Exposure to Interest Rate Risk around Monetary Policy Announcements

Masayuki Okada*

March 11, 2025

Abstract

This paper investigates the monetary policy announcement premium by focusing on the intest rate uncertainty and heteregeneity of asset durations. First, the average returns of long-maturity Treasury bonds are higher than those of short-maturity bonds on monetary policy announcement days. Second, the average returns of long-duration equities are statistically indistinguishable from those of short-duration equities on announcement days, whereas on non-announcement days, long-duration equities yield lower returns. This term structure on announcement days is attributed to the resolution of interest rate uncertainty, as measured by the option-implied volatility of Eurodollar futures. I find that the elasticity of returns to changes in interest rate uncertainty is higher for long-duration assets than for short-duration assets, a result that holds for both bonds and equities. This paper highlights interest rate uncertainty in driving the announcement premium, a factor that has been underemphasized in previous research, which has primarily focused on cash flow uncertainty.

*Ph.D. student at New York University. Email: mo2192@nyu.edu. I thank Kosuke Aoki, Jaroslav Borovička, Simon Gilchrist, Ricardo Lagos, Sydney Ludvigson, and Kenji Wada for helpful comments and suggestions.

1 Introduction

This paper examines the risk resolved by monetary policy announcements and the heterogeneity in asset exposure to these risk. Uncertainty arises before announcements and investors exposed to this risk demand a return. Asset returns are expected to be higher, a phenomenon known as the announcement premium (Savor and Wilson, 2013). Monetary policy announcements reveal information about risk factors, and assets more exposed to these risks predictably yield higher returns. A crucial question is identifying the type of risk investors face and which assets are more exposed to it. The findings are that (i) interest rate risk resolved by announcements brings higher average returns, and (ii) the duration of assets is the source of heterogeneity in risk exposure.

First, monetary policy announcements reveal information about future interest rate as found in the literature (Bauer et al., 2022). The option-implied volatility of interest rate is significantly reduced following monetary policy announcements. However, the resolution of interest rate uncertainty has been underemphasized in the announcement premium literature, which focuses primarily on cash flow uncertainty (Ai and Bansal, 2018; Wachter and Zhu, 2022).

Second, assets with different durations are exposed differently to interest rate risk. When interest rate unexpectedly increases, investors devalue long-duration assets more by discounting future returns with higher rates. Conversely, when the central bank announces an interest rate cut, long-duration assets are valued higher. Announcements generally resolve interest rate uncertainty, leading investors who prefer early resolution to value long-duration assets more. Short-duration assets, on the other hand, are less sensitive to interest rate because they pay more in the near term, resulting in smaller price changes.

I develop a simple asset pricing model where a representative investor with recursive preferences trades assets while facing risks. The investor can trade short-duration assets, which provide claims on consumption in the near future, and long-duration assets, which provide claims on consumption in the distant future. The investor faces two types of risk: cash flow risk and discount rate risk. The investor discounts future consumption, but the discount factor is uncertain before announcements as a key novelty of this paper. Additionally, the future cash flow of assets is uncertain as in the literature. Long-duration assets are more exposed to discount rate risk, as their claims are in the distant future. Short-duration assets are more sensitive to cash flow uncertainty, as monetary policy affects short-term cash flows but has a neutral impact in the long run. An announcement resolves both risks; the central bank announces the short-term interest rate that the investor uses as a discount factor, and the impact of monetary policy on cash flows in the near future is revealed.

There are two theoretical predictions applied to both bonds and equities. The first prediction is about expected return across different durations. For bonds, bonds with longer durations are expected to yield higher average returns than short-duration bonds on announcement days. Returns on long duration bonds are more sensitive to a change in the discount rate, as they give a consumption claim later. The price of long-duration bonds increases more than short duration bonds because monetary policy announcement reduces interest rate uncertainty, leading investors to value long-duration bonds more highly.

In contrast to bonds, the relative expected returns for short- versus long-duration equities are ambiguous. The difference between bonds and equities is that the cash flow of equities is uncertain whereas the cash flow of bonds is fixed. Short-duration equities are more sensitive to cash flow risk from monetary policy announcements, as monetary policy is non-neutral in the short run but neutral in the long run. This higher exposure to cash flow risk could offset the higher exposure of long-duration equities to discount rate risk.

The second prediction is about the contemporaneous relationship between the realized change in interest rate uncertainty and returns on announcement days. The theoretical prediction is that the elasticity of returns to changes in interest rate uncertainty is higher for long-duration assets than for short-duration assets. Intuitively, consider two announcements: When interest rate uncertainty decreases, long-duration assets yield higher returns than short-duration assets. Conversely, when interest rate uncertainty increases, the price of long-duration assets drops more.

I empirically test the theoretical predictions using key variables such as the duration measure and interest rate uncertainty. The duration of bonds is well defined using zero-coupon bond yield data (Liu and Wu, 2021). The duration of equity is measured by the cash flow of firms based on Weber (2018). Additionally, the book-to-market ratio is used as a proxy for the duration of equity (Hansen et al., 2008). Interest rate uncertainty is measured using the option-implied volatility of the Eurodollar future (Bauer et al., 2022). For bonds, I use U.S. Treasury bonds, and for equities, I use publicly traded firms in the U.S.

First, I test predictions about the average returns of bonds and equities. I find that bonds with longer duration have higher expected returns. Treasury bonds with a maturity of 5 years have an average return of 4.8 bps, while those with a maturity of 20 years have an average return of 10.0 bps on monetary policy announcement days. This aligns with the idea that bonds are exposed to discount rate risk, with long-duration bonds being more exposed.

In contrast to bonds, equities do not show a positive relationship between duration and expected returns. Equities with maturities of 13 and 22 years have average returns of 17.5 and 17.3 basis points, respectively, making the returns on short- and long-duration equities statistically indistinguishable. This contrasts with literature observing a downward-sloping term structure of equity (Lettau and Wachter, 2011; Weber, 2018). The average monthly returns of long-duration equities are *lower* than short-duration equities: The return on the shortest duration portfolio is 10.6 bps, while the returns on the longest is 2.5 bps. On FOMC announcement days, the downward-sloping term structure does not hold, suggesting that discount factor risk is as important as cash flow risk.

To verify the importance of discount rate risk, I compare the average returns for two subsamples where interest rate uncertainty increases or decreases beyond a specific threshold. The term structure differs between subsamples. long-minus-short-duration bonds yield 33.9 basis points when uncertainty decreases and -32.3 basis points when it increases. For equities, the average return of long-minus-short-duration is 17.5 basis points when uncertainty decreases and -32.3 basis points when it increases. The downward-sloping term structure is evident for announcements that increase uncertainty.

In the second empirical exercise, I demonstrate that the elasticity of returns to changes in interest rate uncertainty increases with duration for both bonds and equities. For example, when interest rate uncertainty decreases by 1% on FOMC days, the return increases by 6.8 basis points for 10-year bonds and by 4.1 basis points for 5-year bonds.

To further verify the importance of interest rate risk, I also find that the elasticity of returns to changes in the VIX does not increase with duration. When the VIX decreases by 1% on FOMC days, the return increases by 0.1 basis points for 10-year bonds and by 0.9 basis points for 5-year bonds. Interest rate uncertainty is a more important factor in driving the announcement premium for bonds than the VIX.

For equities with a duration of 25 years, the elasticity of the return to interest rate uncertainty is

12, meaning that the return increases by 12bps when interest rate uncertainty decreases by 1% on announcement days. For equities with a duration of 7 years, the elasticity is lower at 8, indicating a weaker response compared to long-duration equities. For bonds, the elasticity is 6 for 10-year maturities and 9 for 20-year maturities, indicating that the elasticity of long-duration bonds is higher than that of short-duration bonds.

As a sensitivity analysis, I test the robustness of the results by using different measures of equity duration and interest rate uncertainty. For the duration of equities, I use the book-to-market ratio as a proxy, following the literature (Lettau and Wachter, 2007; Hansen et al., 2008). For interest rate uncertainty, I use two implied volatility measures based on ATM Eurodollar option prices and Treasury option prices. The results are consistent with the main findings.

The paper proceeds as follows. Section 2 presents data that highlights the cross-sectional heterogeneity in exposure to monetary policy announcements. Section 3 shows a simple theory and presents the testable theoretical predictions. Section 4 explains the data and constructs the variables. Section 5 empirically tests the theoretical predictions for bonds. Section 6 empirically tests the theoretical predictions for equity.

Related Literature This paper relates to three strands of literature. First, this paper relates to the literature on macro announcement premium. Savor and Wilson (2013) find that there is a high excess return of stocks and bonds on the days of macro announcements. Various empirical evidence of announcement premium has been studied in the empirical literature. [1].

Since the emergence of empirical evidence, the theoretical literature has developed a model for the macroeconomic announcement premium. Ai and Bansal (2018) provide a revealed preference theory for the announcement premium. Wachter and Zhu (2022) show a model based on rare disasters and the success of the CAPM model on announcing days. Ai et al. (2022) develop a model in which risk compensation is required because FOMC announcements reveal the Fed's private information about its interest rate target and future economic growth rate.

This paper differs from the literature by analyzing the discount factor risk because of interest

[1] Lucca and Moench (2015) find that a high excess return is driven by a pre-announcement drift on FOMC announcement days. Other example includes Brusa et al. (2020); Neuhierl and Weber (2018); Cieslak et al. (2019); Mueller et al. (2017); Indriawan et al. (2021); Wachter and Zhu (2022)

rate uncertainty from theoretical and empirical perspectives, whereas the literature focuses mainly on uncertainty about future cash flow. Empirically, Lucca and Moench (2015) and Hu et al. (2022) find that the excess return is higher when the uncertainty about the aggregate cash flow, as measured by the VIX, declines more on the day of the FOMC announcement. Zhang and Zhao (2023) also analyses the contemporaneous relation between uncertainty reduction and announcement premium, but the VIX is used to measure the uncertainty. In contrast to their study, I take into account interest rate uncertainty, not aggregate stock return uncertainty measured by VIX. Theoretically, Wachter and Zhu (2022) and Ai et al. (2022) models cash flow risk, where as my paper models both discount factor risk and cash flow risk.

Another difference from the literature is to focus on duration as cross-sectional heterogeneity in exposure to announcements. The literature tests a risk-based hypothesis by examining the cross-sectional heterogeneity of assets. Savor and Wilson (2014) and Wachter and Zhu (2022) show that the relationship between market beta and expected returns is stronger on announcement days. The literature assume that the parameters governing the cross-sectional sensitivity to monetary policy are exogenous, and they do not focus on why they are exposed differently [2]. This paper provides an interpretation of the cross-sectional sensitivity to monetary policy based on duration.

Second, this paper is in line with the literature on the importance of monetary policy uncertainty on asset prices. Bundick et al. (2017) estimates the positive effects of changes in short-term uncertainty on the term premium on announcement days. Bauer et al. (2022) finds effects of uncertainty reduction on asset prices that are distinct from the effects of conventional policy surprises. Lakdawala et al. (2021) show that the change in uncertainty affects the spillovers to global bond yields. Kroencke et al. (2021) identify a change in risk appetite on FOMC announcement days and show that this measure is correlated with stock returns.

My contribution to this literature is to relate the high excess returns on FOMC announcement days to a measure of monetary policy uncertainty. The literature examines the causal impact of monetary policy uncertainty on financial and macroeconomic variables. The measure of monetary policy uncertainty is used to test the relationship with high excess returns on FOMC announcement days.

[2] Other example is Ai et al. (2022). This paper provides empirical evidence that a firm's expected option-implied variance reduction on announcement days strongly predicts excess returns.

Third, my paper relates to the literature that studies the heterogeneous impact of monetary policy on firm-level equity. Bernanke and Kuttner (2005) show that the response of stock returns varies across industries. Ippolito et al. (2018) find that stock prices of bank-dependent firms are more responsive to changes in the federal funds rate. Ozdagli (2018) and Chava and Hsu (2020) study the relationship between financially constrained firms and the return response after a monetary policy shock. Lagos and Zhang (2020) shows heterogeneity in stock turnover liquidity as a novel mechanism of monetary policy. Gürkaynak et al. (2022) shows that the stock price response to monetary policy depends on the maturity of debt issued by firms. Döttling and Ratnovski (2022) find that stock prices of firms with relatively more intangible assets respond less to monetary policy. My contribution to the literature is the study of the heterogeneous effect of the second moment of the policy rate on stocks. The literature focuses mainly on the change in the first moment of the federal funds rate. The heterogeneous effect of monetary policy uncertainty on firm stock prices is studied in this paper.

2 Cross-sectional Heterogeneity in Exposure to Monetary Policy Announcements

This section shows the cross-sectional heterogeneity in the risk exposure of S&P 500 firms to monetary policy announcements. I compute the time-series average of daily returns on FOMC days for each of the S&P 500 firms over the sample period (1990/1-2019/12). Firms were then sorted into five groups, from low to high, based on these time-series average returns. The mean and standard deviation of daily returns on FOMC and non-FOMC days for each group are reported in Table 1. The results show variation in FOMC day returns across the five groups, with the highest group having an average return of 64.1 bps and the lowest group having an average return of 6.7 bps. While returns on FOMC days exhibit heterogeneity, non-FOMC day returns are similar across all five groups, suggesting a variation in firms' exposure to monetary policy announcements.

Savor and Wilson (2013) find that the return on the S&P 500 Index is higher on FOMC days (25.5 bps) than on non-FOMC days (2.7 bps). While the literature often focuses on the "aggregate" stock returns, such as the S&P 500 Index, Table 1 shows that these higher returns are not uniform

Table 1: Cross-sectional Heterogeneity in Average Daily Returns on FOMC and non-FOMC Days.

	S&P500	Group				
	Index	1	2	3	4	5
Mean on FOMC	25.5	6.7	19.4	28.5	39.7	64.1
Mean on Non-FOMC	2.7	5.2	5.4	5.5	6.0	7.2
SD on FOMC	108	194	204	234	263	329
SD on Non-FOMC	109	192	206	230	253	297

Note: Table 1 shows a cross-sectional heterogeneity in average returns for SP500 firms. 500 Firms are sorted based on the time-series average returns on FOMC days. The firms are then assigned ranks from one to five based on these averages, and the average daily returns on FOMC days and non-FOMC days are calculated for each group. "Mean on FOMC" represents the time-series average returns for each group on FOMC days. "Mean on Non-FOMC" represents the time-series average returns for each group on non-FOMC days. "SD" denotes the standard deviation. "S&P500 Index" represents the mean and standard deviation of the S&P500 Index. Returns are expressed in basis points. Groups "1" through "5" denote the portfolios from low to high. The sample period is from January 1990 to December 2019.

across all 500 firms. Insted, they are driven by a subset of firms. The underlying causes of this heterogeneity are explored in section 3, where a theoretical framework is presented to explain the differences between these groups.

3 Theory

This section constructs a model to present testable theoretical predictions about risk factors and expected returns on announcement days.

The model is based on Ai and Bansal (2018), with extensions that incorporate discount factor risk and cross-sectional heterogeneity across assets. There is a representative investor with four periods. Periods 1 and 2 are trading periods. Periods 2, 3, and 4 are consumption periods. The investor trades two types of assets: short-duration assets and long-duration assets. The short-duration assets give a claim of consumption in period 3, while the long-duration asset gives a claim in period 4.

An investor in period 1 faces two sources of risk: the discount factor risk and the cash flow risk of short-duration equity. The investor does not know the state of the economy in period 1. She believes that the discount rate is high (state s_1) with $\pi\alpha_1$ and it is low (state s_2) with $\pi(1-\alpha_1)$. The cash flow of short-duration equity is high (state s_3) with probability $(1-\pi)\alpha_2$ and the cash flow is low (state s_4) with probability $(1-\pi)(1-\alpha_2)$. The parameter π governs the probability of revealing the information about the discount rate. At the beginning of period 2, announcements are made to reveal the state of the economy (s_1, s_2, s_3, s_4). Agents know the state of the economy in periods 2, 3, and 4. It is important to note that an investor does not face any uncertainty about the cash flow on long-run assets. Ai and Bansal (2018) and Wachter and Zhu (2022) assume that the central bank announces uncertainty about cash flow. This paper generalizes their framework and incorporate discount rate risk.

In the first period, the market for assets opens, where a short-duration asset is traded at a price of P_1^S and a long-duration asset is traded at P_1^L. The second asset market opens in period 2 after the announcement. In periods 3 and 4, the investor consumes the return on assets, with consumption financed solely by assets.

The equilibrium condition is that aggregate consumption is exogenously given. Consumption in period 2 cannot depend on the state s.

