# Monetary Policy and Firm Heterogeneity: The Role of Leverage Since the Financial Crisis *

**Aeimit Lakdawala**†
Wake Forest University

**Timothy Moreland**
UNC Greensboro

**Min Fang**
University of Florida

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**Abstract**

We show that the role of leverage in explaining firm-level responses to monetary policy changed around the financial crisis of 2007-09. Stock prices of firms with high leverage were less responsive to monetary policy shocks in the pre-crisis period but have become more responsive since the crisis. Using expected volatility measures from firm-level options, we further document that financial markets have been aware of this change. To explain this, we consider a model where firms borrow using both short-term and long-term debt. The reversal relies on the relative strength of two competing channels of monetary transmission through the existing level of debt: debt dilution and debt overhang. Before the crisis, the debt overhang channel dominated, so firms with high leverage were less responsive. Since the crisis, unconventional monetary policy has had an outsized effect on long-term interest rates, strengthening the debt dilution channel that benefits firms with high leverage more. Additional firm-level evidence supports this mechanism.

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**Keywords:** Monetary policy transmission, leverage, debt maturity, firm heterogeneity.

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†Corresponding author: lakdawa@wfu.edu; Kirby Hall 217, Winston-Salem, NC, 27109 USA.

# 1 Introduction

Since the federal funds rate hit the zero lower bound in December 2008 during the financial crisis, the Federal Reserve has relied more on unconventional policy tools like quantitative easing. In this paper, we explore how the monetary transmission mechanism may have changed since the crisis, with a focus on the role of heterogeneity in firms' financing conditions. While the importance of the balance sheet of firms for the monetary transmission mechanism has long been established, recent work has highlighted the role of firm-level heterogeneity.[1] However, this literature on firm-level financial heterogeneity has typically focused on the pre-crisis period to study the transmission of conventional monetary policy actions. Our main contribution is to show that the role of financing conditions in explaining the firm-level response to monetary shocks has *reversed* in the post-crisis sample.

Our main empirical framework documents this pattern for non-financial firms in the S&P 500 index using stock price movements on FOMC announcement days. We combine firm-level characteristics (including stock prices) with measures of monetary policy shocks constructed in a narrow window around FOMC announcements from Swanson (2021). Using leverage as the measure of the firm's financial position, we find that before the financial crisis of 2007-09, stock prices of firms with higher leverage respond *less* to monetary policy shocks on FOMC announcement days. However, this pattern is reversed after the crisis: in the post-crisis sample firms with higher leverage respond *more* to monetary shocks. The panel data allows us to control for a variety of firm-level variables including a firm fixed effect to account for any permanent features at the firm level and a sector-time fixed effect to control for both aggregate factors and industry-specific patterns that could be changing over time. We also interact the monetary policy shock with various firm characteristics to show that our results are not explained by these other variables.

Our results hold across a variety of robustness checks, including using alternative measures of leverage and monetary shocks, interacting various firm controls with the monetary policy shock and accounting for the "information effect" in monetary shocks. A natural question is whether our results

[1] For an early survey of the importance of the credit channel of monetary policy, see Bernanke and Gertler (1995). For recent work on firm-level heterogeneity, see Ottonello and Winberry (2020), Jeenas (2019b), Ozdagli (2018), and Deng and Fang (2022), among others.

are driven by the changing behavior of leverage since the crisis. We document that most firms have not moved around much in the leverage distribution since the crisis and that our results are not driven by firms that did move around a lot. Using a rolling regression framework we also check that the change in responsiveness that we highlight does indeed happen around the financial crisis and not considerably earlier or later.

Our results from the stock price response do not imply a specific direction for the expected movement in stock prices of firms with higher (or lower) leverage on FOMC announcement days. This is because the sign of the monetary shock that will occur on the FOMC announcement day is unknown ex-ante. However, there is an implication for the magnitude of the movement in the stock price, regardless of the sign of the monetary shock. Specifically, if investors have internalized our empirical results, they should expect firms with high leverage to be less volatile on FOMC announcement days in the pre-crisis sample. Moreover, this relationship should flip with the crisis making high leverage firms more volatile on announcement days in the post-crisis sample. We test this implication using high frequency firm-level options data. The options data allow for the construction of a measure of expected volatility for each firm. We analyze these firm-level expected volatility measures on the day before the FOMC announcement and confirm the reversal in the relationship between leverage and monetary policy announcements since the financial crisis. This also means that stock market participants were aware of this changing relationship and have updated their expectations of how volatile firms with high leverage will be on FOMC announcement days.

