	10.4	-0.29	0.62	+1.0	8.4	0.01	0.21	+1.0	8.9	0.08	0.39
+0.5	18.1	-0.18	0.40	+0.5	16.0	0.07	0.50	+0.5	17.8	-0.00	0.25
+0.2	35.9	-0.21	0.75	+0.2	33.2	-0.22	0.79	+0.2	35.3	-0.22	0.83
+0.1	51.5	-0.19	0.80	+0.1	47.9	-0.13	0.39	+0.1	49.9	-0.11	0.26
+0	89.57	-0.09	0.20	+0	85.0	-0.12	0.52	+0	85.1	-0.11	0.35
-0	92.2	-0.00	0.71	-0	87.4	0.06	1.24	-0	87.4	0.04	1.07
-0.1	52.8	0.09	1.10	-0.1	49.7	0.10	1.11	-0.1	52.8	0.08	1.04
-0.2	36.2	0.11	1.00	-0.2	34.3	0.16	1.23	-0.2	37.2	0.13	1.13
-0.5	19.0	0.01	0.32	-0.5	16.1	0.29	1.27	-0.5	18.3	0.10	0.65
-1.0	11.2	-0.38	0.90	-1.0	9.0	-0.28	0.54	-1.0	9.4	-0.30	0.60
-1.5	7.7	-0.19	0.29	-1.5	5.7	-0.13	0.12	-1.5	6.3	-0.37	0.64
-2.0	5.8	-0.53	0.94	-2.0	4.0	-0.11	0.06	-2.0	4.0	-0.29	0.37

Note: This table presents the 2-year bond yield change after highlighted risk days, which are determined by Equation 9 and 10, so that risk is higher than the previous exponential moving average μ_{t-1} (see Equation 11) by the cutoff. ”N Days” represents how many days in one year (on average) belong to the heightened risk days. ”Return” gives the next-day bond yield change. ”T-stat” compares the mean of yield change to ordinary days.