There are two points to highlight. Firstly, an investor faces uncertainty about the discount factor. This can be understood as the announcement of the risk-free short-term interest rate. The risk-free rate is used by investors to discount future cash flows since it represents a payoff without risk. Before the announcement of the risk-free rate, investors are uncertain about it, and, therefore, uncertain about how to discount the future.[3]

Second, it is assumed that only the uncertainty about the return on a short-duration asset is resolved through an announcement, while information about the cash flow of a long-duration asset is not revealed, resulting in an equal return of X^L in all states. The reason for resolving only the uncertainty about the return on short-duration equity is that monetary policy's effects are often temporary in empirical analyses (Christiano et al. (2005), Ramey (2016)). It is reasonable to assume that the central bank announcement contains no information about the distant future return but some

[3] This argument assumes that the real interest rate is equal to the nominal interest rate. Recent literature shows that the long-term real interest rate varies in response to monetary policy. See Hanson and Stein (2015) and Bianchi et al. (2022).

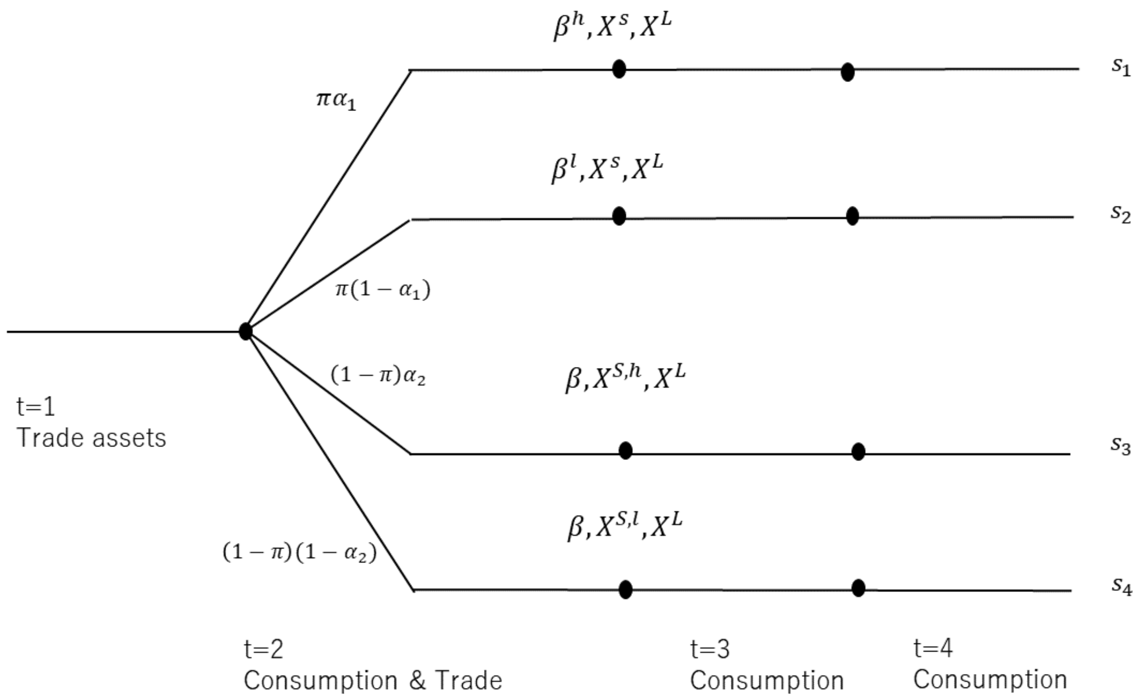


Figure 1: Model Overview

information about the near future return. Therefore, before the central bank announces, an investor faces uncertainty about the return on short-term equity that is resolved by the announcement.

Figure 1 shows an overview of the model. The investor maximizes

$$\max_{\theta_1^S,\theta_1^L,\theta_2^S,\theta_2^L} \left\{ E_1 \left[\left(C_2(s)^{1-\frac{1}{\psi}} + \beta(s) V_3(s)^{1-\frac{1}{\psi}} \right)^{\frac{1-\gamma}{1-\frac{1}{\psi}}} \right] \right\}^{\frac{1}{1-\gamma}}$$

$$V_3(s) = \left[C_3(s)^{1-\frac{1}{\psi}} + \beta(s) C_4(s)^{1-\frac{1}{\psi}} \right]^{\frac{1}{1-\frac{1}{\psi}}}$$

such that

$$e = P_1^L \theta_1^L + P_1^S \theta_1^S + S_1,$$

$$S_1 = C_2(s) + P_2^L(s)\theta_2^L(s) + P_2^S(s)\theta_2^S(s), \quad s \in \{s_1, s_2, s_3, s_4\}$$

$$C_3(s) = X^S(s)(\theta_1^S + \theta_2^S(s)), \quad s \in \{s_1, s_2, s_3, s_4\}$$

$$C_4(s) = X^L(\theta_1^L + \theta_2^L(s)), \quad s \in \{s_1, s_2, s_3, s_4\}$$

There is no consumption growth, $C_3(s_i) = C_4(s_i)$, for $s_i \in \{s_1, s_2, s_3, s_4\}$, and the return of long-duration equity is the same as the return of short-duration equity when cash-flow is not announced ($s_i \in \{s_3, s_4\}$),

$$X^S(s_3) = X^S(s_4) = X^L \equiv \overline{X}.$$

Also, investors does not have upward or downward bias on the expected psot-announcement cash flow and discount factor. The average of realized high state and low state in post-announcement periods is equal to the average of expectation formed in pre-announcement periods.

$$\beta^l = \beta\left(1-\sigma_1\right), \quad \beta^h = \beta\left(1+\sigma_1\left(\frac{1}{\alpha_1}-1\right)\right),$$
$$X^{S,l} = \overline{X}\left(1-\sigma_2\right), \quad X^{S,h} = \overline{X}\left(1+\sigma_2\left(\frac{1}{\alpha_2}-1\right)\right)$$

where σ_1 and σ_2 represents a dispersion.

In period 2, an investor knows the state of the economy as it is announced. Thus, the asset price is given by the CRRA case. Consumption in period 2 does not depend on the state due to the market clearing condition.

$$P_2^S(s_i) = \beta(s_i)\left(\frac{C_3(s_i)}{C_2}\right)^{-\frac{1}{\psi}} X^S(s_i), \quad s_i \in \{s_1, s_2, s_3, s_4\}$$

$$P_2^L(s_i) = \beta^2(s_i)\left(\frac{C_4(s_i)}{C_2}\right)^{-\frac{1}{\psi}} X^L, \quad s_i \in \{s_1, s_2, s_3, s_4\}$$

The prices in period 1 are given by

$$P_1^S = \frac{E_1\left[\left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}} \beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]}{E_1\left[\left(C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right)^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\right] C_2^{-\frac{1}{\psi}}}$$

$$P_1^L = \frac{E_1\left[\left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}} \beta^2(s)C_4(s)^{-\frac{1}{\psi}}X^L\right]}{E_1\left[\left(C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right)^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\right] C_2^{-\frac{1}{\psi}}}$$

In the CRRA case, $\frac{1}{\psi} = \gamma$, the price in period 1 is equal to the expected price in period 2. However, if risk aversion is sufficiently high, the price rises on average after the announcement.

Proposition 1. *The expected price in period 2 is higher than the price in period 1 for short- and long-duration assets if and only if* $\gamma > \frac{1}{\psi}$.

$$P_1^S < E_1[P_2^S(s)], \quad P_1^L < E_1[P_2^L(s)],$$

Proof. See Appendix A.1. $\square$

The expected return on announcement days is greater than one for both short- and long-duration assets. In the following analysis, I show (i) the comparative statistics on which asset's expected return is higher and (ii) the relationship between the expected return and the characteristic of monetary policy announcements.

3.1 Bond as a No Cash Flow Uncertainty Case

In this section, theoretical predictions are presented for the case where the probability of revealing the discount rate is equal to one, $\pi = 1$. In this scenario, assets are not exposed to cash flow risk. Assets can be interpreted as bonds, as the cash flow on a bond remains constant regardless of economic conditions, at least in nominal terms. In this limiting case, the average announcement premium for a long-maturity bond is higher than that for a short-maturity bond.

Proposition 2. *The average announcement premium of a long-maturity bond is higher than that of a short-maturity bond if and only if* $\gamma > \frac{1}{\psi}$.

$$E_1\left[\frac{P_2^L(s)}{P_1^L}\right] > E_1\left[\frac{P_2^S(s)}{P_1^S}\right].$$

Proof. See Appendix A.2. $\square$

Intuitively, the discount factor is only the source of uncertainty for bonds. Long-maturity bonds are more exposed to monetary policy announcements. If $\gamma < \frac{1}{\psi}$ holds, the investor gives more weight to good states and less weight to bad states. The announcement premium of both bond maturities is less than one because assets are less exposed after the announcement. Since the long-maturity bond is a riskier asset, the price of the long-maturity bond falls more than the price of the short-dated bond.

The impact of volatility on the premium is also larger for a long-maturity bond.

Proposition 3. *Consider the volatility of discount factor increases keeping $\beta^h \beta^l$ constant. The announcement premium of a long-maturity bond increases more than that of short maturity bond if and only if $\gamma > \frac{1}{\psi}$*

$$\frac{\partial E_1 \left[P_2^L(s)/P_1^L\right]}{\partial(\beta^h - \beta^l)} > \frac{\partial E_1 \left[P_2^S(s)/P_1^S\right]}{\partial(\beta^h - \beta^l)}$$

Proof. See Appendix A.3. □

3.2 Equity as a Cash Flow Uncertainty Case

This section provides theoretical predictions for equity, which is characterized by $\pi < 1$. This means that a central bank announcement reveals information about the future cash flow, which is uncertain before the announcements. The analysis compares the announcement premium of short-duration equity and long-duration equity.

$$E_1\left[\frac{P_2(s)^S}{P_1^S}\right] - E_1\left[\frac{P_2(s)^L}{P_1^L}\right]$$

The sign of the difference between the announcement premiums of short-duration equity and long-duration equity depends on the values of the parameters. While there is an analytical expression for this difference, determining whether the premium for long-duration equity is higher or lower than that for short-duration equity cannot be done through simple conditions. To illustrate numerically, I present figures 2 through 4, which show the difference between $E_1\left[\frac{P_2^S(s)}{P_1^S}\right]$ and $E_1\left[\frac{P_2^L(s)}{P_1^L}\right]$, with each line representing a contour. The figures demonstrate the parameter values for which the premium is higher for short-duration equity.

In summary, when σ_1 is low, σ_2 is high and π is low, the premium of short duration is higher. Figure 2 shows the relationship between the volatility of the discount rate (σ_1) the volatility of the cash flow (σ_2). The premium of short-duration equity is high when return volatility is high and discount rate volatility is low. The volatility of cash flow measures the exposure of short-duration assets to an announcement. Long-duration equity exposure is measured by discounted volatility.

Figure 3 shows the relationship between discount rate volatility (σ_1) and discount rate disclosure probability (π). The premium of short-term equity is higher when π is low. When an announcement is about the discount rate, the premium for long duration is higher than that for short duration. When an announcement is about yield, the short-duration premium is higher. When π increases, an

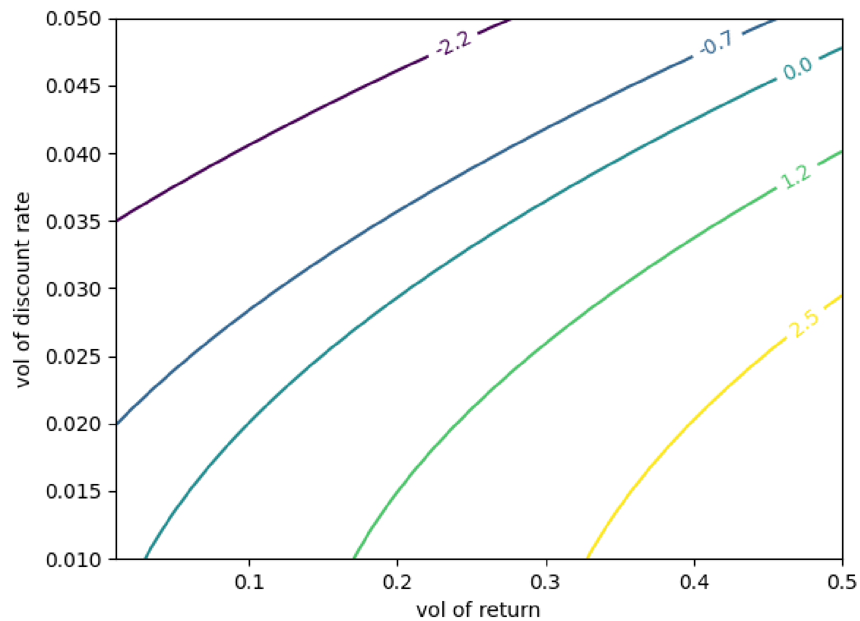


Figure 2: Numerical illustration.

announcement is more likely to be about the discount rate. The long-duration premium increases with π.

Figure 4 displays a contour depicting the relationship between the discount rate volatility and the degree of risk aversion (γ). The premium for short-duration equity increases as the level of risk aversion increases, given that the volatility of the discount rate is low. Intuitively, when the volatility of the discount rate is low, the premium for short-duration equity exceeds that of long-duration equity. The risk aversion amplifies the differences between premiums, leading to an increase in the premium for short-duration equity. Conversely, when the volatility of the discount rate is high, the premium for long-duration equity increases with risk aversion since the premium for long-duration equity is higher.

In summary, the announcement premium of short-duration equity can be higher or lower than that of long-duration equity. The short duration is higher when return volatility is high, risk aversion is high, consumption volatility is high, and the probability of discount rate announcement is low.

I make three theoretical predictions for bonds and stocks. First, bonds have an upward sloping yield curve. For stocks, it can be upward-sloping or downward-sloping. It depends on the

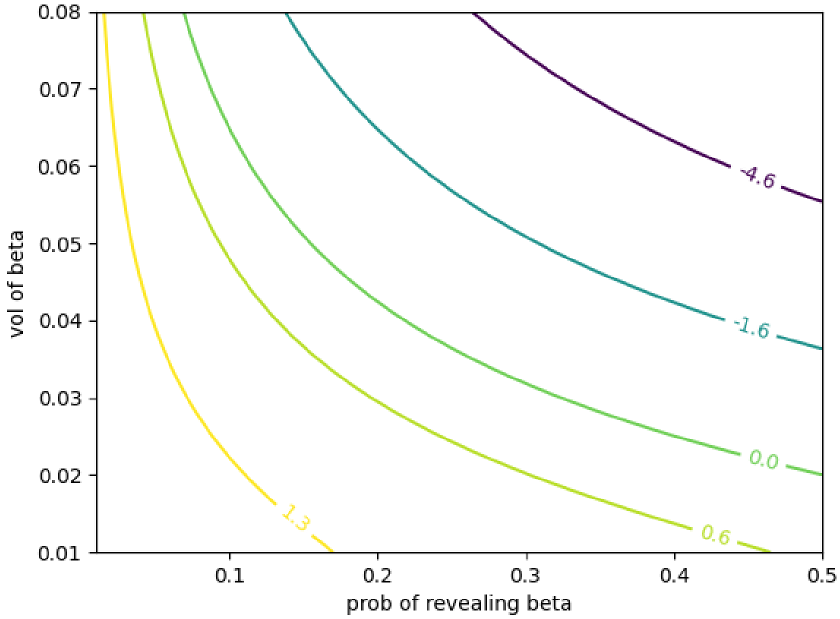


Figure 3: Numerical illustration.