In the next part of the paper, we shed light on the mechanism that drives our empirical results. We develop a stylized version of the heterogeneous firm model with borrowing and default risk as in Ottonello and Winberry (2020), but with one key difference: firms borrow using both short-term and long-term debt. The key insight of our model is that monetary policy affects firms through two competing channels based on their existing debt level: debt dilution and debt overhang. Through the debt dilution channel, firms with high existing debt levels have stronger incentives to take on new debt following a monetary expansion, as they do not internalize the potential default costs on existing debt. This incentive is particularly strong for long-term debt issuance because shareholders benefit from lower borrowing costs while passing some of the default risk to existing debt holders. Through the debt overhang channel, firms with high existing debt are less likely to invest following a monetary expansion because some of the benefits from reducing default risk accrue to existing debt holders rather than shareholders. The investment decision is distorted because shareholders do not capture the full marginal benefit of investment - part of the gains from lower default risk flow to existing debt-holders through the increased value of outstanding debt.

The relative strength of these two channels depends crucially on how monetary policy affects long-term versus short-term interest rates. Our model shows that changes in long-term rates are particularly important because they affect both the cost of new borrowing and the market value of existing debt. Before the financial crisis, monetary policy expansions led to relatively small declines in long-term rates compared to short-term rates. In this environment, the debt overhang channel dominated – firms with high leverage were less responsive to monetary policy as the costs of having high existing debt outweighed any benefits from new borrowing. The small decline in long-term rates meant limited opportunities to benefit from new debt issuance through the debt dilution channel.

However, after the crisis, monetary policy had a much larger effect on long-term rates. Our empirical evidence shows that monetary transmission to long-term rates changed dramatically with the shift from conventional to unconventional policy. A one-standard-deviation unconventional monetary shock in the post-crisis period moves the 10-year Treasury rate four times more than a conventional shock of similar magnitude in the pre-crisis period. In this environment, the debt dilution channel becomes more powerful – the increased sensitivity of long-term rates made new borrowing especially attractive for high-leverage firms, as they could lock in low long-term rates while not fully internalizing the costs to existing debt-holders.

We provide empirical evidence consistent with the key mechanism underlying our model. First, we document that high-leverage firms respond to monetary policy shocks in the post-crisis sample by disproportionately increasing their debt issuance, consistent with strengthening of the debt dilution channel. Second, we show that for high-leverage firms, capital investment responds relatively more in the post-crisis period, consistent with the mitigation of the debt overhang channel coming from stronger debt dilution. Finally, when calibrated to realistic parameters, our model simulations also successfully reproduce the documented reversal between leverage and monetary policy transmission.

**Related Literature** Our paper is related to four strands of the literature. The first strand identifies firm-level characteristics, particularly financial constraints such as leverage, associated with a heterogeneous stock market response to monetary policy shocks. Both Ehrmann and Fratzscher (2004) and Ottonello and Winberry (2020) find that financial constraints affect the strength of a firm's response to monetary policy. Consistent with our results, they find evidence that stock prices for firms with high leverage are relatively less responsive to monetary shocks in the pre-crisis period.[2] Ippolito et al. (2018) and Gürkaynak et al. (2022) show that the stock price of firms with more variable debt is more responsive to monetary policy shocks. While most of the literature focuses on the period prior to the financial crisis, Wu (2018) analyses stock price responsiveness to monetary policy during the 2008-2012 period. Consistent with our results, he finds that firms with higher leverage were more responsive to monetary policy during this period.

Our paper closely relates to two recent papers that are consistent with our post-crisis results. First, Anderson and Cesa-Bianchi (2020) use firm-level bond yields to show that credit spreads of higher leverage firms are more sensitive to monetary shocks. This is consistent with our post-crisis result.[3] Second, Palazzo and Yamarthy (2020) find that firm-level risk plays an important role in the response of credit default swap spreads to US monetary shocks. Specifically, firms with higher credit risk are more responsive. This is also consistent with our post-crisis results, as we show that firm leverage correlates with risk measures.

Second, our paper adds to the growing literature on the heterogeneous effects of unconventional monetary policy since the crisis. Grosse-Rueschkamp et al. (2019) study the effect of the ECB's corporate sector purchase program on a firm's capital structure, showing that firms with bonds eligible for the ECB's program chose to shift from bank loans to bond debt. Daetz et al. (2018) investigate the impact of the ECB's longer-term refinancing operations on corporate investment. They show that the riskiness of their lender influenced firms' investment choices. Foley-Fisher et al.

[2]Many recent papers have explored different firm characteristics. Ozdagli (2018) finds that firms that have higher information frictions are less responsive, while Ippolito et al. (2018) and Chava and Hsu (2019) find that more financially constrained firms have a stronger response to monetary policy, while Lakdawala and Moreland (forthcoming) show that firms that face higher uncertainty respond less. Pollio (2022) investigates the relationship between information shocks and firm leverage. Other related work studies the role of the firm balance sheet in responding to ECB monetary shocks: Darmouni et al. (2020) and Holm-Hadulla and Thürwächter (2021) explore bond debt, while Auer et al. (2019) explore leverage.