Table A-12. 5 Year Bond Yield Change After Highlighted Risk Days

Cutoff	N Days	Ret	T-stat	Cutoff	N Days	Ret	T-stat	Cutoff	N Days	Ret	T-stat
(%)	(/year)	(bps)		(%)	(/year)	(bps)		(%)	(/year)	(bps)	
Vol	$\eta = 0$			Vol	$\eta = 0.15$			Vol	$\eta = 0.30$		
+1.4	4.2	-0.13	0.08	+1.4	3.9	0.31	0.55	+1.4	4.0	0.53	0.88
+1.2	5.8	-0.37	0.53	+1.2	6.1	-0.17	0.18	+1.2	5.9	0.04	0.19
+1.0	9.21	-0.18	0.25	+1.0	8.7	-0.05	0.04	+1.0	8.4	-0.17	0.21
+0.8	13.5	-0.42	0.96	+0.8	13.2	-0.18	0.29	+0.8	13.2	-0.13	0.15
+0.6	20.2	-0.15	0.27	+0.6	20.2	-0.15	0.27	+0.6	19.8	-0.01	0.20
+0.4	34.9	-0.11	0.17	+0.4	33.7	-0.10	0.14	+0.4	34.2	0.00	0.35
+0.2	61.4	-0.06	0.08	+0.2	61.7	-0.12	0.34	+0.2	61.5	-0.05	0.17
+0	118.6	0.01	0.88	+0	119.1	-0.05	0.23	+0	117.8	-0.01	0.68
-0	130.1	-0.14	0.85	-0	130.4	-0.09	0.23	-0	131.6	-0.13	0.68
-0.2	65.2	0.43	-0.2	65.1	-0.12	0.30	-0.2	65.8	-0.20	0.89	
-0.4	33.1	-0.48	1.84	-0.4	33.3	**-0.52**	2.02	-0.4	33.9	-0.39	1.44
-0.6	20.1	-0.59	1.77	-0.6	18.8	**-0.81**	2.40	-0.6	18.9	-0.59	1.70
-0.8	12.1	-0.52	1.14	-0.8	12.2	-0.58	1.32	-0.8	11.3	-0.64	1.43
-1.0	8.0	-0.77	1.45	-1.0	7.6	-0.58	1.02	-1.0	7.5	-0.78	1.42
-1.2	5.2	-0.77	1.15	-1.2	4.8	-0.46	0.62	-1.2	4.9	-0.72	1.05
-1.4	3.5	0.39	0.63	-1.4	3.3	0.39	0.61	-1.4	3.0	-0.05	0.03
Cutoff	N Days	Ret	T-stat	Cutoff	N Days	Ret	T-stat	Cutoff	N Days	Ret	T-stat
	(/year)	(bps)		(%)	(/year)	(bps)		(%)	(/year)	(bps)	
Skew	$\eta = 0$			Skew	$\eta = 0.15$			Skew	$\eta = 0.30$		
+5.0	4.8	0.30	0.59	+5.0	2.5	0.09	0.18	+5.0	2.3	-0.07	0.01
+4.0	6.7	-0.02	0.09	+4.0	3.6	-0.09	0.02	+4.0	3.6	0.10	0.24
+3.0	8.6	0.04	0.25	+3.0	5.1	-0.21	0.22	+3.0	5.1	-0.44	0.61
+2.0	12.6	-0.10	0.07	+2.0	8.4	-0.38	0.66	+2.0	8.7	-0.43	0.79
+1.0	24.3	-0.15	0.27	+1.0	18.4	0.12	0.63	+1.0	18.2	-0.01	0.21
+0.5	43.1	-0.23	0.83	+0.5	35.8	-0.12	0.20	+0.5	36.5	-0.17	0.46
+0.1	86.7	0.02	0.76	+0.1	80.9	0.16	1.88	+0.1	82.8	0.09	1.34
+0	117.6	-0.05	0.27	+0	113.3	0.04	1.15	+0	112.5	0.09	1.74
-0	120.8	-0.03	0.47	-0	133.3	-0.12	0.48	-0	114.0	-0.17	1.07
-0.1	89.1	-0.05	0.15	-0.1	81.7	-0.06	0.10	-0.1	82.7	-0.12	0.37
-0.5	40.4	-0.08	0.06	-0.5	33.8	-0.28	0.94	-0.5	33.6	-0.18	0.46
-1.0	24.6	-0.19	0.44	-1.0	18.0	-0.21	0.45	-1.0	17.2	-0.3	0.71
-2.0	12.7	0.07	0.37	-2.0	7.8	-0.05	0.05	-2.0	7.7	0.11	0.37
-3.0	8.4	0.23	0.64	-3.0	4.6	0.52	0.92	-3.0	4.6	0.26	0.53
-4.0	6.2	0.09	0.3	-4.0	3.3	0.47	0.71	-4.0	3.2	-0.13	0.08
-5.0	4.7	0.45	0.83	-5.0	2.4	0.26	0.38	-5.0	2.4	0.61	0.77

Note: This table presents the 5-year bond yield change after highlighted risk days, which are determined by Equation 9 and 10, so that risk is higher than the previous exponential moving average μ_{t-1} (see Equation 11) by the cutoff. ”N Days” represents how many days in one year (on average) belong to the heightened risk days. ”Return” gives the next-day bond yield change. ”T-stat” compares the mean of yield change to ordinary days.