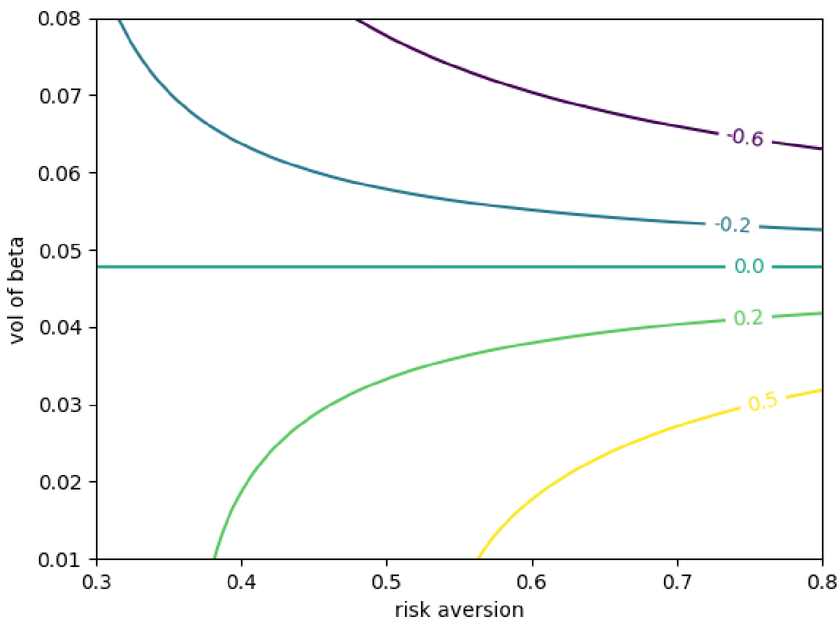


Figure 4: Numerical illustration.

uncertainty about returns and the discount rate. Second, the price increase of long-dated assets is larger than that of short-dated assets when an announcement removes more uncertainty about the discount rate. For both bonds and stocks, this prediction holds. It is illustrated by the contemporaneous relationship between the realized change in the uncertainty level and the realized return on the asset. Finally, the price increase is larger for long-duration assets than for short-duration assets when ex ante uncertainty about the discount rate is high. This prediction holds for both bonds and equities. This relationship is predictive.

4 Data

This section explains the construction of the main variables: bond and equity returns, equity duration, and interest rate uncertainty. Bond returns are based on U.S. Treasury bonds. The dataset on equities includes firms incorporated in the U.S. and trading on the NYSE, Amex, or Nasdaq, excluding financial industries. Balance sheet data are sourced from the Compustat database. A detailed description of the data sources can be found in Appendix B. The sample period spans from the first quarter of 1990 to the fourth quarter of 2019.

4.1 Returns of Equity and Bond.

The daily return of the assets on announcement days is expressed as $\frac{p_t}{p_{t-1}} - 1$. For equities, I use the daily closing price data from CRSP. Here, p_t represents the closing price on the announcement day, and p_{t-1} is the closing price one day before the announcement day.

For Treasury bonds, the returns are constructed using the data from Liu and Wu (2021). This dataset provides the daily zero-coupon yield of U.S. Treasury bonds for various maturities, $Y(n)$. The price of a bond with a maturity of n years, $p_t(n)$, is given by $p_t(n) = \frac{1}{(Y_t(n))^n}$, where $Y(n)$ is the annualized yield of a bond with a maturity of n years at time t.

4.2 The Duration of Assets

To analyze the heterogeneous exposure of assets with different durations, it is essential to measure the duration of these assets. For bonds, the duration can be directly observed. A bond with n years to maturity is assigned a duration of n.

For equities, their duration is not directly observed. I followed Weber (2018) to construct the duration. This method is based on the timing of cash flows and resembles Macaulay duration, which reflects the weighted average time to maturity of cash flows. The ratio of discounted cash flows to the price determines the weighted average:

$$\text{Duration}_{it} = \frac{\sum_{s=1}^{\infty} s \times \text{CF}_{i,t+s}/(1+r)^s}{P_{it}},$$

where Duration_{it} is the duration of firm i at time t, $\text{CF}_{i,t+s}$ is the cash flow at time $t+s$, P_{it} is the current equity price, and r is the discount rate. Unlike bonds, equities do not have observable finite maturities and predetermined cash flows. To address this issue, the duration formula is divided into two parts: a finite horizon of length T and an infinite terminal expression.

$$\text{Duration}_{it} = \frac{\sum_{s=1}^{T} s \times \text{CF}_{i,t+s}/(1+r)^s}{P_{it}} + \left(T + \frac{1+r}{r}\right) \frac{P_{i,t} - \sum_{s=1}^{T} \text{CF}_{i,t+s}/(1+r)^s}{P_{it}}. \quad (1)$$

A derivation of this equation can be found in Appendix C.1. Future cash flows are forecasted using the projected return on equity and growth in book equity, based on clean surplus accounting,

$$\begin{aligned} \text{CF}_{i,t+s} &= \text{E}_{i,t+s} - (\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}) \\ &= \text{BV}_{i,t+s-1}\left[\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}} - \frac{\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}}\right]. \end{aligned} \quad (2)$$

Return on equity, $\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}}$, is the ratio of income before extraordinary items over the lagged book equity. Returns on equity and growth in equity are modeled to follow an autoregressive process. The parameters in the autoregressive process are estimated using pooled CRSP-Compustat firms. The details on this process are described in Appendix C.

Table 2 reports the summary statistics for various firm characteristics in Panel A. The average payoff horizon implied by stock prices is 18.0 years. The standard deviation of duration is 4.1 years, indicating considerable heterogeneity in the data. On average, the public (19.8 years) and transportation (18.0 years) industries have longer durations, while the utilities (16.3 years) and wholesale (16.8 years) industries have shorter durations.

Panel B shows the cross-sectional correlations for various firm characteristics. The book-to-market ratio at time t is defined as the book equity at time t divided by the market equity at time

Table 2: Summary Statistics and Correlations for Firm Characteristics

	Dur	BM	Size	Prof	Lev	Sales g	ME
	Panel A. Means and Standard Deviations						
Mean	18.0	0.78	5.8	0.01	0.21	1.66	2337
SD	4.1	1.0	2.1	0.05	0.22	20.6	9628
	Panel B. Correlations						
Dur		-0.66	-0.02	-0.09	-0.04	0.01	0.13
BM			-0.00	-0.08	-0.09	-0.05	-0.12
Size				0.19	0.24	-0.00	0.42
Prof					0.08	0.16	0.12
Lev						-0.00	0.06
Sales g							0.00

Note: Table 2 reports time series averages of quarterly cross-sectional means and standard deviations for firm characteristics in Panel A and correlations of these variables in Panel B. "Dur" is cash-flow duration in years; "BM" is the book-to-market ratio; "Size" is log of assets; "Prof" is profit devided by assets; "Lev" is a leverage ratio. "Sales g" is the sales growth represented in percent. "ME" is the market capilization in millions. Financial statement data comes from quarterly Compustat. The sample period is 1990Q1-2019Q4.

t. Book equity is calculated as total stockholder's equity plus deferred taxes and investment tax credit, minus the book value of preferred stock. Market equity is the total market capitalization. Panel B shows a strong negative correlation between duration and the book-to-market ratio, with a correlation coefficient of -0.66. Given that a negative linear relationship exists under certain assumptions, as detailed in Appendix C.2, the book-to-market ratio is often used as an alternative measure of duration (Lettau and Wachter, 2007; Hansen et al., 2008). In the robustness checks, I use the book-to-market ratio as an alternative measure of duration and confirm consistent results.

4.3 Interest Rate Uncertainty Data

The data on interest rate uncertainty is based on the market-based conditional volatility of the future short-term interest rate from Bauer et al. (2022). They construct the standard deviation of the Eurodollar (ED) futures one year ahead, conditional on the current information, $\text{IRU}_t \equiv \sqrt{\text{Var}(\text{ED}_{t+\tau}|I_t)}$. This methodology provides a model-free estimate of the conditional standard deviation, given the prices of futures and options.

Figure 5 shows a histogram of the two-day change in interest rate uncertainty around FOMC announcement days, calculated as $\log(\text{IRU}_{t+1}) - \log(\text{IRU}_{t-1})$ when t is the FOMC day. The sample covers the period from 1990 to 2019, with eight scheduled FOMC announcements per year, resulting in a total of 240 observations. The average change in the uncertainty measure is -0.021 with a t-value of -7.12, indicating that monetary policy announcements reduce the standard deviation of future interest rate by 2.1% on average.

The standard deviation of the changes in interest rate uncertainty is 0.047. The variation in the resolution of interest rate uncertainty is related to a specific change in the Federal Reserve's forward guidance (Lakdawala et al., 2021) [4]. In the following analysis, I exploit this variation in the change in interest rate uncertainty to estimate the elasticity of returns to changes in interest rate uncertainty. Intuitively, the empirical specification compares the returns of assets on two announcements that change interest rate uncertainty to different degrees.

5 Empirical Analysis of Bonds

5.1 Average Return on FOMC days

This subsection empirically tests the theoretical prediction about the average returns of bonds on FOMC days. Proposition 2 states that the return on long-duration bonds is higher than the return on short-duration bonds. Figure 6-(a) shows the average return on FOMC days across different durations from 1990 to 2019, with 95% confidence intervals for Newey-West standard errors. The results indicate that returns increase monotonically with duration. For example, while the average return on a one-year Treasury bond is 0.62 basis points, the average return on a twenty-nine-year

[4] For example, the largest decrease occurred in August 2011; monetary policy uncertainty decreases by 29%, shown in the left tail of the histogram in Figure 5. Before the meeting, the FOMC stated that interest rate would be kept low "... for an extended period". At the August meeting, the FOMC explicitly signaled that rates would remain low "at least through mid-2013". The market was able to interpret the statement with less uncertainty about future interest rate. The central bank's guidance played a crucial role in reducing interest rate uncertainty.

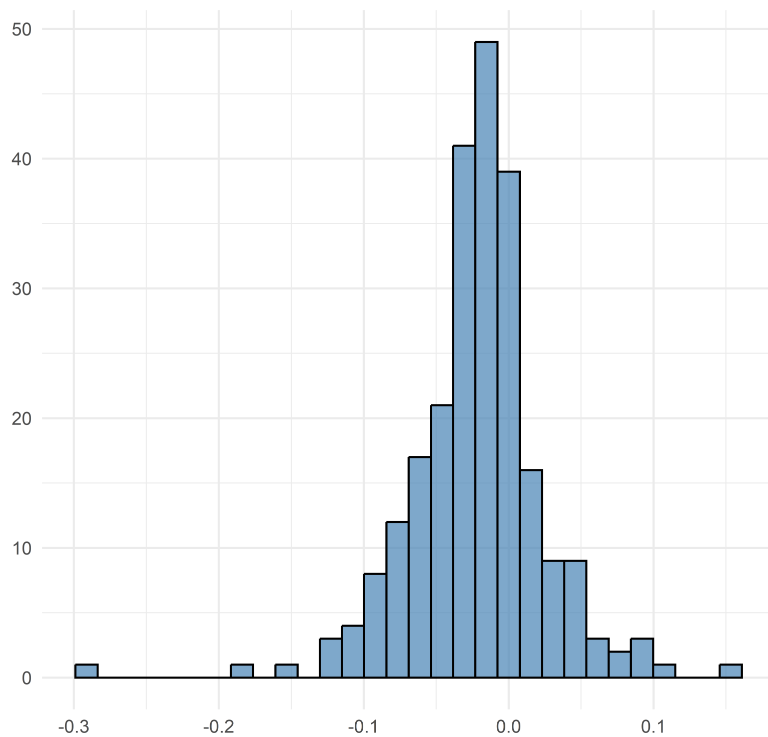


Figure 5: Histogram of Changes in Interest Rate Uncertainty on FOMC days

Note: Figure 5 shows a histogram of the two-day change in interest rate uncertainty on FOMC days. Interest rate uncertainty is measured using the risk-neutral standard deviation of the three-month interest rate at a one-year horizon, estimated from Eurodollar futures and options. The two-day change is calculated as the log of uncertainty at $t + 1$ minus the log of uncertainty at $t - 1$, where t represents FOMC announcement days. The sample period spans from January 1990 to December 2019, including 240 announcements, with eight announcements per year over thirty years. The data is obtained from Bauer et al. (2022).

Treasury bond is 10.22 basis points. This result is consistent with Proposition 2.

The intuition behind the result is as follows: prior to the announcements, the discount rate is uncertain. Since the value of long-duration bonds is more sensitive to the discount rate, investors who prefer early resolution of uncertainty devalue long-duration bonds more. After the announcements, interest rate uncertainty is resolved, causing the value of long-duration bonds to increase more than that of short-duration bonds.

Long-duration bonds exhibit larger standard errors. The underlying reason is that as the duration (n) increases, the bond price becomes more sensitive to fluctuations in yields. This is evident in the price formula: $p_t(n) = \frac{1}{(Y_t(n))^n}$. The same change in $Y_t(n)$ leads to greater variability in price when the duration is longer, resulting in larger standard errors. This pattern is also observed in Wachter and Zhu (2022).

Since the focus of this paper is on the relationship to interest rate uncertainty, Figure 6-(b) shows average returns for subsamples conditional on changes in interest rate uncertainty. The sample is divided into two groups: the top 20% and bottom 20% of changes in interest rate uncertainty. The red line represents the top 20%, while the blue line represents the bottom 20%.

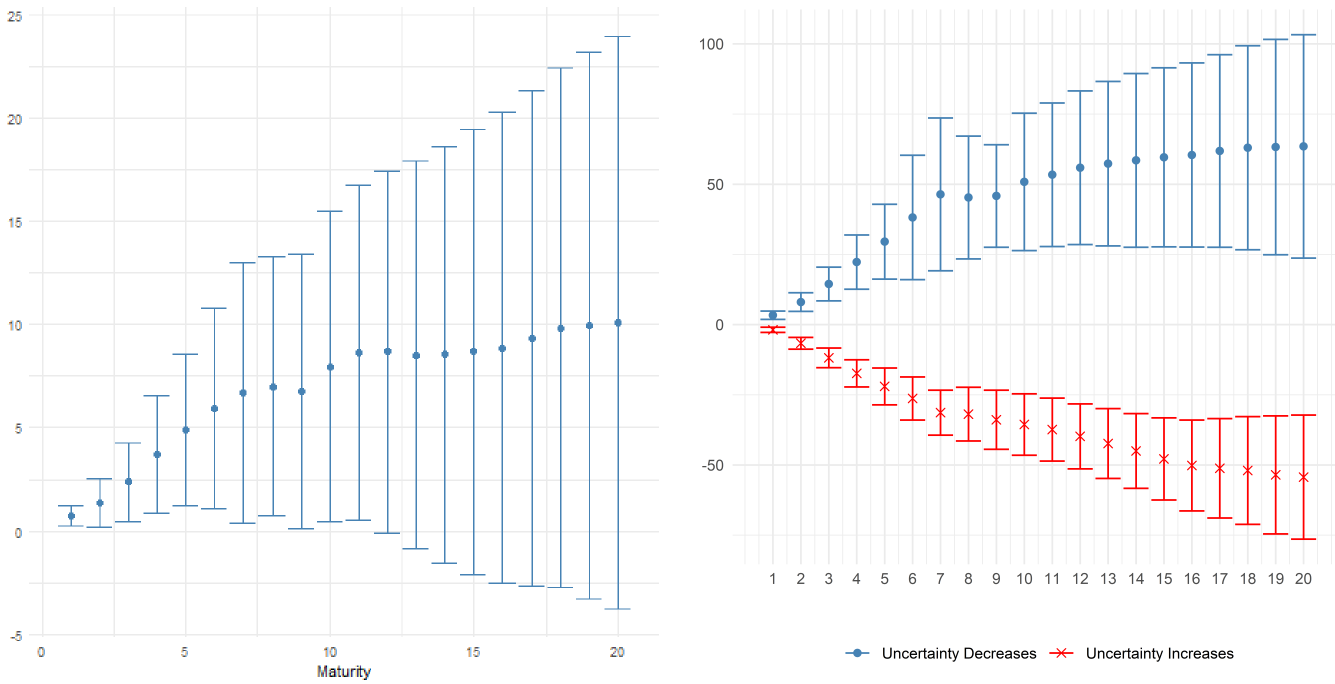
Figure 6-(b) shows a clear difference in the term structure of returns between the two groups. When the interest rate decreases significantly, the return on 5 years bonds is 29.5 bps while the return on 20 years bonds is 63.4 bps. In contrast, when the interest rate uncertainty decreases slightly, the return on 5 years bonds is -22.0 bps while the return on 20 years bonds is -54.3 bps. The results suggest that changes in interest rate uncertainty determine the term structure of bond returns on FOMC days.

I also regress returns of Treasury bonds with different durations on risk factors. The empirical specification is

$$y_t^m = \alpha^m + \beta_s^m X_{s,t} + \epsilon_{it}, \tag{3}$$

where y_t^m is the returns of bonds with maturity m at time t, α^m is the model-specific pricing error, and $\beta_{i,s}^m$ is the time-series loading of returns on rask factors s, and $X_{s,t}$ is a market excess return. Bond returns and the market excess returns are expressed in basis points.

Table 3 presents the average returns on FOMC days and non-FOMC days for different maturities. To save space, I report the returns on Treasury bonds with maturities of 1, 5, 10, 15, and 20 years. Panel A shows the results for FOMC days. On average, a long-short portfolio earns 9.6 basis points



(a) All FOMC days

(b) Conditional on a Change in Uncertainty

Figure 6: Average Return on Treasury Bonds on FOMC days.