[3]Our pre-crisis results are somewhat different. This is likely due to differences in the sample (our sample of firms and pre-crisis dates are different) and empirical specification (we control for the interaction of firm characteristics with the monetary policy shock).

(2016) find that firms that are more dependent on long-term debt responded more to the Federal Reserve's Maturity Extension Program implemented in 2011 and 2012. We find that this amplifying role of long-term debt holds more generally and is a pervasive feature of the post-crisis period.

Third, our paper is related to the emerging literature that explores heterogeneous responses of real economic activity to changes in monetary policy. Ottonello and Winberry (2020) find that investment spending at firms with higher leverage is less responsive to monetary policy shocks in the quarter of a monetary shock. In contrast, Jeenas (2019a) and Jeenas (2019b) find that sales and investment of higher leverage firms are more responsive to monetary policy shocks after approximately eight quarters. We provide evidence that the contemporaneous effect on higher-leverage firms has become larger following the financial crisis. A related line of work (Cloyne et al., 2018; Casiraghi et al., 2021) stresses the importance of firm age for monetary transmission. In our analysis we control for the interaction of monetary policy with firm age to confirm that age is not driving the changing relationship between leverage and monetary transmission.

Finally, our paper links to the literature on long-term corporate debt and its macro-finance implications. Moving from short-term debt to long-term debt induces or amplifies two channels: debt dilution (Bizer and DeMarzo, 1992; DeMarzo and He, 2021) and debt overhang (Myers, 1977; Hennessy, 2004; Diamond and He, 2014). Gomes et al. (2016) first explored how long-term debt matters for monetary policy, focusing on how shocks to inflation change the real burden of outstanding nominal long-term debt and thereby distort investment. Deng and Fang (2022) and Jungherr et al. (2022) show how the heterogeneity of long-term debt share matters for firms' investment responses to monetary policy. Our contribution is by showing the changes in both channels of debt dilution and debt overhang of monetary policy due to the fact that unconventional monetary policy works primarily through long-term rates.

## 2 Data

This paper uses the daily share prices for firms in the S&P 500 index from the CRSP/Compustat Merged Security Daily dataset for July 1991 to June 2019 and firm characteristics from the 1991:Q3 to 2019:Q3 CRSP/Compustat Merged Fundamentals Quarterly dataset. We combine this firm-level data with measures of monetary policy shocks that occur on FOMC meeting days. Additionally, we merge this with a dataset of firm-level implied volatility from OptionMetrics. This section further describes these three data sources.

## 2.1 Monetary Policy Shocks

In the high-frequency monetary policy literature, the most common method to construct shocks involves looking at the change in futures contracts around FOMC announcements, where the underlying asset is the fed funds rate, see for example Kuttner (2001) and Bernanke and Kuttner (2005). However, in more recent years, the Federal Reserve has been using alternative, unconventional policy tools, including large scale asset purchases (quantitative easing). To account for both the conventional and unconventional monetary policy decisions, we use the shocks from the recent work of Swanson (2021). Swanson (2021) uses the methodology of Gürkaynak et al. (2005) to construct three different shocks: fed funds rate (FFR) shock, forward guidance (FG) shock, and large scale asset purchases (LSAP) shock. In our analysis, we will focus on the differential effect of FFR shock in pre-crisis vs. LSAP shock in the post-crisis sample. We scale the shocks so that the FFR shock has a unit effect on the current month's fed funds futures contract (sometimes called MP1), and the LSAP shock has a unit effect on the 10-year Treasury yield. Table 1 shows the summary statistics for the monetary policy shock measures for a pre-crisis sample (July 1991 to June 2008) and a post-crisis sample (August 2009 to June 2019).

## 2.2 Firm-Level Variables

We use the CRSP/Compustat Merged Fundamentals Quarterly sample beginning in 1991:Q3. We use the firms in the S&P 500 index and, as is common in the literature, we exclude financial firms (SIC 6000-6999). We focus on S&P 500 firms because our use of stock market data requires that news revealed in the FOMC announcements is accurately and quickly incorporated into stock prices. As discussed in Gorodnichenko and Weber (2016) there is evidence that stocks of smaller firms had no or few trades in the few hours after major macroeconomic news announcements, especially in the pre-crisis sample. On the other hand, there is evidence that stock prices of S&P 500 firms move very quickly to incorporate the information from FOMC announcements, see for example Zebedee et al. (2008). Moreover, recent work (Gürkaynak et al., 2022) shows that for S&P 500 firms, investors do take into account firm balance sheet characteristics when responding to monetary policy surprises.