Table A-13. 30 Year Bond Yield Chnage After Highlighted Risk Days

Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat
Vol	$\eta = 0$			Vol	$\eta = 0.15$			Vol	$\eta = 0.30$		
+1.2	4.7	0.89	1.72	+1.2	4.8	**1.22**	2.32	+1.2	5.3	**1.64**	3.25
+1.0	6.6	0.48	1.18	+1.0	6.8	**1.03**	2.38	+1.0	7.3	**1.18**	2.80
+0.8	10.3	-0.08	0.59	+0.8	11.4	0.17	0.66	+0.8	11.5	0.31	1.07
+0.6	17.2	0.33	1.39	+0.6	17.5	0.45	1.84	+0.6	18.2	0.41	1.73
+0.4	29.9	0.10	0.82	+0.4	30.8	0.28	1.69	+0.4	31.9	**0.37**	2.17
+0.2	60.6	0.09	1.15	+0.2	59.8	**0.24**	2.24	+0.2	60.3	**0.36**	3.08
+0	115.1	-0.02	0.6	+0	114.5	0.07	1.6	+0	113.8	**0.13**	2.29
-0	133.4	-0.12	0.72	-0	132.6	-0.18	1.47	-0	133.4	**-0.22**	2.16
-0.2	69.8	-0.21	1.09	-0.2	68.5	**-0.35**	2.21	-0.2	69.2	**-0.32**	1.96
-0.4	32.6	**-0.58**	2.56	-0.4	31.4	**-0.76**	3.35	-0.4	32.4	**-0.61**	2.69
-0.6	14.4	**-1.06**	3.16	-0.6	13.6	**-0.91**	2.60	-0.6	14.6	**-0.99**	2.95
-0.8	6.5	**-1.07**	2.11	-0.8	6.4	-0.74	1.40	-0.8	6.5	-0.61	1.14
-1.0	3.4	-0.71	0.97	-1.0	3.3-1.04	1.45		-1.0	3.4	-0.62	0.83
-1.2	1.6	**-2.05**	2.03	-1.2	1.9	-1.66	1.79	-1.2	1.8	**-2.5**	2.7
Cutoff	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat	Cutoff (%)	N Days (/year)	Ret (bps)	T-stat
Skew	$\eta = 0$			Skew	$\eta = 0.15$			Skew	$\eta = 0.30$		
+2.5	4.4	-0.36	0.50	+2.5	4.2	-0.38	0.52	+2.5	4.3	-0.34	0.46
+2.0	6.1	0.02	0.18	+2.0	5.6	-0.31	0.47	+2.0	5.6	-0.13	0.12
+1.5	10.4	0.04	0.28	+1.5	9.1	-0.09	0.04	+1.5	9.5	0.08	0.39
+1.0	17.5	0.05	0.42	+1.0	16.9	0.15	0.75	+1.0	16.6	0.27	1.18
+0.5	42.1	-0.21	0.83	+0.5	40.2	-0.14	0.39	+0.5	39.3	-0.06	0.03
+0.2	78.8	-0.13	0.54	+0.2	77.4	-0.01	0.55	+0.2	77.8	-0.07	0.03
+0	123.3	-0.14	0.96	+0	122.4	-0.14	0.86	+0	121.4	-0.12	0.57
-0	124.9	-0.0	0.85	-0	123.6	0.0	0.93	-0	124.6	-0.02	0.64
-0.2	85.4	-0.12	0.46	-0.2	82.5	-0.12	0.43	-0.2	81.1	-0.05	0.17
-0.5	44.2	-0.07	0.03	-0.5	41.4	-0.01	0.34	-0.5	39.9	-0.19	0.66
-1.0	17.3	-0.27	0.70	-1.0	15.7	-0.34	0.91	-1.0	14.7	-0.67	1.92
-1.5	8.0	-0.33	0.62	-1.5	7.0	-0.25	0.39	-1.5	7.4	-0.2	0.31
-2.0	4.6	-0.27	0.36	-2.0	4.6	-0.13	0.10	-2.0	4.5	0.18	0.44
-2.5	3.1	-0.16	0.14	-2.5	3.0	0.04	0.15	-2.5	2.8	0.22	0.41

Note: This table presents the 30-year bond yield change after highlighted risk days, which are determined by Equation 9 and 10, so that risk is higher than the previous exponential moving average μ_{t-1} (see Equation 11) by the cutoff. ”N Days” represents how many days in one year (on average) belong to the heightened risk days. ”Return” gives the next-day bond yield change. ”T-stat” compares the mean of yield change to ordinary days.