Notes: Figure 6 shows average returns on Treasury bonds with different maturities on FOMC days. The vertical represents the returns on Treasury bonds expressed in basis points. The horizontal axis repressents the maturity of bonds. Figure (a) uses all FOMC days from 1990 to 2019. Figure (b) is conditional on changes in interest rate uncertainty, with the red line representing the top 20% of changes and the blue line representing the bottom 20%. The 95% confidence intervals are calculated. The sample period is 1990/1-2021/12.

Table 3: Average Returns of Treasury Bonds with Duration

	Maturity				
	1	5	10	15	20
	Panel A: FOMC days				
Average Return	0.7	5.0	8.2	9.0	10.3
	(0.26)	(1.60)	(3.64)	(5.41)	(6.73)
α_{capm}	0.7	4.4	7.7	8.8	11.1
	(0.34)	(1.91)	(3.55)	(5.16)	(7.15)
β_{capm}	0.00	0.02	0.02	0.01	-0.03
	(0.006)	(0.03)	(0.06)	(0.07)	(0.09)
	Panel B: Non-FOMC days				
Average Return	0.06	0.3	0.7	1.3	1.8
	(0.05)	(0.33)	(0.62)	(0.90)	(1.14)
α_{capm}	0.07	0.4	1.0	1.7	2.3
	(0.06)	(0.34)	(0.64)	(0.93)	(1.15)
β_{capm}	-0.01	-0.06	-0.11	-0.16	-0.20
	(0.002)	(0.008)	(0.016)	(0.023)	(0.032)

Note: Table 3 reports the returns of Treasury bonds on FOMC days, time=series factor loadings (β), and pricing errors (α) for different maturities. The return of treasury is defined as $\frac{p_t(n)}{p_{t-1}(n)}$ where $p(n)_t$ is daily price of Treasury with maturity m. Returns are stated in basis points. α_{capm} and β_{capm} are from the CAPM model. Newey-West standard errors are shows in parenteses. Maturity is in years.

on a FOMC announcement day. I also report CAPM alphas and betas. Risk-adjusted returns, as measured by alphas, increase monotonically from short to long maturities. The CAPM alpha for a one-year maturity bond is 0.7, whereas for 20-year bonds, it is 11.1.

In contrast, the return on non-FOMC days is lower than on FOMC days. The average return for a one-year maturity bond is 0.06 basis points on non-FOMC days, compared to 0.7 basis points on FOMC days. This is because interest rate uncertainty is not significantly resolved on non-FOMC days. Additionally, the average return for short- and long-duration assets does not differ much on non-FOMC days; a long-short portfolio earns 1.7 basis points on non-FOMC days.

5.2 Interest Rate Uncertainty and Contemporaneous Regression.

This section empirically demonstrates that the returns on bonds with longer durations are more responsive to changes in interest rate uncertainty than shorter durations. This hypothesis is derived from Proposition 3. I separately estimate the time-series regression of

$$y_t^m = \beta_{iru}^m \Delta \text{IRU}_t + \epsilon_t, \tag{4}$$

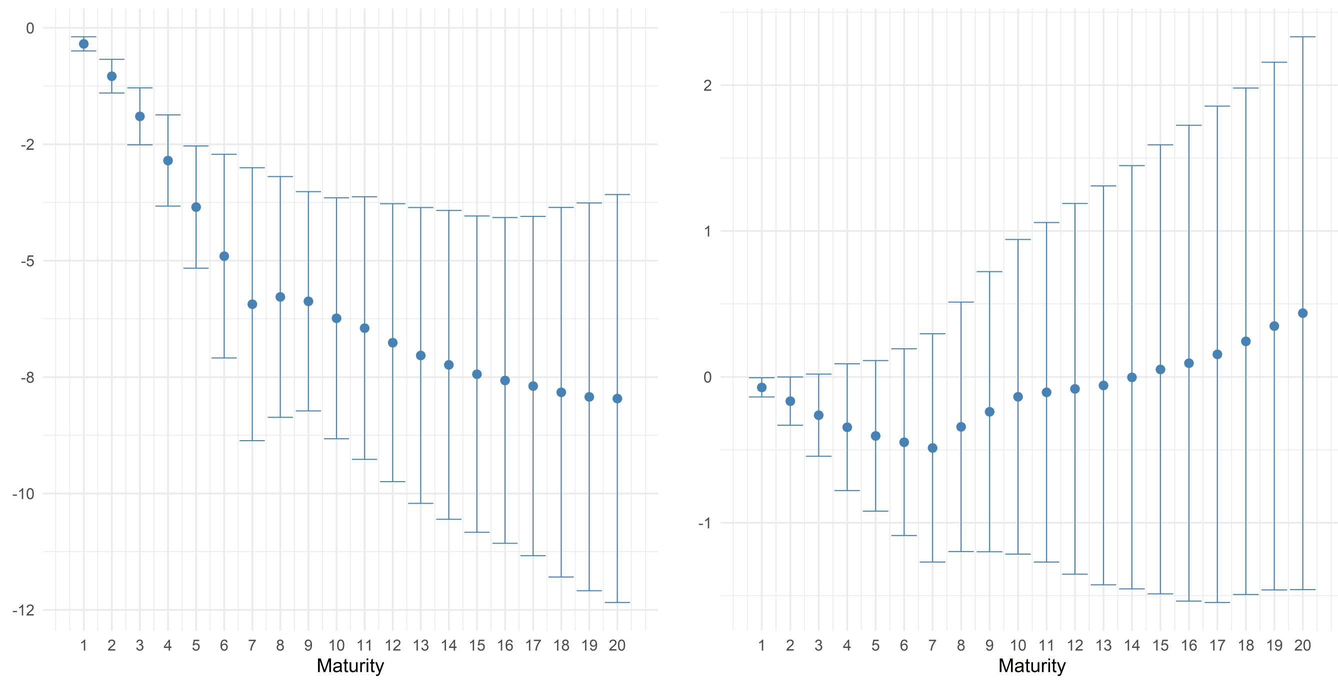
where t is the tth FOMC announcement, y_t^m is the return on Treasury bonds with duration m represented in percentage points. ΔIRU_t is the logarithm of tomorrow's interest rate uncertainty minus yesterday when today is the tth FOMC day; $\log(\text{IRU}_{t+1}) - \log(\text{IRU}_{t-1})$. The coefficients β_{iru}^m are separately estimated using the data on bonds with maturity m.

Figure 7-(a) shows the estimated β_{iru}^m as a function of m, with 95% confidence intervals of Newey-West standard errors. The coefficient monotonically decreases with duration. For a 10-year bond, β_{iru} is -6.8, meaning a 1% decrease in implied interest rate volatility increases the return by 6.8 basis points. For a 5-year bond, the coefficient is -4.1. Longer duration bonds are more responsive to changes in interest rate uncertainty, consistent with Proposition 3. Intuitively, when monetary policy announcements reduce interest rate uncertainty, investors value long-duration bonds more due to their higher sensitivity of consumption claim in the future to discount rate.

In contrast to the interest rate uncertainty that is the focus of this paper, the literature focuses on the uncertainty about cash flow that is often proxied by VIX (Lucca and Moench, 2015; Hu et al., 2022). To demonstrate that the high return on bonds is primarily driven by a decline in interest rate uncertainty, rather than uncertainty about aggregate cash flow, I also examine the contemporaneous relationship between the VIX and Treasury bonds. I estimate

$$y_t^m = \beta_{vix}^m \Delta \text{VIX}_t + \epsilon_t, \tag{5}$$

where ΔVIX_t is a logarithm of tomorrow's VIX minus yesterday's VIX when today is the tth FOMC day. Figure 7-(b) displays the estimated values of β_{vix}^m. The coefficients are not significantly different from zero. More importantly, they do not exhibit a clear monotonic pattern with duration, which contrast with the interest rate uncertainty case. For instance, the estimated coefficient for a 5-year bond is -0.9, while for a 10-year bond, it is -0.1. These results suggest that Treasury bonds are not significantly exposed to the risks captured by VIX, despite its use in the literature. Instead, the resolution of interest rate uncertainty appears to be the primary driver of bond returns.



(a) Interest Rate Uncertainty

(b) VIX

Figure 7: The Elasticity of Return to Change in Uncertainty Conditional on Duraiton

Note: Figure 7 shows a sensitivity of returns to a change in (a) interest rate uncertainty and (b) VIX for different maturities. I regress the Treasury returns on a change in uncertainty measure,

$$y_t^m = \beta^m \Delta \text{Unc}_t + \epsilon_t, \tag{6}$$

where ΔUnc_t is a change in interest rate uncertainty in Figure (a) and VIX in Figure (b). The vertical plots the coefficients β^m for each maturity m, and its 95% confindence intervals.

I regress returns of bonds for different durations on a change in interest rate uncertainty to test whether the returns of longer duration statistically significantly responds to the resolution of interest rate uncertainty. The empirical specification is

$$\text{Return}_{n,t} = \beta_1 \Delta UNC_t + \beta_2 \text{Duration}_{nt} + \beta_3 \Delta UNC_t \times \text{Duration}_{nt} + \gamma X_{it} + \epsilon_{it}, \quad (7)$$

where Return_{nt} is the return of bonds with duration n years at the tth FOMC represented in basis points, ΔUNC_t is the measured change in IRU_t at the tth FOMC, and Duration_{nt} is equal to n as bonds matures in n years.

Control variables, X_{it}, include a two day window change in VIX, monetary policy shock, the interaction of a change in VIX and duration, and the interaction of monetary policy shock and duration. Monetary policy shock is identified by the high-frequency change in federal fund future (Bernanke and Kuttner, 2005). I include the monetary policy shock (the change in the first moment of fed fund rates, Bernanke and Kuttner (2005)) and the change in VIX around monetary policy announcements. The resolution of interest rate uncertainty might be correlated with change in aggregate uncertainty (VIX) or change in the first moment (monetary policy shock), and that might leads to the heterogeneous sensitivity of return across durations. For example, average change in fed funds rate leads to more change in return for longer duration bonds than shorter duration bonds. This change in the first-moment might be correlated with the change in the second-moment. To control this channel, monetary policy shock are included. VIX is also included in control variables because of its common use to proxy for the uncertainty in the literature.

Table 4 presents the estimated results. Column (1) excludes control variables, while Column (2) includes them. The coefficient of interest, β_3, is estimated to be -0.24 in Column (1) and -0.26 in Column (2). The negative coefficient of the interaction term indicates that when the interest rate uncertainty increases by 1%, the return of bonds decreases by 0.24-0.26 bps more compared to the return of bonds with one year shorter duration.

Sensitivity analysis This subsection shows sensitivity analysis. First, I use different measure of interest rate uncertainty; basis point volatility and MOVE. Second, I conduct subsample analysis.

In the baseline analysis, the discount factor risk investors face is proxied by the standard deviation of the Eurodollar future one-year ahead. Since the discount factor risk for investors

Table 4: The Elasticity of Return to Change in Uncertainty Conditional on Duration

	(1)	(2)	(3)	(4)	(5)	(6)
IRU	-2.800	-1.887				
	(0.5495)	(0.5277)				
Duration × IRU	-0.2449	-0.2675				
	(0.1022)	(0.0850)				
BP vol			-2.045	-1.422		
			(0.4064)	(0.3988)		
Duration × BP vol			-0.1759	-0.1852		
			(0.0701)	(0.0623)		
MOVE					-1.470	-0.8990
					(0.4502)	(0.4596)
Duration × MOVE					-0.1256	-0.1605
					(0.0856)	(0.0796)
Controls		✓		✓		✓
R^2	0.10061	0.15016	0.08712	0.14093	0.04576	0.11597
Observations	7,047	7,018	7,047	7,018	7,047	7,018

Note: Table 4 reports the coefficient estimates of the pooled regression of Treasury returns for 1990-2019. The explanatory variables are the change in interest rate uncertainty, duration, and the interaction of the two. The standard errors are OLS. The independent variables are returns of Treasury bonds with different maturities represented in basis points. Columns (1) and (2) use the Interest rate uncertainty. Columns (3) and (4) use Bp vol. Columns (5) and (6) use MOVE. Control variables are a two day window change in VIX, monetary policy shock, the interaction of a change in VIX and duration, and the interaction of monetary policy shock and duration. The regression equation is

$$\text{Return}_{n,t} = \beta_1 \Delta UNC_t + \beta_2 \text{Duration}_{nt} + \beta_3 \Delta UNC_t \times \text{Duration}_{nt} + \gamma X_{it} + \epsilon_{it},$$

where Return_{nt} is the return of bonds with duration n years at the tth FOMC, ΔUNC_t is the measured change in uncertainty at the tth FOMC, and Duration_{nt} is equal to n as bonds matures in n years. Standard error is clustered at time dimension.

cannot be directly observed, I use other plausible data to proxy for the discount factor risk. Basis point volatility (BP Vol) is the product of Black IV with the futures price. It is based on the assumption of log-normal prices and uses only ATM Eurodollar option prices in the IV calculation. MOVE is a weighted average of basis point volatility for one-month Treasury options across bond maturities.

Table 4 shows the estimated results. Columns (3) and (4) use BP vol as uncertainty measure, while columns (5)and (6) use MOVE. The estimated β_3 is significantly negative for all specifications. For example, in column (3), when the BP vol increases by 1%, the return of bonds decreases by 0.17 bps more compared to the return of bonds with one year shorter duration. This means that the return sensitivity, in absolute terms, increases with duration, consistent with the benchmark analysis in the previous section. Table 4 shows that the results are robust for the choice of uncertainty measures. Columns (4) and (6) show that this result is not driven by a change in VIX or monetary policy shocks.

I also conduct subsample analysis by dividing the period into pre-crisis (1990-2007) and post-crisis (2008-2019). The empirical specification is equation (7). The uncertainty measure is benchmark measure of interest rate uncertainty, IUR_t. The result is shown in Table 5. The columns (1) and (2) use the pre-crisis period and columns (3) and (4) use the post-crisis period. The results are consistent across the subsamples. The interaction term if duration and uncertainty measure is significantly negative. The results are robust to the choice of uncertainty measures and subsamples.

Quantitatively, the coefficients for post-crisis period are smaller in absolute terms. During the post-crisis period, the nominal interest rate is close to zero, and inverstors face less uncertainty about future interest rate. The resolution of interest rate uncertainty is less significant during the post-crisis period, and thus the response of return to the resolution of interest rate uncertainty is smaller during the post-crisis period.

Table 5: Bond Return sensitivity to interest rate uncertainty

	(1)	(2)	(3)	(4)
IRU	-2.149	-1.010	-3.190	-2.350
	(0.5889)	(0.4584)	(0.8077)	(0.7801)
Duration $\times$ IRU	-0.3196	-0.3139	-0.2115	-0.2840
	(0.1146)	(0.1161)	(0.1474)	(0.0996)
Controls		✓		✓
R^2	0.10815	0.13756	0.10013	0.24261
Observations	4,321	4,292	2,726	2,726

Note: Table 5 reports the coefficient estimates of the pooled regression of Treasury returns for the subsamples of 1990-2019. The explanatory variables are the change in interest rate uncertainty, duration, and the interaction of the two. The standard errors OLS. The independent variables are returns of Treasury bonds with different maturities represented in basis points. Columns (1) and (2) use the period into pre-crisis (1990-2007). Columns (3) and (4) use post-crisis (2008-2019). Columns (2) and (4) include a two day window change in VIX, monetary policy shock, the interaction of a change in VIX and duration, and the interaction of monetary policy shock and duration. The regression equation is

$$\text{Return}_{n,t} = \beta_1 \Delta IRU_t + \beta_2 \text{Duration}_{nt} + \beta_3 \Delta IRU_t \times \text{Duration}_{nt} + \gamma X_{it} + \epsilon_{it},$$

where Return_{nt} is the return of bonds with duration n years at the tth FOMC, ΔIRU_t is the measured change in interest rate uncertainty at the tth FOMC, and Duration_{nt} is equal to n as bonds matures in n years. Standard error is clustered at time dimension.

6 Empirical Analysis of Equities

6.1 Average Return on FOMC days

I empirically test whether short- or long-term equities have a higher return on the announcement days. Theoretical predictions imply that if the resolution of discount rate uncertainty is siginificant, the return on long-duration equities will be higher than that on short-duration equities, as is the case for Treasury bonds. In contrast, if the resolution of cash flow uncertainty is more significant, the return on short-duration equities will be higher than that on long-duration equities.