Our primary measure of interest from Compustat is the firm's leverage ratio. The baseline results use the ratio of debt-to-assets measured as the sum of debt in current liabilities (Compustat item: DLCQ) and long-term debt (DLTTQ) over the book value of assets (ATQ). We also confirm our results below using an alternative measure of leverage: debt-to-capital, measured as the sum of debt in current liabilities and long-term debt over the sum of debt in current liabilities, long-term debt, and stockholder's equity (SEQQ). Table 1 displays the summary statistics for these definitions of leverage measured as the 4-quarter rolling average at the firm level.

We also use daily stock returns and implied volatility measures at the firm level. We use the daily return of a firm's share price on the day of an FOMC meeting, measured as the log difference between the closing share price on the day of the FOMC meeting and the closing share price on the day prior to the FOMC meeting. The implied volatility measures are computed using firm-level options data from OptionMetrics. The methodology used to do this calculation closely follows the one used for implied volatility of the S&P 500 index, i.e. the VIX. This daily data is available from January 1996 to June 2019. The implied volatility measures for options set to expire in greater than 3 months have the highest liquidity. But we show that our results are very similar for shorter-term options, i.e. those set to expire in less than 1 month and those set to expire between 1 month and 3 months.

Additionally, we create several control variables using these quarterly data: year-over-year real sales growth, firm size as measured by the log of the book value of assets, price-to-cost margin, receivables-minus-payables to sales, depreciation to assets, firm age, the ratio of current assets to total assets, Tobin's q and an indicator for the firm's fiscal quarter. Using CRSP, we also include the log of market capitalization, measured for a firm on the day prior to an FOMC meeting. Including these controls are intended to capture important characteristics of the firm that could be correlated with both firm leverage and firm performance. The construction of these variables follows standard methods in the literature; we include all the details of the sample construction and summary in the online appendix.

# 3 Results

This section presents the main results illustrating how leverage explains the firm-level response to monetary shocks and how that relationship has changed since the financial crisis. First, we document this changing effect using high-frequency data on stock prices. Next, we use firm-level options data to show that financial market participants have been aware of this changing responsiveness.

## 3.1 Evidence from Firm-level Stock Returns

We start by examining how leverage explains the stock price response to monetary policy shocks. In our baseline results, we will consider a pre-crisis sample ranging from July 1991 to June 2008 and a post-crisis sample from August 2009 to June 2019. We are thus leaving out the crisis period as categorized by July 2008 to July 2009. These dates are commonly used in the literature to identify the crisis due to turbulence in the financial markets and the presence of some asset pricing anomalies, for example, Nakamura and Steinsson (2018).

**Specification** Our baseline regression is estimated separately for the pre-crisis and post-crisis samples as follows:

$$s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t} \tag{1}$$

where $s_{i,t}$ is the (daily) return on firm $i$'s share price on FOMC meeting day $t$,[4] $\alpha_i$ is a firm $i$ fixed effect, $\alpha_{s,t}$ is a sector $s$ x FOMC meeting day $t$ fixed effect, $l_{i,t-1}$ is firm $i$'s average leverage (measured as debt-to-assets) for the four quarters preceding the quarter of the FOMC announcement, $\epsilon_t^m$ is the monetary policy shock, and $Z_{i,t-1}$ is a vector of firm-level controls (lagged by a quarter).

The monetary policy shock $\epsilon_t^m$ is not included separately as a regressor because it is subsumed by the sector-time fixed effect. $Z_{i,t-1}$ includes the following firm-level financial measures as controls: real sales growth, the log of the book value of assets, the price-to-cost margin, receivables-minus-payables to sales, depreciation to assets, firm age, the log of daily market capitalization, the ratio of current assets to total assets and Tobin's q. Since the firm-level characteristics are measured at the quarterly

[4] $s_{i,t} = ln(p_{i,t}) - ln(p_{i,t-1})$ where the stock price $p$ is measured at the end of the day.

level, the leverage ratio and the firm-level controls are lagged to ensure they are predetermined at the time of the FOMC announcement. We also include a dummy for the fiscal quarter to account for differences across firms due to different positions in their fiscal year. The firm fixed effect accounts for permanent characteristics of the change in firm $i$'s stock price that are not captured by our controls. The sector-time fixed effects are included to control for unobserved sector-level and FOMC day shocks, which may influence firm-level outcomes across all firms within the same sector. The standard errors reported in the parentheses are calculated using two-way clustering along the time and firm dimensions, but our results are also robust to using Driscoll-Kraay standard errors.

We use the high-frequency shocks from Swanson (2021) as our baseline monetary shocks. In the pre-crisis sample, we set $\epsilon_t^m$ equal to the FFR shock, which captures surprise changes in the federal funds rate. In the post-crisis sample, we set $\epsilon_t^m$ equal to the LSAP shock, which captures surprise changes to large scale asset purchases. Thus, we are not using the LSAP shock in the pre-crisis sample (since there were no large scale asset purchases in that sample), and we are not using the FFR shock in the post-crisis sample (for most of our sample, the fed funds rate is stuck at the zero lower bound). We include the FG shock (surprise changes in forward guidance) in both the pre- and post-crisis samples but do not report the corresponding coefficients here for space reasons. In the appendix we show that the forward guidance shocks do not induce the changing relationship with leverage that we find with FFR and LSAP. We scale the monetary policy shock measure so that $\epsilon_t^m$ corresponds to an expansionary shock.

The coefficient $\beta$ captures how the share price response to a monetary policy shock depends on leverage. We standardize leverage to be mean zero and unit variance, so these coefficients can be interpreted as the additional change in a firm's daily stock price in response to a unit expansionary monetary shock by moving from an average level of leverage to one standard deviation above the average leverage. In standardizing leverage, we use the full sample mean and standard deviation of leverage across all firms; we check for different standardization in the online appendix.

**Results** The top panel of Table 2 presents the results for non-financial firms in the S&P 500 without the firm characteristics interacted with the monetary policy shock (i.e., setting $\Upsilon$ to zero in Equation 1). The interaction coefficient of the FFR shock and leverage in the pre-crisis sample is *negative* and significant. However, in the post-crisis sample, the interaction of LSAP shock and leverage is *positive* and significant. In particular, for firms that were one standard deviation above average leverage, their stock price rises by 2.72% *less* in the pre-crisis sample but rises by 2.15% *more* in the post-crisis sample. The third column shows that the difference between the pre-crisis and post-crisis samples is economically large and statistically significant. To calculate this difference and corresponding standard error, we use a "fully interacted" pooled sample with $D_t^{post}$ being a dummy that turns on for the post-crisis sample, again setting $\Upsilon$ to zero, as follows:

$$s_{i,t} = \left(1 + \zeta D_t^{post}\right) \left[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}\right] + e_{i,t} \tag{2}$$

In the bottom panel of Table 2, we add interactions of the monetary policy shock with firm characteristics listed above (i.e., we allow $\Upsilon$ to be non-zero in Equation 2). Columns (1) - (5) show the results of individual interaction of the firm characteristics with the monetary shock, while in column (6), we interact all the characteristics with the monetary shock. The triple interaction coefficient measuring the difference between the pre-crisis and post-crisis samples remains statistically significant and of roughly the same magnitude across all the specifications. Thus, we can rule out the potential concern that our leverage results are driven by these other firm characteristics.

**Robustness** In Section 3.3, we provide a plethora of additional robustness checks, but before that, we provide evidence from firm-level option prices that are consistent with the idea that the role of leverage in monetary transmission has changed since the crisis.

### 3.2 Evidence from Firm-level Options Data

Our main empirical fact so far is that the stock price of high-leverage firms responds differentially to monetary shocks. The knowledge of this fact does not help an investor predict which *direction* the stock price of a high-leverage firm will move on the FOMC day because the investor does not know which direction the monetary shock will go. However, the investor can use our empirical fact to predict the *relative magnitude* of the movement. Specifically, in the pre-crisis period, if one believes that the stock price of high-leverage firms will respond more to monetary shocks, then the ex-ante expectation should be that the stock price should move less in magnitude relative to a low-leverage firm. Moreover, this ex-ante expectation about movement in magnitude should flip after the crisis.

We test this implication using options data. Specifically, we construct firm-level measures of expected volatility for non-financial S&P 500 firms using options data from the OptionMetrics dataset. The methodology used to do this calculation closely follows the one used for implied volatility of the S&P 500 index, i.e., the VIX. For each firm, we volume-weight the implied volatility of its associated options prices within three different maturity classifications. Short maturities are options expiring within 30 days; medium maturities are options expiring after 30 days but within 90 days; and long maturities are options expiring after 90 days. This gives us three measures of the implied volatility of the expected stock return.[5]

**Specification** Using these implied volatility measures, we explore whether the interrelation between firm-level expected volatility, leverage, and FOMC announcements has changed in a way that is consistent with our earlier results from Section 3.1. Specifically, we run the following regression

$$ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right)\left[\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}\right] + e_{i,t} \quad (3)$$

where for an FOMC meeting occurring on day $t$, $ivol_{i,t-1}$ is the level of implied volatility for firm $i$ on the day before the FOMC meeting, $l_{i,t-1}$ is average leverage (debt-to-assets) for firm $i$ for the four quarters preceding the quarter of the FOMC announcement, $D_t^{post}$ is a dummy that is set to 1 for the post-crisis sample of August 2009 to June 2019, $Z_{i,t-1}$ contains a variety of firm-level controls,[6] $\alpha_i$ is a firm fixed effect and $\alpha_{s,t}$ is a sector-time fixed effect. Due to the data availability of options data, our sample runs from January 1996 to June 2019.