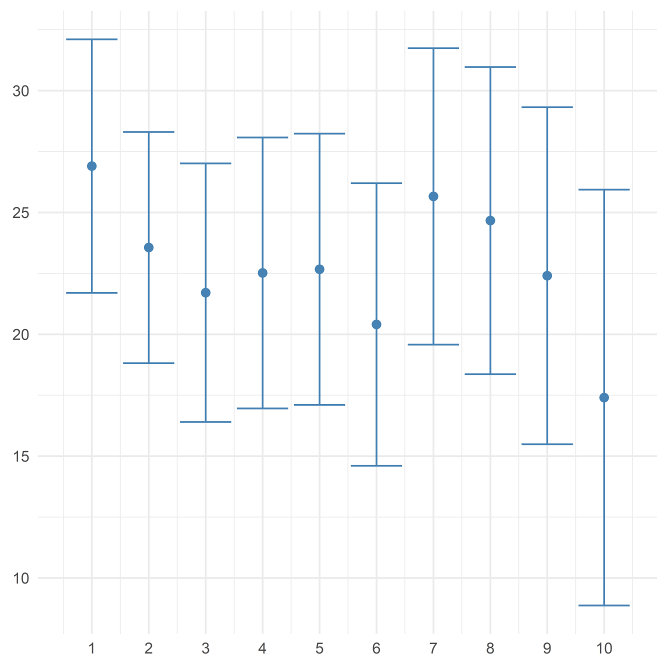
From 1990 to 2019, I sort equities into 10 deciles based on cash-flow duration for the previous quarter and rebalance the portfolios every quarter. Figure 8-(a) shows the average return of these portfolios represented in basis points with 95% confidence intervals of Newey-West standard errors as a function of cash-flow duration. The average returns on short-duration and long-duration equities are statistically indistinguishable. The average return of the shortest-duration portfolio is 26.9 basis points, while that of the second-longest duration portfolio is 22.4 basis points, and the longest-duration portfolio is 17.4 basis points.

This empirical pattern contrasts with that of Treasury bonds, where long-duration bonds yield higher returns. Figure 8-(a) demonstrates that short duration equities are exposed to cash flow risk associated with short-run monetary policy non-nuetrality.

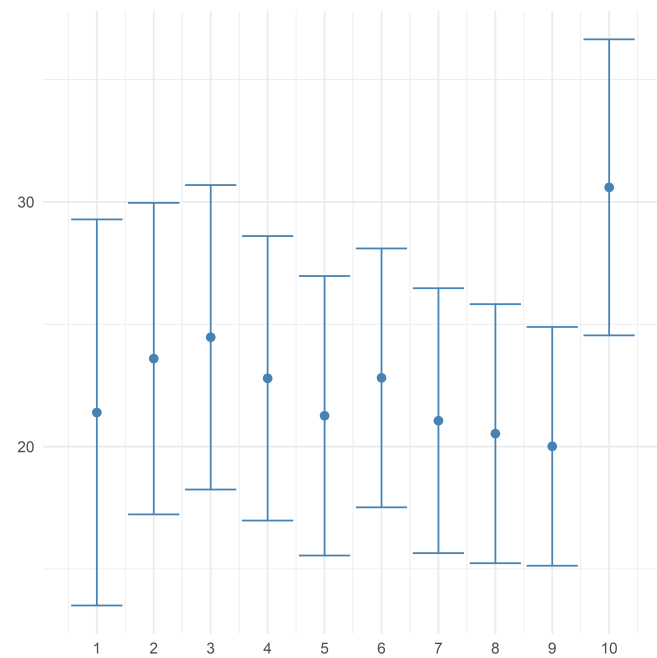
Since cash flow duration is not directly observed from the data, I conducted a sensitivity analysis using an alternative measure for duration. I used the book-to-market ratio as an alternative measure, following Lettau and Wachter (2007) and Hansen et al. (2008). Figure 8-(b) shows the average returns for each portfolio based on the book-to-market ratio. The portfolios are rebalanced from low to high. The returns on portfolios with low and high book-to-market ratios are statistically indistinguishable.

This term structure of average returns on FOMC days sharply contrasts on that on monthly average returns. Weber (2018) finds that the term structure of monthly equity returns is downward sloping. Figure 9-(a) confirms this by showing the monthly average returns of portfolios sorted by cash-flow durations. The monthly return decreases with duration, with the shortest-duration portfolio returning 11.3 basis points and the longest-duration portfolio returning 0.3 basis points[5].

[5]Monthly returns are defined as the difference in prices between the beginning and the end of the month and



(a) Cash Flow Duration



(b) Book-to-Market Ratio

Figure 8: Average Returns Conditional on Duration

Note: Figure 8 plots the time-series average of portfolio returns on FOMC days. The horizontal axis represents the duration of portfolios, ranging from short (one) to long (ten). The vertical axis represents the average return on FOMC days for each portfolio. Equities are divided into ten groups based on duration, and the average return within each group is calculated. The portfolios are rebalanced every quarter. Figure (a) uses cash flow duration as defined by Weber (2018) to form the portfolios. Figure (b) uses the book-to-market ratio. Standard errors are Newey-West standard errors.

Figure 9-(b) illustrates the monthly average returns of portfolios sorted by the book-to-market ratio. It also demonstrates the downward-sloping term structure observed by Lettau and Wachter (2007). The return on the shortest-duration portfolio is 10.6 basis points, while the return on the longest-duration portfolio is 2.5 basis points[6].

Figures 8 and 9 reveal a stark contrast in the term structure. The term structure is downward sloping on non-FOMC announcement days, but this pattern does not hold on FOMC days. This paper posits that the average return on long-duration equities is higher on FOMC days than on non-FOMC days (i.e., the term structure is not downward sloping) because interest rate uncertainty resolved by announcements drives higher returns of long-duration equities.

To further explore the relationship between average returns and interest rate uncertainty, I conducted a subsample analysis. I focused on the subset of announcements where the decline in interest rate uncertainty exceeded a specific threshold. This threshold is defined as the 80th percentile of the change in interest rate uncertainty[7]. I then calculated the time-series average of portfolio returns for these selected announcements.

Figure 10 illustrates the average returns of portfolios on FOMC days using all announcements (blue), as well as a subsample of announcements where an increase in interest rate uncertainty exceeds a threshold (red). The difference in the term structure between the entire sample and the subsample is significant. When interest rate uncertainty increases, the term structure becomes downward sloping. Intuitively, investors devalue the long-duraiton equities as the discount factor is more uncertain after the announcements and long-duration equities are sensitive to discount factor. Investors devalue the long-duration equities more significantly. Figure 10 provides more direct evidence that the resolution of interest rate uncertainty is a crucial driver of the term structure on FOMC days.

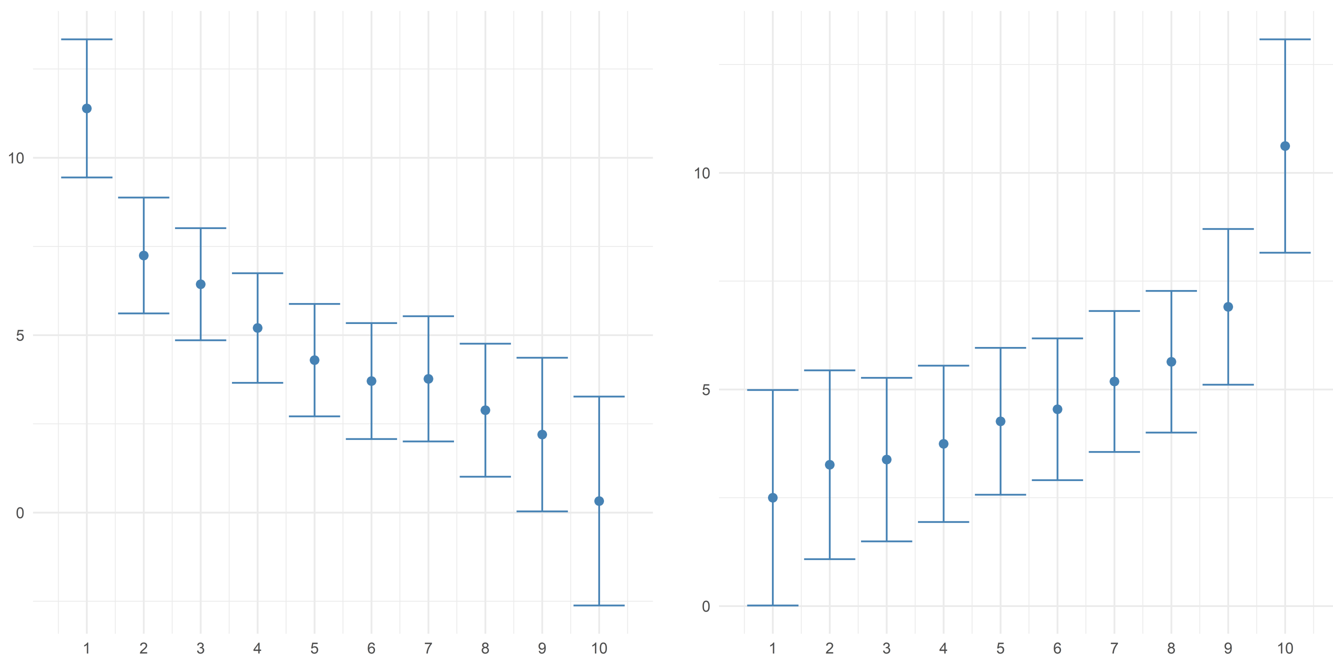
I also regress excess returns at the portfolio level on risk factors. The empirical specification is

$$y_t^m = \alpha^m + \beta_s^m X_{s,t} + \epsilon_{it}, \tag{8}$$

converted to daily returns by dividing by the number of business days in the month. Equities are sorted into 10 deciles based on duration for the previous quarter.

[6] Average monthly returns are converted to daily returns by dividing by the number of business days in the month.

[7] $(\log(\text{IRU}_{t+1}) - \log(\text{IRU}_{t-1}))$ in the total sample, is 0.004 Consequently, I analyzed 48 announcements (20% of 240 announcements) that increased interest rate uncertainty by 0.4%.



(a) Cash Flow Duration

(b) Book-to-Market Ratio

Figure 9: Monthly Average Returns Conditional on Duration

Note: Figure 9 plots the time-series average of monthly returns for each portfolio. The horizontal axis represents the duration of portfolios, ranging from short (one) to long (ten). The vertical axis represents the average monthly return for each portfolio, expressed in basis points. Returns are converted from monthly to daily returns by dividing the monthly returns by the number of business days in the month. Equities are divided into ten groups based on (a) cash-flow duration and (b) book-to-market ratio. The average return within each group is calculated. Standard error is Newey-West standard error. 95% confidence intervals are shown. The portfolios are rebalanced every quarter.

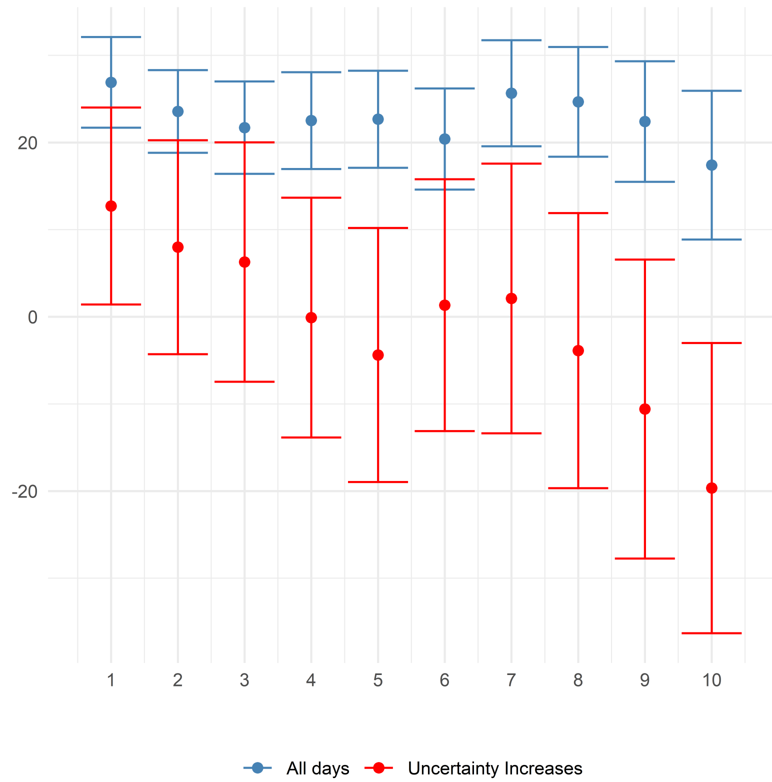


Figure 10: Average Returns Conditional on Duration and an Increase of Uncertainty

Note: Figure 10 plots the time-series average of portfolio returns for all announcements and a subsample of announcements. The blue points represent the average returns for all announcements from 1990 to 2019, while the red points represent the average returns for the subset of announcements where the change in interest rate uncertainty $(\log(\mathrm{IUR}_{t+1}) - \log(\mathrm{IUR}_{t-1}))$ is higher than 0.004. The 80th percentile of the change in interest rate uncertainty in the entire sample period is 0.004. The horizontal axis represents the duration of portfolios, ranging from short (one) to long (ten). The vertical axis represents the average return on FOMC days for each portfolio. The 95% confidence intervals with Newey-West standard errors are shown. The portfolios are rebalanced every quarter.

where y_t^m is the excess return of portfolio m at time t, $m \in \{1, \cdots, 10\}$ represents the portfolio based on duration, α^m is the model-specific pricing error, and $\beta_{i,s}^m$ is the time-series loading of returns on rask factors s, $X_{s,t}$. Risk factors are Fama and French's three factors.

Panel A in Table 6 presents the mean excess returns (OLS regression coefficients) and pricing errors for the three-factor model. A clear upward or downward term structure is not observed, although the returns on the first and second portfolios are higher than those on the others, and the returns on the ninth and tenth portfolios are lower. The three-factor model exhibits limited explanatory power for returns on FOMC days, as the average returns and the pricing errors for the three-factor model are quite similar.

Panel B in Table 6 shows the average returns and pricing errors for the three-factor model using monthly returns. The average returns are monotonically decreasing with duration. The third line in panel B shows that duration is strongly positively related to CAPM betas. High-duration stocks have a CAPM beta of 2.6 compared to low-duration stocks, which have an exposure to the market of only 1.4. As a result, a pricing error and durtion is negatively related.

Sensitivity Analysis The cash-flow duration measure constructed in Section 4.2 relies on six parameters: the persistence in ROE and sales growth, the long-run growth rate in sales and ROE, the discount rate, and the forecasting horizons. To address concerns about the sensitivity of the results to these parameters, I conduct a sensitivity analysis by varying these parameters, as detailed in Appendix D. The results are robust to the choice of parameters.

6.2 Interest Rate Uncertainty and Contemporaneous Regression.

This section estimates the elasticity of returns with different duration to a change in interest rate uncertainty. I test the theoretical prediction that the return on long-duration equities is more sensitive to changes in interest rate uncertainty than is the return on short-duration equities.

I seperately regress the return of portfolios on a change in uncertainty measure,

$$y_t^m = \beta_{iru}^m \Delta \mathrm{IRU}_t + \epsilon_t,$$

where y_t^m is the return of portfolio m at time t represented in percentage points, $\Delta\mathrm{IRU}_t$ is a change in interest rate uncertainty at time t and a portfolio is indexed by $m \in \{1, \cdots, 10\}$. The portfolio

Table 6: Average Returns of Portfolios Sorted on Duration

Portfolio	1	2	3	4	5	6	7	8	9	10
	Panel A: FOMC days									
Average returns	26.9	23.6	21.7	22.5	22.7	20.4	25.7	24.7	22.4	17.4
	(2.6)	(2.4)	(2.7)	(2.8)	(2.8)	(2.9)	(3.1)	(3.2)	(3.5)	(4.4)
CAPM α	26.1	22.5	20.1	20.9	20.4	17.6	22.5	21.5	18.1	11.9
	(2.7)	(2.5)	(2.8)	(2.9)	(2.9)	(3.0)	(3.1)	(3.2)	(3.5)	(3.4)
CAPM β	0.2	0.28	0.42	0.41	0.57	0.70	0.80	0.80	1.05	1.29
	(0.14)	(0.14)	(0.15)	(0.16)	(0.16)	(0.16)	(0.17)	(0.16)	(0.17)	(0.29)
FF3 α	26.0	20.8	19.6	20.6	19.9	18.1	23.1	22.5	19.1	13.3
	(2.6)	(2.5)	(2.7)	(2.8)	(2.8)	(2.8)	(3.0)	(3.1)	(3.4)	(3.0)
	Panel B: Average Monthly Returns									
Average returns	11.4	7.2	6.4	5.2	4.3	3.7	3.8	2.9	2.2	0.3
	(1.0)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.9)	(1.0)	(1.1)	(1.5)
CAPM α	10.5	6.4	5.6	4.4	3.4	2.7	2.6	1.6	0.5	-1.7
	(1.0)	(0.8)	(0.8)	(0.7)	(0.7)	(0.8)	(0.8)	(0.9)	(1.0)	(1.3)
CAPM β	1.4	1.4	1.3	1.3	1.5	1.6	1.8	2.1	2.6	3.0
	(0.25)	(0.23)	(0.22)	(0.21)	(0.21)	(0.21)	(0.23)	(0.23)	(0.27)	(0.37)
FF3 α	9.4	5.3	4.5	3.4	2.5	1.9	2.0	1.3	0.6	-1.2
	(1.0)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.9)	(0.9)	(1.0)	(1.4)
	Panel C: Property of Portfolios									
Duration	9.5	14.3	16.1	17.3	18.2	19.1	19.9	20.8	21.7	23.6

Note: The table shows the time series average of the portfolio returns. "Average returns" is the average returns on the portfolios in basis points. "FF3 α" reports alphas from the three-factor model of Fama and French (1992). "1"-"10" represents the portfolio from short to long. Panel A uses daily returns on FOMC days. Panel B uses monthly returns of portfolios. In Panel B, returns are converted into daily scale by deviding monthly returns by the number of business days in the month. Panel C shows the average of cash-flow duration of the portfolio in years. Standard errors in parenteses are Newey-West standard errors. The sample period is 1990/1-2019/12.

is formed by sorting stocks into 10 deciles based on duration in previosu quarter.