**Results** The estimates are presented in Table 3 with two-way clustered standard errors along the firm and time dimensions. The three columns show the results for the three different maturities. For all columns, the coefficient on leverage ($\delta$) is negative. This means that in the pre-crisis sample, firms with higher leverage had lower levels of expected volatility on the day before the FOMC announcement. However, the coefficient on the interaction of leverage and the post-crisis dummy ($\zeta\delta$) is positive. Relative to the pre-crisis sample, leverage is more positively associated with implied volatility in the post-crisis sample. Moreover, the total effect in the post-crisis sample ($\delta + \zeta\delta$) is

[5] The long maturity options are more liquid than the other two classifications, i.e., there are fewer missing observations for the long maturities.

[6] The controls include the same as those in our baseline stock market regression, as well as the firm-level stock price on the trading day prior to the FOMC day.

positive. This means that as measured on the day before the FOMC announcement, high-leverage firms were expected to be *less* volatile in the pre-crisis sample but *more* volatile in the post-crisis sample.

These results imply that financial market participants are aware of this changing relationship and have updated their expectations about how leverage is related to expected volatility due to FOMC announcements. In summary, we view this options-based result as supporting evidence for the results we have shown with the stock price data.

### 3.3 Robustness Checks and Additional Results

In this section, we provide a variety of robustness checks to address various concerns and additional results of broader interests. Please refer to the online appendix for the detailed discussions. Below, we provide a summary of these results.

**Robustness Checks in Leverage Measures** Our first set of robustness checks includes four tests regarding the leverage measures. In the first test (A.2.1), we start by considering whether the firms with high pre-crisis leverage also had high leverage in the post-crisis sample. We find that there is remarkable stability in the leverage distribution across the two periods, with only modest increases in average leverage post-crisis. In the second test (A.2.2), we check the main results while excluding outliers in leverage, which demonstrates that our main findings are not driven by firms that substantially changed their leverage position. In the third and the fourth tests (A.2.3) and (A.2.4), we show that the main results are robust to alternative standardization of firm leverage measure and to an alternative measure of firm leverage using debt-to-capital ratios.

**Robustness Checks in Sample Composition** Our second set of robustness checks includes three tests regarding the sample. We first show that our stock market results are not driven by a change in the sample composition between the pre-crisis and post-crisis periods in the first test (A.2.5). We rerun our stock market specification, limiting the sample to only those firms that entered Compustat prior to 1994 and remained in the sample through at least 2017, and the results closely match our baseline results. We then show that the main results still hold for non-S&P 500 Compustat firms in the second test (A.2.6). Finally, in our baseline specification, we excluded the crisis period from

July 2008 to July 2009. We show that our results are similar when we include the crisis dates in the post-crisis sample in the third test (A.2.7).

**Robustness Checks in Monetary Policy Shocks** Our third set of robustness checks addresses three tests regarding the monetary shocks.[7] First, we want to ensure our results are not driven by these unscheduled meetings since unscheduled FOMC meetings can affect financial markets differently from regularly scheduled meetings, or maybe the Federal Reserve is more likely to release information about economic fundamentals (Lakdawala and Schaffer (2019)). In the first one (A.2.8), we show that excluding the unscheduled meetings gives results that are quite similar to the baseline case. Second, there may still be a concern that even in regularly scheduled FOMC meetings, high-frequency monetary policy shocks contain substantial information. In the second (A.2.9) and third (A.2.10), we use information effect robust shocks, following Lakdawala (2019) and Bauer and Swanson (2023), respectively, to confirm that the information effects issue does not drive our baseline results.

**Robustness Checks in Financial Variables** We also check for different financial measures, including a test (A.2.11) to include the Fama-French excess return factors and a test (A.2.12) replacing the daily stock return with the open-to-close measure. Our baseline results hold in both cases.

**Additional Results** Finally, we also provide three pieces of additional results to strengthen our main results. In the first piece (A.3.1), we show that the shift in responsiveness occurred sharply around early 2009, with the leverage-monetary policy interaction remaining consistently negative before and positive after this point using rolling window estimates. In the second piece (A.3.2), we show that the average effects of monetary policy shocks are consistent with the literature. In the final piece (A.3.3), we divide the leverage into both long-term and short-term components and show that the changing role of the long-term components before and after the financial crisis is at the central stage. This provides a strong motivation for our mechanisms below to explore the essential role of debt dilution through firms' existing long-term debt positions.

[7] Since we mainly follow the Swanson (2021) shocks for the particular distinctions of Federal Fund Rate shocks and the Large Scale Asset Purchasing shocks, it is inappropriate to use other unified shocks, i.e., Bu et al. (2021), to check robustness. Therefore, we mainly check the effects of specific types of shocks and the potential information effects.

# 4 Mechanism

In this section, we shed light on the mechanism underlying the role of leverage in monetary transmission and why it has changed since the financial crisis. Using a heterogeneous firm model incorporating both short-term and long-term debt, we highlight the importance of the interaction of unconventional monetary policy and long-term debt in the post-crisis period. After presenting the model and explaining the mechanism through first-order conditions, we provide empirical evidence supporting its key implications.

## 4.1 A Stylized Heterogeneous Firm Model

The economy consists of heterogeneous firms making investment and financing decisions, a risk-neutral creditor lending at different maturities, and a monetary authority controlling the real interest rates at different maturities.[8] Firms are subject to their own idiosyncratic productivity shocks and unexpected aggregate real interest rate shocks from the monetary authority. Each firm $i \in [0, 1]$ decides investment, debt issuance, dividend, and whether to default on its debt in each period. The key difference with respect to Ottonello and Winberry (2020) is that with long-term debt, shareholders are now incentivized to dilute the value of their existing long-term debt to benefit themselves, according to Bizer and DeMarzo (1992).

**Firm's Production** Each firm $j$ produces using capital $k$ and labor $l$ with decreasing returns to scale production function $y_{jt} = z_{jt} k_{jt}^{\theta} l_{jt}^{\nu}, \theta + \nu < 1$, where $z_{jt}$ is the persistent idiosyncratic productivity shock for firm $j$ that follows distribution $p(z_{jt}|z_{jt-1})$. Earnings before interest and taxes are $ebita_{jt} \equiv y_{jt} + \varepsilon_{jt} k_{jt} - w l_{jt} - \delta k_{jt} - f$ where $\varepsilon_{jt}$ is a firm-specific capital quality shock, $\delta$ is the depreciation rate, and $f$ is a fixed cost of operation. Productivity $z_{jt}$ is persistent and follows a Markov process. The capital quality shock $\varepsilon_{jt}$ is i.i.d. normal with mean zero and $\sigma_{\epsilon}$, which is realized after production has taken place in period $t$.

**Firm's Financing and Default** The firm can finance capital with equity, one-period short-term,

[8] The firms' problem closely follows the optimal debt maturity choice problem in Jungherr and Schott (2020), but now firms face additional unexpected aggregate real interest rate shocks from the monetary authority. We assume that monetary policy directly affects the path of real interest rates, and creditors discount the prices of short-term and long-term debts with risk-free debt rates in their corresponding maturities.

and multi-period long-term debt at the end of the period $t-1$. Let $b_{jst}$ and $b_{jlt}$ denote the issuance of short-/long-term debt and $b_{jt-1}$ denote the stock of outstanding long-term debt. We follow Leland (1994) by assuming that a fraction $\lambda$ of the long-term principal is paid back every period while the remaining $(1-\lambda)$ remains outstanding. Debt issuance costs are flotation fees for new debt issues and bank fees as $\Theta_b = \Theta(b_{jst}, b_{jlt}, b_{jt-1})$. The firm can also finance by injecting equity $e_{jt-1}$ at the end of period $t-1$. We denote $n_{jt-1}$ as the net worth.

Firm earnings are taxed at rate $\tau$, and coupon payments $c$ are tax-deductible, which provides additional motivation for firms to borrow. Shareholders are protected by limited liability, so they are free to default. A defaulting firm exits the economy. In addition to this, there is exogenous exit risk. With probability $\kappa$, a non-defaulting firm exogenously leaves the economy. We assume default and exogenous firms have zero value to show the mechanism more straightforwardly. We can now describe the capital and net worth functions:

$$k_{jt} = n_{jt-1} + e_{jt-1} + b_{jst}q_{jst-1} + (b_{jlt} - b_{jt-1})\, q_{jlt-1} - \Theta(b_{jst}, b_{jlt}, b_{jt-1}) \tag{4}$$

$$n_{jt} = k_{jt} - b_{jst} - \lambda b_{jlt} + (1-\tau)\left[ebita_{jt} - c\,(b_{jst} + b_{jlt})\right] \tag{5}$$

**Firm's Recursive Problem** Firms maximize shareholder value, the expected present value of net cash flows to shareholders. They discount cash flows at a stochastic discount factor of $1/(1+r_s)$. The shareholder value of a continuing firm at the end of period $t$ can be written as the sum of net worth and a continuation value: $n_{jt} + V_t\,(b_{jt}, z_{jt+1})$, where $b_{jt} = (1-\lambda)b_{jlt}$ is the remaining outstanding debt at the next period $t+1$.