Figure 11-(a) shows the estimated coefficients, β^m_{iru}, as a function of m with the 95% confidence interval. The standard error is OLS. The estimated coefficient is monotonically decreasing with duration. The estimated coefficient for the portfolio with the shortest duration is -5.3, while that longest duration is -9.85. This implies that the return sensitivity to interest rate uncertainty increases with duration in absolute terms. The theoretical prediction is consistent with the empirical result.

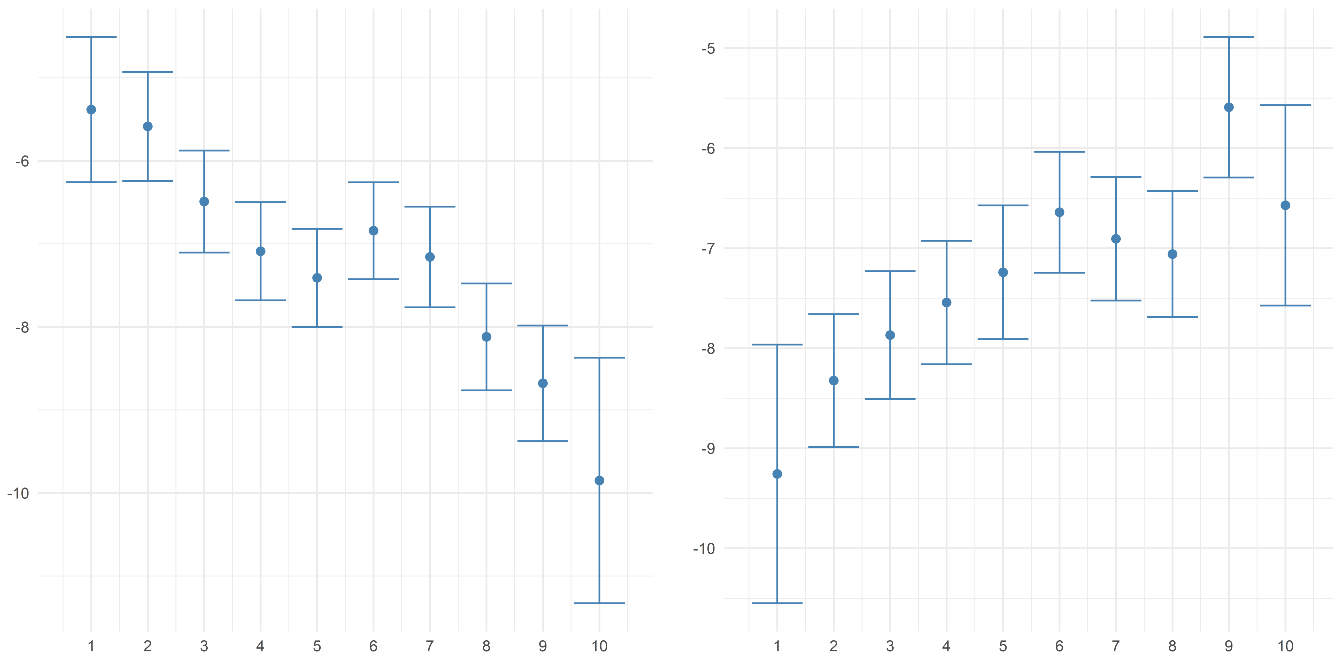
Figure 11-(b) shows the estimated coefficient on the change in the interest rate uncertainty, β^m_{iru}, but the portfolio is sorted based on the book-to-market measure. The estimated coefficient is monotonically increasing with the book-to-market ratio. The estimated coefficient for the portfolio with the lowest book-to-market ratio is -9.2, while that for the highest book-to-market ratio is -6.5. As shown in Appendix C.2, the book-to-market ration has a negative linear relationship with the cash-flow duration under some assumptions. Given the negative relationship, the reslts using book-to-market ratio is consistet withe the results with cash-flow duration.

This monotonic relationship between the elasticity of returns to uncertainty and duration is observed in both equities and bonds. Intuitively, conditional on the resolution of interest rate uncertainty, bonds (which have no cash-flow risk) and equities (which have cash-flow risk) are more responsive when the duration is longer. Importantly, despite the similarity in return sensitivity, the term structure of *average* returns differs between equities and bonds. The average return on long-duration equities is not higher than that on short-duration equities, whereas the average return on long-duration bonds is higher than that on short-duration bonds. This difference arises from the cash flow risk to which equities and bonds are exposed.

I regress returns of equities on a change in interest rate uncertainty and duration to test whether the return of longer-duration equities is more sensitive to the resolution of interest rate uncertainty. The empirical specification is

$$\text{Return}_{i,t} = \beta_1 \Delta IRU_t + \beta_2 \text{Duration}_{it} + \beta_3 \Delta IRU_t \times \text{Duration}_{it} + \gamma X_{it} + \epsilon_{it}, \tag{9}$$

where i is the index of the firm, t is the tth FOMC, Return_{it} is the stock return of firm i at the tth FOMC represented in basis points, ΔIRU_t is the measured change in uncertainty caused by the tth FOMC, and Duration_{it} is the measured duration of firm i at the tth FOMC. X_{it} are control variables including (i) firm and year fixed effects, (ii) size, profitability, leverage, sales growth, and (iii) the



(a) Cash Flow Duration

(b) Book-to-Market Ratio

Figure 11: The Elasticity of Returns to Interest Rate Uncertainty Conditional on Duration

Note: Figure 11 the sensitivity of equity returns to a change in interest rate uncertainty. I seperately regress the return of portfolios on a change in uncertainty measure,

$$y_t^m = \beta^m \Delta \text{IRU}_t + \epsilon_t,$$

where y_t^m is the return of portfolio m at time t represented in basis points, ΔIRU_t is a change in interest rate uncertainty. Portfolios are indexed by $m \in \{1, \cdots, 10\}$. The portfolio is sorted based on cash-flow duration in figure (a) and book-to-market ratio in figure (b). Interest rate uncertainty is taken from Bauer et al. (2022). The vertical plots the coefficients β^m for each portfolio m, and its two OLS standard error bands.

interaction of variables in (ii) and ΔIRU_t. Balance sheet variables are based on informaiton in the previous quarter. Robust standard errors clustered at firm level.

Table 7 reports the results. Column (1) does not include control variables or fixed effects. Column (2) includes control variables, and Column (3) includes control variables and firm fixed effects. The coefficients of interest, β_3, are significantly negative in all columns; it is -0.3 in Column (1). This coefficient indicates that when the duration of equities is one year longer, the elasticity of return to the change in interest rate uncertainty decreases by 0.3 percentage points. The elasticity of return to changes in interest rate uncertainty increases with duration in absolute terms. This empirical specification implies that the estimated

As discussed in section 6.1, the cash-flow duration measure relies on parameters. The sensitivity analysis for those parameters are presented in Appendix D. It is showsn that the results are not sensitive to the assumed parameters.

7 Conclusion

This paper provides empirical evidence and a simple model for cross-sectional returns on FOMC announcement days. In particular, this paper focuses on to determine what specific type of uncertainty is resolved by FOMC announcements and the factors that contribute to the heterogeneity of stock returns. The findings of this study align with existing literature that emphasizes risk-based explanations for the elevated excess returns observed on FOMC announcement days. However, instead of cash flow uncertainty, the analysis highlights the significance of interest rate uncertainty in driving these returns. To assess the importance of interest rate uncertainty, the study formulates theoretical predictions regarding announcement returns based on the duration of assets and subsequently provides empirical evidence that supports these theoretical expectations.

References

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

Table 7: The Elasticity of Returns to Interest Rate Uncertainty Conditional on Duration

	(1)	(2)	(3)
Duration × IRU	-0.3194	-0.3674	-0.3908
	(0.0570)	(0.0573)	(0.0549)
Profit × IRU		20.30	13.52
		(11.47)	(10.15)
Leverage × IRU		1.009	-0.3120
		(0.9006)	(0.8878)
Sales growth × IRU		-1.538	-1.652
		(0.7683)	(0.7817)
IRU	-1.591	5.210	5.205
	(0.9639)	(0.9060)	(0.9119)
R^2	0.00473	0.00547	0.02777
Observations	775,506	698,297	698,297
Controls		✓	✓
Firm fixed effects			✓
Year fixed effects			✓

Note: Table 7 reports the coefficient estimates of the pooled regression of equity returns over 240 FOMC event days. The explanatory variables are the change in uncertainty measure, duration, the interaction of the two, and control variables. Control variables include (i) firm and year fixed effects, (ii) size, profitability, leverage, sales growth, and (iii) the interaction of variables in (ii) and a change in interest rate uncertainty. The standard errors OLS. The independent variables are returns of equities in basis points. Column (2) includes control variables of (ii) and (iii). Column (3) includes firm and year fixed effects. The regression equation is

$$\text{Return}_{i,t} = \beta_1 \Delta IRU_t + \beta_2 \text{Duration}_{it} + \beta_3 \Delta IRU_t \times \text{Duration}_{it} + \gamma X_{it} + \epsilon_{it},$$

where i is the index of the firm, t is the tth FOMC, Return_{it} is the stock return of firm i at the tth FOMC, ΔIRU_t is the measured change in uncertainty caused by the tth FOMC, and Duration_{it} is the measured duration of firm i at the tth FOMC. Standard errors are clustered at firm level.

H. Ai, L. J. Han, X. N. Pan, and L. Xu. The cross section of the monetary policy announcement premium. *Journal of Financial Economics*, 143(1):247–276, 2022.

M. D. Bauer, A. Lakdawala, and P. Mueller. Market-based monetary policy uncertainty. *The Economic Journal*, 132(644):1290–1308, 2022.

B. S. Bernanke and K. N. Kuttner. What explains the stock market's reaction to federal reserve policy? *The Journal of finance*, 60(3):1221–1257, 2005.

F. Bianchi, M. Lettau, and S. C. Ludvigson. Monetary policy and asset valuation. *The Journal of Finance*, 77(2):967–1017, 2022.

F. Brusa, P. Savor, and M. Wilson. One central bank to rule them all. *Review of Finance*, 24(2): 263–304, 2020.

B. Bundick, T. Herriford, and A. Smith. Forward guidance, monetary policy uncertainty, and the term premium. *Monetary Policy Uncertainty, and the Term Premium (July 2017)*, 2017.

S. Chava and A. Hsu. Financial constraints, monetary policy shocks, and the cross-section of equity returns. *The Review of Financial Studies*, 33(9):4367–4402, 2020.

L. J. Christiano, M. Eichenbaum, and C. L. Evans. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of political Economy*, 113(1):1–45, 2005.

A. Cieslak, A. Morse, and A. Vissing-Jorgensen. Stock returns over the fomc cycle. *The Journal of Finance*, 74(5):2201–2248, 2019.

P. M. Dechow, R. G. Sloan, and M. T. Soliman. Implied equity duration: A new measure of equity risk. *Review of Accounting Studies*, 9(2):197–228, 2004.

R. Döttling and L. Ratnovski. Monetary policy and intangible investment. *Journal of Monetary Economics*, 2022.

E. F. Fama and K. R. French. The cross-section of expected stock returns. *the Journal of Finance*, 47(2):427–465, 1992.

R. Gürkaynak, H. G. Karasoy-Can, and S. S. Lee. Stock market's assessment of monetary policy transmission: The cash flow effect. *The Journal of Finance*, 77(4):2375–2421, 2022.

L. P. Hansen, J. C. Heaton, and N. Li. Consumption strikes back? measuring long-run risk. *Journal of Political economy*, 116(2):260–302, 2008.

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

G. X. Hu, J. Pan, J. Wang, and H. Zhu. Premium for heightened uncertainty: Explaining pre-announcement market returns. *Journal of Financial Economics*, 145(3):909–936, 2022.

I. Indriawan, F. Jiao, and Y. Tse. The fomc announcement returns on long-term us and german bond futures. *Journal of Banking & Finance*, 123:106027, 2021.

F. Ippolito, A. K. Ozdagli, and A. Perez-Orive. The transmission of monetary policy through bank lending: The floating rate channel. *Journal of Monetary Economics*, 95:49–71, 2018.

T. A. Kroencke, M. Schmeling, and A. Schrimpf. The fomc risk shift. *Journal of Monetary Economics*, 120:21–39, 2021.

R. Lagos and S. Zhang. Turnover liquidity and the transmission of monetary policy. *American Economic Review*, 110(6):1635–72, 2020.

A. Lakdawala, T. Moreland, and M. Schaffer. The international spillover effects of us monetary policy uncertainty. *Journal of International Economics*, 133:103525, 2021.

M. Lettau and J. A. Wachter. Why is long-horizon equity less risky? a duration-based explanation of the value premium. *The Journal of Finance*, 62(1):55–92, 2007.

M. Lettau and J. A. Wachter. The term structures of equity and interest rates. *Journal of Financial Economics*, 101(1):90–113, 2011.

Y. Liu and J. C. Wu. Reconstructing the yield curve. *Journal of Financial Economics*, 142(3): 1395–1425, 2021.

D. O. Lucca and E. Moench. The pre-fomc announcement drift. *The Journal of finance*, 70(1): 329–371, 2015.

P. Mueller, A. Tahbaz-Salehi, and A. Vedolin. Exchange rates and monetary policy uncertainty. *The Journal of Finance*, 72(3):1213–1252, 2017.

A. Neuhierl and M. Weber. Monetary momentum. Technical report, National Bureau of Economic Research, 2018.

A. K. Ozdagli. Financial frictions and the stock price reaction to monetary policy. *The Review of Financial Studies*, 31(10):3895–3936, 2018.

V. A. Ramey. Macroeconomic shocks and their propagation. *Handbook of macroeconomics*, 2: 71–162, 2016.

P. Savor and M. Wilson. How much do investors care about macroeconomic risk? evidence from scheduled economic announcements. *Journal of Financial and Quantitative Analysis*, 48(2): 343–375, 2013.

P. Savor and M. Wilson. Asset pricing: A tale of two days. *Journal of Financial Economics*, 113 (2):171–201, 2014.

J. A. Wachter and Y. Zhu. A model of two days: Discrete news and asset prices. *The Review of Financial Studies*, 35(5):2246–2307, 2022.

M. Weber. Cash flow duration and the term structure of equity returns. *Journal of Financial Economics*, 128(3):486–503, 2018.

C. Zhang and S. Zhao. The macroeconomic announcement premium and information environment. *Journal of Monetary Economics*, 2023.

Appendix A Proof

A.1 Proposition 1

The expected announcement premium for short-duration stock is

$$
\begin{aligned}
& E\left[\frac{P_2^S(s)}{P_1^S}\right] \\
&= \frac{E\left[\left[C_2^{1-\frac{1}{\psi}}+\beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\right]E\left[\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]}{E\left[\left[C_2^{1-\frac{1}{\psi}}+\beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]} \\
&= 1-\frac{\operatorname{cov}\left(\left[C_2^{1-\frac{1}{\psi}}+\beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}},\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right)}{E\left[\left[C_2^{1-\frac{1}{\psi}}+\beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]}
\end{aligned}
$$

Focusing on post-announcement price, $P_3(s)$ is higher when $X(s)$ is high. Then,

$$\beta^h C_3(s_1)^{-\frac{1}{\psi}}\overline{X}^S > \beta^l C_3(s_2)^{-\frac{1}{\psi}}\overline{X}^S$$

$$\beta C_3(s_3)^{-\frac{1}{\psi}}X^{S,h} > \beta C_3(s_4)^{-\frac{1}{\psi}}X^{S,l}$$

holds. In this case, the covariance is negative if and only if $\gamma > \frac{1}{\psi}$ holds. This is because

$$\left[C_2^{1-\frac{1}{\psi}}+\beta(s_2)V_3(s_2)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}} > \left[C_2^{1-\frac{1}{\psi}}+\beta(s_1)V_3(s_1)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}$$

$$\left[C_2^{1-\frac{1}{\psi}}+\beta(s_4)V_3(s_4)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}} > \left[C_2^{1-\frac{1}{\psi}}+\beta(s_3)V_3(s_3)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}$$

holds. The expected announcement premium is higher than one. The same argument applies for long-duration stock.

A.2 Proposition 2

The announcement premium of long-maturity bonds and short-maturity bonds is given by

$$
\begin{aligned}
& E_1\left[\frac{P_2(s)^S}{P_1^S}\right] - E_1\left[\frac{P_2(s)^L}{P_1^L}\right] \\
&= \frac{E\left[\left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\right] E\left[\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]}{E\left[\left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]} \\
&- \frac{E\left[\left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\right] E\left[\beta^2(s)C_4(s)^{-\frac{1}{\psi}}X^L(s)\right]}{E\left[\left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}\beta^2(s)C_4(s)^{-\frac{1}{\psi}}X^L(s)\right]}
\end{aligned}
\tag{10}
$$

Denote

$$
A(s) \equiv \left[C_2^{1-\frac{1}{\psi}} + \beta(s)V_3(s)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}
$$

The equation 10 is written as

$$
\begin{aligned}
& E_1\left[\frac{P_2(s)^S}{P_1^S}\right] - E_1\left[\frac{P_2(s)^L}{P_1^L}\right] \\
&= \left(E\left[A(s)\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right] E\left[A(s)\beta^2(s)C_4(s)^{-\frac{1}{\psi}}X^L(s)\right]\right)^{-1} E[A(s)] \\
&\times \left(E\left[\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right] E\left[A(s)\beta^2(s)C_4(s)^{-\frac{1}{\psi}}X^L(s)\right]\right. \\
&\left. - E\left[A(s)\beta(s)C_4(s)^{-\frac{1}{\psi}}X^S(s)\right] E\left[\beta^2(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]\right)
\end{aligned}
$$

The cash-flow of bonds is the same for the states and maturities. Also, I have assumed that the consumption in period three and four are the same in all state, $C_3(s_i) = C_4(s_i)$. The sign of this equation is equal to

$$
\begin{aligned}
&\left(E\left[\beta(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]E\left[A(s)\beta^2(s)C_4(s)^{-\frac{1}{\psi}}X^L(s)\right]\right.\\
&\left.-E\left[A(s)\beta(s)C_4(s)^{-\frac{1}{\psi}}X^S(s)\right]E\left[\beta^2(s)C_3(s)^{-\frac{1}{\psi}}X^S(s)\right]\right)\\
&=(1-\alpha)\beta(s_2)C_3(s_2)^{-\frac{1}{\psi}}\alpha A(s_1)\beta^2(s_1)C_4(s_1)^{-\frac{1}{\psi}}\overline{X}\\
&+\alpha\beta(s_1)C_3(s_1)^{-\frac{1}{\psi}}(1-\alpha)A(s_2)\beta^2(s_2)C_4(s_2)^{-\frac{1}{\psi}}\overline{X}\\
&-(1-\alpha)A(s_2)\beta(s_2)C_4(s_2)^{-\frac{1}{\psi}}\alpha\beta^2(s_1)C_4(s_1)^{-\frac{1}{\psi}}\overline{X}\\
&-\alpha A(s_1)\beta(s_1)C_4(s_1)^{-\frac{1}{\psi}}(1-\alpha)\beta^2(s_2)C_4(s_2)^{-\frac{1}{\psi}}\overline{X}\\
&=\alpha(1-\alpha)\beta(s_1)\beta(s_2)C(s_1)^{-\frac{1}{\psi}}C(s_2)^{-\frac{1}{\psi}}(A(s_1)-A(s_2))(\beta(s_1)-\beta(s_2)) \qquad (11)
\end{aligned}
$$

The difference between the discount factor in two states are positive, $\beta(s_1)=\beta^h>\beta(s_2)=\beta^l$. Also,

$$
A(s_1)=\left[C_2^{1-\frac{1}{\psi}}+\beta(s_1)V_3(s_1)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}<A(s_2)\left[C_2^{1-\frac{1}{\psi}}+\beta(s_2)V_3(s_2)^{1-\frac{1}{\psi}}\right]^{\frac{\frac{1}{\psi}-\gamma}{1-\frac{1}{\psi}}}
$$

is true if and only if $\gamma>\frac{1}{\psi}$. Therefore, the equation 11 is negative, and the expected return on the long-maturity bond is higher than the short-maturity bonds.

A.3 Proposition 3

Appendix B Data Sources and Descriptions

1. FOMC dates are obtained from the website of the Board of Governors of the Federal Reserve System[8].

2. Daily SP 500 return is obtained from CRSP through WRDS. CRSP - Annual Update - Index/SP 500 Indexes - Index File on SP 500. Return on SP composite Index is item $sprtrn$.

3. Daily return on the Center for Research in Security Prices (CRSP) value-weighted NYSE / NASDAQ / AMEX is from CRSP-Annual Update - Stock-Version 2-Daily Stock Market Indexes.

[8] https://www.federalreserve.gov/monetarypolicy/fomc_historical_year.htm

4. VIX data is from Chicago Board Options Exchange through WRDS. I use “CBOE S&P500 Volatility Index - Close” (item is vix).

5. Monetary policy uncertainty measure is from Daily market-based data in Bauer et al. (2022) is from Michael Bauer’s web page.

6. Daily stock returns of individual firms are from CRSP.

7. Firm characteristics are from Compustat. I use Compustat - North America - Fundamental Quarterly.

8. Daily Treasury data is from Liu and Wu (2021). I obtain data from Liu’s website.

Appendix C Constructin of Duration Measure

In this section, I describe the construction of duration measures.

This subsection describes the cash flow duration based on Dechow et al. (2004) and Weber (2018). This measure reflects the weighted average time to maturity of cash flow.

$$\text{Duration}_{it} = \frac{\sum_{s=1}^{T} s \times \text{CF}_{i,t+s}/(1+r)^s}{P_{it}},$$

where Duration_{it} is the duration of firm i at time t, $\text{CF}_{i,t+s}$ is the cash flow at time $t+s$, P_{it} is the price of current equity, r is the risk-free rate. A risk-free rate is common across time and firms.

Equities do not have a well-defined finite maturity, so I split the duration formula into a finite period and an infinite terminal value.

$$\text{Duration}_{it} = \frac{\sum_{s=1}^{T} s \times \text{CF}_{i,t+s}/(1+r)^s}{P_{it}} + (T + \frac{1+r}{r}) \times \frac{P_{it} - \sum_{s=1}^{T} \text{CF}_{i.t+s}/(1+r)^s}{P_{it}}$$

Since cash flow is not known in advance, it is approximated by the AR(1) process.

$$\begin{aligned} \text{CF}_{i,t+s} &= \text{E}_{i,t+s} - (\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}) \\ &= \text{BV}_{i,t+s-1} \left[\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}} - \frac{\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}} \right] \end{aligned} \tag{12}$$

Future return on equity ($\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}}$) and growth in book equity ($\frac{\text{BV}_{i,t+s}-\text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}}$) follows autoregressive one process with mean reversion.

$$\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}} = (1-\rho_1)\overline{\frac{\text{E}}{\text{BV}}} + \rho_1 \frac{\text{E}_{i,t+s-1}}{\text{BV}_{i,t+s-2}},$$

$$\frac{\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}} = (1-\rho_2)\overline{\text{BVG}} + \rho_2 \frac{\text{BV}_{i,t+s-1} - \text{BV}_{i,t+s-2}}{\text{BV}_{i,t+s-2}},$$

where $\overline{\frac{\text{E}}{\text{BV}}}$ is average cost of equity and $\overline{\text{BVG}}$ is average growth in book equity [9]. Return on equity has an AR(1) coefficient of 0.67and growth in book equity of 0.18.

The procedure to get $\text{CF}_{i,t+1}$ given $\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}}$ and $\frac{\text{BV}_{i,t+s}-\text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}}$ is

1. Compute $\frac{\text{BV}_{i,t+s+1}-\text{BV}_{i,t+s}}{\text{BV}_{i,t+s}}$ with AR(1) process.

2. Compute $\frac{\text{E}_{i,t+s+1}}{\text{BV}_{i,t+s}}$ with AR(1) process.

3. Compute $\text{CF}_{i,t+1}$ with equation (12).

4. Update $\text{BV}_{i,t+1}$ with

$$\text{BV}_{i,t+1} = \left(1 + \frac{\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}}\right)\text{BV}_{i,t+s-1}$$

This is a recursive procedure, so the future cash flow is obtained in the same way. Duration is measured with the future cash flow.

I use quarterly Compustat as a dataset. BV is an item *ceqq* (common/ordinary equity) minus item *pstkq* (Preferred/Preference Stock). Return on equity is an item *ibq* (Income after all expenses) divided by lagged BV. P_{it} is an item *prccq* (equity price close) multiplied by an item *cshoq* (common shares outstanding).

C.1 Derive equation (1)

This section derives the equation (1). The cash flow duration is given by

$$\text{Duration}_{it} = \frac{\sum_{s=1}^{\infty} s \times \text{CF}_{i,t+s}/(1+r)^s}{P_{it}}.$$

[9] They are set to 0.03 and 0.015, respectively. The risk-free rate is set to 0.03. A termination period, T, is set to 60 quarters. They are all from Weber (2018).

This equation is decomposed into a finite term and an infinite term

$$\begin{aligned}\text{Duration}_{it} = {} & \frac{\sum_{s=t}^{T} s \times \text{CF}_{i,t+s}/(1+r)^s}{\sum_{s=t}^{T} \text{CF}_{i,t+s}/(1+r)^s} \frac{\sum_{s=t}^{T} \text{CF}_{i,t+s}/(1+r)^s}{P_{it}} \\ & + \frac{\sum_{s=T+1}^{\infty} s \times \text{CF}_{i,t+s}/(1+r)^s}{\sum_{s=T+1}^{\infty} \text{CF}_{i,t+s}/(1+r)^s} \frac{\sum_{s=T+1}^{\infty} \text{CF}_{i,t+s}/(1+r)^s}{P_{it}}. \end{aligned} \tag{13}$$

I assume that the terminal cash flow stream is equal to the difference between the observed market capitalization in the stock price and the present discounted value of cash flow over the finite period,

$$\sum_{s=T+1}^{\infty} \text{CF}_{i,t+s}/(1+r)^s = P_{i,t} - \sum_{s=t}^{\infty} \text{CF}_{i,t+s}/(1+r)^s \tag{14}$$

I also assume that after $t = T$, the cash flow is constant over time. Then, I have

$$\frac{\sum_{s=T+1}^{\infty} s \times \text{CF}_{i,t+s}/(1+r)^s}{\sum_{s=T+1}^{\infty} \text{CF}_{i,t+s}/(1+r)^s} = T + \frac{1+r}{r}$$

By substituting this and equation (14) into equation (13), I obtain the equation (1).

C.2 Negative relationship between cash flow duration and book-to-market

In section 6.2, I use book-to-market ratio for alternative measure of duration as a robustness check. In this subsection, a linear relationship between cash flow duraiton and book-market ratio exist under some assumptions.

The cash flow duration is defined as

$$\text{Duration}_{it} = \frac{\sum_{s=1}^{T} s \times \text{CF}_{i,t+s}/(1+r)^s}{P_{it}} + (T + \frac{1+r}{r}) \times \frac{P_{it} - \sum_{s=1}^{T} \text{CF}_{i.t+s}/(1+r)^s}{P_{it}}$$

and with the accounting identity, net cash distribution is given by

$$\text{CF}_{i,t+s} = \text{BV}_{i,t+s-1} \left[\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}} - \frac{\text{BV}_{i,t+s} - \text{BV}_{i,t+s-1}}{\text{BV}_{i,t+s-1}} \right]$$

If we assume that the growth in the book value of equity is zero for all finite periods ($\text{BV}_{i,t+s-1} = \text{BV}_{i,t+s}$) and the return on equity is constant over periods ($\frac{\text{E}_{i,t+s}}{\text{BV}_{i,t+s-1}} = \frac{\text{E}_{i,t}}{\text{BV}_{i,t-1}}$), then $\text{CF}_{i,t+s} = \text{E}_{i,t}$.

Under this assumption, cash flow duration can be written as

$$\text{Duration}_{it} = T + \frac{1+r}{r} - \frac{E_{i,t}T}{rP_{i,t}}$$

Also assume that the return on equity is always equal to the cost of capital, $\frac{E_{i,t}}{BV_{i,t-1}} = r$.Then, duration can be written as

$$\text{Duration}_{it} = T + \frac{1+r}{r} - \frac{BV_{i,t}T}{P_{i,t}}$$

In this special case, there exists a linear and negative relationship between duration and book-to-market ratio.

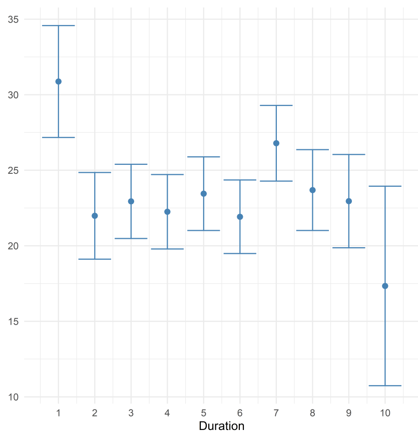
Appendix D Sensitivity Analysis

To construct the cash-flow duration, the parameters to be fed are the persistence in ROE (ρ_1), the persistence in sales growth (ρ_2), the long-run groth rate in sales ($\overline{BVG}$), the long-run growth rate in ROE ($\overline{\frac{E}{BV}}$), the discount rate (r), and the forecasting horizon (T). All variables are defined in Appendix C.

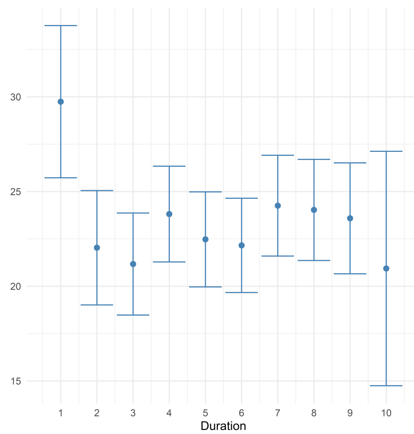
I conduct a sensitivity analysis by changing the parameters. I set the base case as $\rho_1 = 0.67$, $\rho_2 = 0.18$, $\overline{BVG} = 0.015$, $\overline{\frac{E}{BV}} = 0.03$, $r = 0.03$, and $T = 60$. I change one parameter at a time and keep the others constant. Specificaly, the perisistence in ROE is 0.55 and 0.75 (baseline is 0.67), the persistence in sales growth is 0.1 and 0.3 (baseline is 0.18), the long-run growth rate in sales is 0.01 and 0.02 (baseline is 0.015), the long-run growth rate in ROE is 0.02 and 0.04 (baseline is 0.03), the discount rate is 0.025 and 0.035 (baseline is 0.03), and the forecasting horizon is 12 years and 18 years (baseline is 15 years).

D.1 Average returns on FOMC days

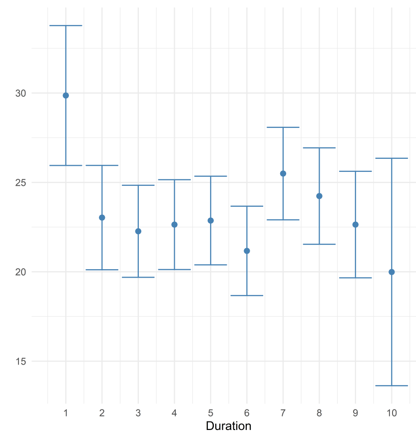
I calculate the cash-flow duration for each firm under twelve different values of a parameter. Then, I sort firms based on durations and estimate the average returns on FOMC days for each portfolio. Figures 12 and 13 show the average return as a function of cash-flow duration under twelve different parameters. Each figure changes only one parameter while keeping the other parameters fixed at their baseline values.



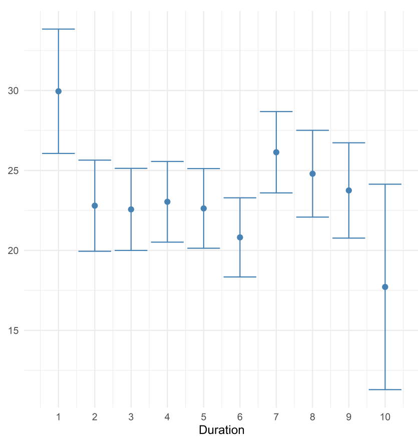
(a) $\rho_1 = 0.75$



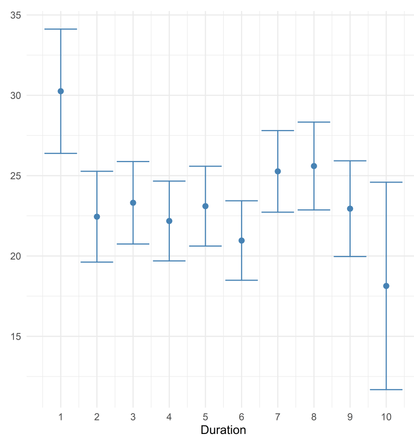
(b) $\rho_1 = 0.55$



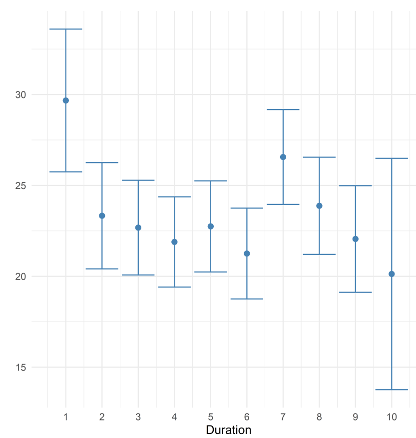
(c) $\rho_2 = 0.3$



(d) $\rho_2 = 0.1$



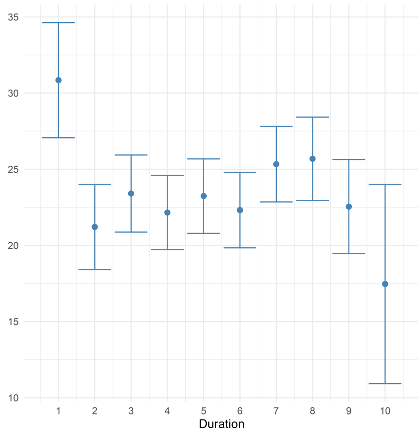
(e) $r = 0.02$



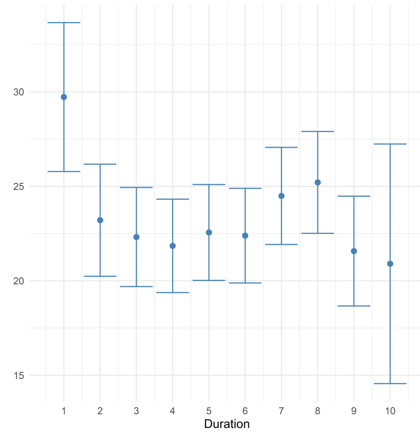
(f) $r = 0.01$

Figure 12: Sensitivity Analysis for Average Returns

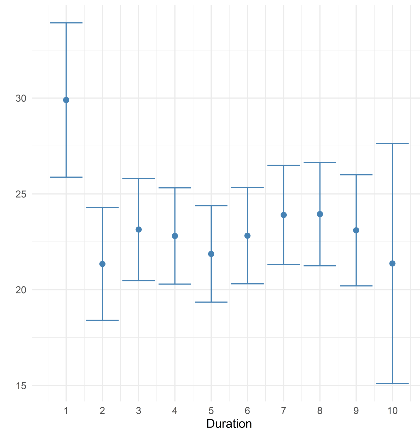
Note: Figure 12 plots the time-series average of portfolio returns on FOMC days under different parameters. The horizontal axis represents the duration of portfolio form short (one) to long (ten). The vertical axis represents the average return on FOMC days for each portfolio. I divide the equities into ten groups from low to high based on duration and calculate average returns within the groups. Each panel changes one parameter at a time and keeps the others constant.



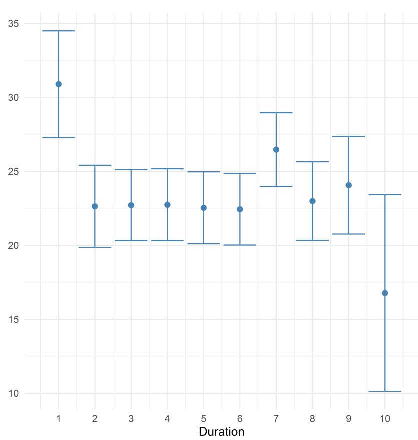
(a) $\overline{BVG} = 0.02$



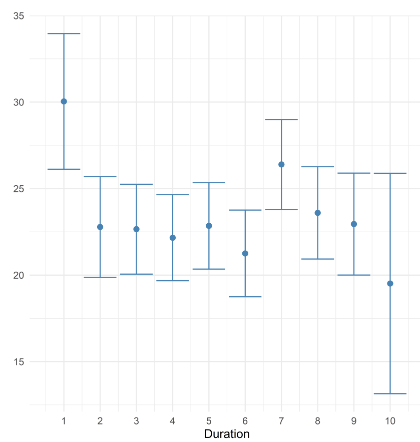
(b) $\overline{BVG} = 0.01$



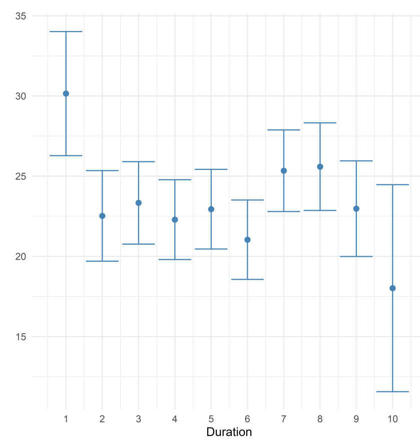
(c) $\overline{\frac{E}{BV}} = 0.04$



(d) $\overline{\frac{E}{BV}} = 0.02$



(e) $T = 18$ years



(f) $T = 12$ years

Figure 13: Sensitivity Analysis for Average Returns

Note: Figure 13 plots the time-series average of portfolio returns on FOMC days under different parameters. The horizontal axis represents the duration of portfolio form short (one) to long (ten). The vertical axis represents the average return on FOMC days for each portfolio. I divide the equities into ten groups from low to high based on duration and calculate average returns within the groups. Each panel changes one parameter at a time and keeps the others constant.

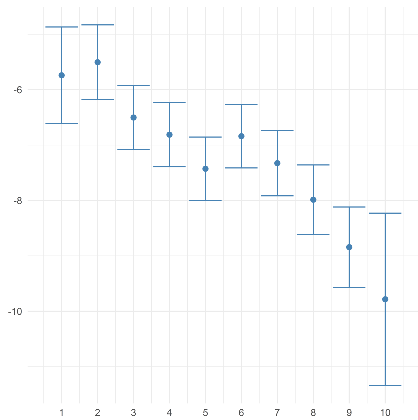
D.2 Interest Rate Uncertainry and Contemporaneous Relationship

This subsection shows a sensitivity analysis for the elasticity of equity returns to interest rate uncertainty. After calculating cash flow duration under different value of parameters and sorting firms based on duration, I regress the return of portfolios on a change in interest rate uncertainty. The equation is

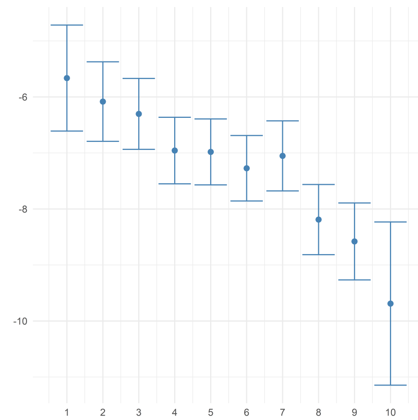
$$y_t^m = \beta^m \Delta \mathrm{IRU}_t + \epsilon_t, \tag{15}$$

where $\Delta\mathrm{IRU}_t$ is a change in interest rate uncertainty and a portfolio is indexed by $m \in \{1, \cdots, 10\}$.

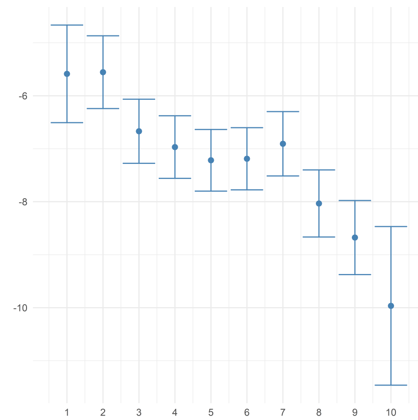
Figure 14 and 15 show the coefficients β^m for each portfolio m and its two standard error bands. The figures show that the elasticity of equity returns to interest rate uncertainty increases with the duration in absolute terms. The result does not depend on the value of parameters that are assumed when calculating cash flow duration.



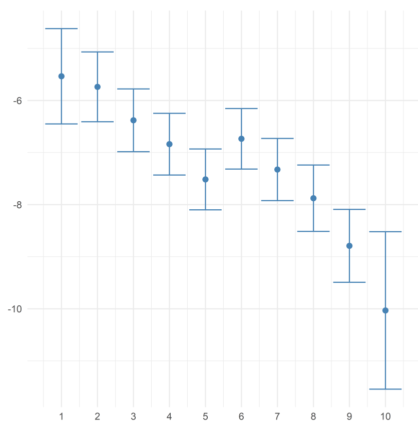
(a) $\rho_1 = 0.75$



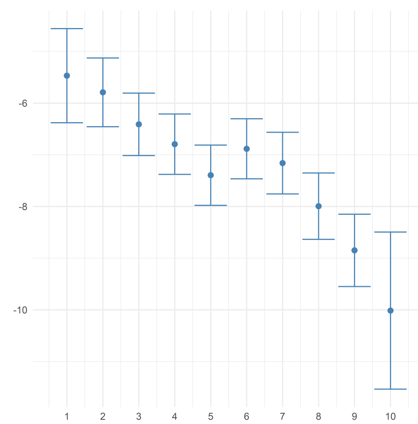
(b) $\rho_1 = 0.55$



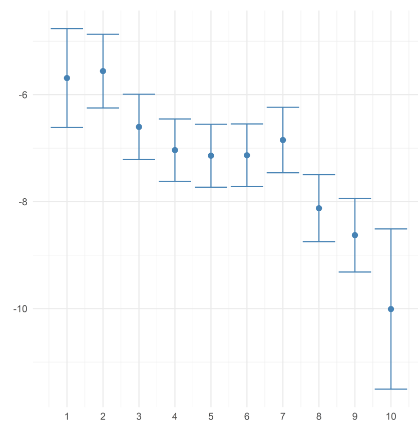
(c) $\rho_2 = 0.3$



(d) $\rho_2 = 0.1$



(e) $r = 0.02$



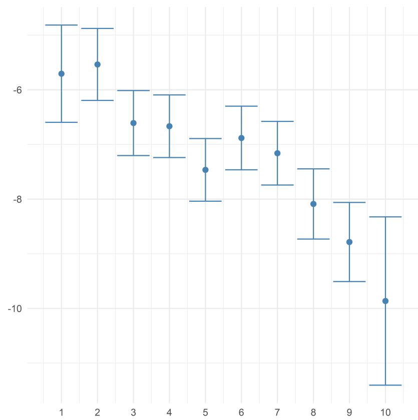
(f) $r = 0.01$

Figure 14: Sensitivity Analysis for the Elasticity to Interest Rate Uncertainty

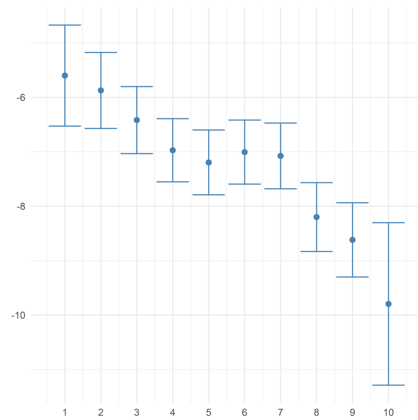
Note: Figure 14 the sensitivity of equity returns to a change in interest rate uncertainty. I seperately regress the return of portfolios on a change in uncertainty measure,

$$y_t^m = \beta^m \Delta \text{IRU}_t + \epsilon_t, \tag{16}$$

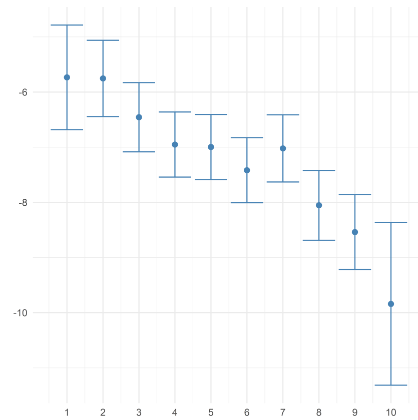
where ΔIRU_t is a change in interest rate uncertainty and a portfolio is indexed by $m \in \{1, \cdots, 10\}$. The portfolio is sorted based on cash-flow duration in figure (a) and book-to-market ratio in figure (b). Interest rate uncertainty is taken from Bauer et al. (2022). The vertical plots the coefficients β^m for each portfolio m, and its two standard error bands. Each panel changes one parameter at a time and keeps the others constant.



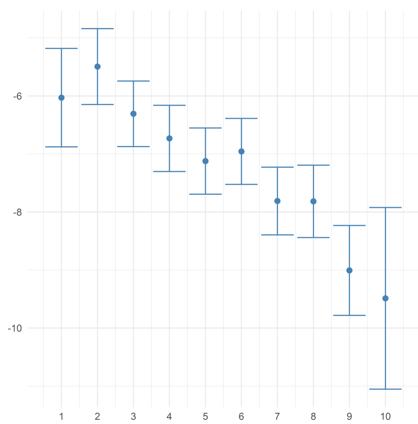
(a) $\overline{BVG} = 0.02$



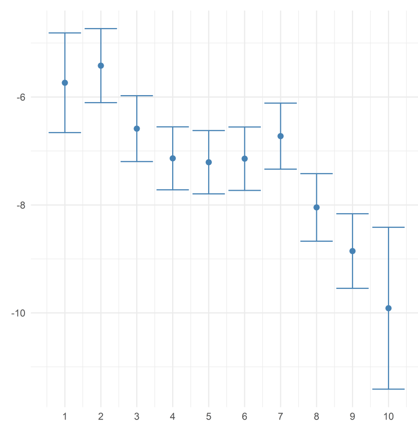
(b) $\overline{BVG} = 0.01$



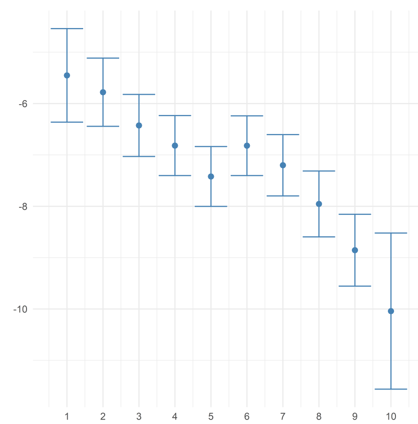
(c) $\overline{\frac{E}{BV}} = 0.04$



(d) $\overline{\frac{E}{BV}} = 0.02$



(e) $T = 18$ years



(f) $T = 12$ years

Figure 15: Sensitivity Analysis for the Elasticity to Interest Rate Uncertainty

Note: Figure 15 the sensitivity of equity returns to a change in interest rate uncertainty. I seperately regress the return of portfolios on a change in uncertainty measure,

$$y_t^m = \beta^m \Delta \text{IRU}_t + \epsilon_t, \tag{17}$$

where ΔIRU_t is a change in interest rate uncertainty and a portfolio is indexed by $m \in \{1, \cdots, 10\}$. The portfolio is sorted based on cash-flow duration in figure (a) and book-to-market ratio in figure (b). Interest rate uncertainty is taken from Bauer et al. (2022). The vertical plots the coefficients β^m for each portfolio m, and its two standard error bands. Each panel changes one parameter at a time and keeps the others constant.