We describe the firm problem starting from the default decision at the end of period $t$. The idiosyncratic capital quality shock $\varepsilon_{jt}$ has been realized, but future firm productivity $z_{t+1}$ is still uncertain. If the firm does not default, the expected shareholder value is $n_{jt} + EV_t\,(b_{jt}, z_{jt+1})$, where the expectation $E$ is taken over future firm productivity. There exists a unique default threshold realization $\bar{\varepsilon}_{jt}$ which sets expected shareholder value to zero:

$$\bar{\varepsilon}_{\mathbf{jt}}: \quad n_{jt}(\bar{\varepsilon}_{jt}) + EV_t\,(b_{jt}, z_{jt+1}) = 0, \quad \text{default if } \varepsilon_{jt} < \bar{\varepsilon}_{jt} \tag{6}$$

At the end of the period of $t-1$, the firm chooses its corporate policies: current period finance and next period production $\{e_{jt-1}, b_{jst}, b_{jlt}, k_{jt}, l_{jt}\}$. The firm anticipates that shareholder value will be positive if $\varepsilon_{jt}$ is higher than the threshold value $\bar{\varepsilon}_{jt}$ and zero otherwise. Given a net worth $n_{jt-1}$, existing debt $b_{jt-1}$, and productivity $z_{jt}$, a firm solves:

$$V_{t-1}\left(b_{jt-1}, z_{jt}\right) = \max\left\{-e_{jt-1} + \frac{1}{1+r_s}\int_{\bar{\varepsilon}_{jt}}^{\infty}\left[n_{jt} + EV_t\left(b_{jt}, z_{jt+1}\right)\right]\varphi(\varepsilon)d\varepsilon\right\} - n_{jt-1}$$

subject to capital function (4), net worth function (5), default cutoff function (6), and the law of motion of long-term debt. The firm's choice of $e_{jt-1}$ is bounded from below: $e_{jt-1} \geq \underline{e}$, with $\underline{e} < 0$. This constitutes an upper limit for dividend payments. Since the value of the beginning of the period net worth $n_{jt_1}$ is predetermined, we will refer to the continuation shareholder's value, the variable component, as $V_{t-1}\left(b_{jt-1}, z_{jt}\right)$ for simplicity. Details of the firm's recursive problem are omitted here but presented in the Online Appendix B.1.1.

**Creditor's Problem** Creditors are perfectly competitive and break even on expectations for both short- and long-term bonds $\{b_{jst}, b_{jlt}\}$ given the corresponding risk-free rates $\{r_{st}, r_{lt}\}$. They buy firm bonds $b_{jst}$ and $b_{jlt}$ at the end of the period $t-1$. If the firm does not default in period $t$, short-term creditors receive $(1+c)b_{jst}$, and long-term creditors are paid $(\lambda + c)b_{jlt}$. To keep the model analytically trackable, we assume they receive nothing in case of default. The break-even prices are

$$q_{jst-1} = \frac{1}{1+r_s}\left[1 - \Phi\left(\bar{\varepsilon}_{jt}\right)\right](1+c) \tag{7}$$

$$q_{jlt-1} = \frac{1}{1+r_l}\left[1 - \Phi\left(\bar{\varepsilon}_{jt}\right)\right]\left(\gamma + c + (1-\gamma)Eg_t\left(b_{jt}, z_{jt+1}\right)\right) \tag{8}$$

where $1 - \Phi\left(\bar{\varepsilon}_{jt}\right)$ is the probability that $\varepsilon_t > \bar{\varepsilon}_{jt}$ and $q_{jlt} = g_t\left(b_{jt}, z_{jt+1}\right)$ is the future market value of long-term debt. The price of short-term debt only depends on firm behavior at time $t$ on the risk of default $\Phi\left(\bar{\varepsilon}_{jt}\right)$. In contrast, the price of long-term debt also depends on the future market value of the remaining fraction $1-\lambda$ of long-term debt $q_{jlt} = g_t\left(b_{jt}, z_{jt+1}\right)$, which depends on expected future firm behavior.

**Monetary Policy** We model monetary policy in a reduced-form setting as a one-time unexpected change in the path of real interest rates since we primarily focus on the heterogeneous firms' stock returns and decisions. We assume the monetary authority directly manipulates the exogenous path of the real interest rates $\{r_{st}, r_{lt}\}$, consistent with recent heterogeneous firm New Keynesian models (Ottonello and Winberry, 2020; Jeenas, 2019a; Fang, 2020), which show that monetary policy affects firm investment primarily through the real interest rate channel. In our model, the shocks in the real interest rates enter into three parts of a firm's decision process: the stochastic discount factor $1/(1+r_s)$, and the risk-free interest rates in short-term and long-term bond prices $r_s$ and $r_l$.

## 4.2 Characterizing the Mechanism in the Model

We then qualitatively characterize the effects of monetary policy shocks in the model. The details of derivatives of all equations in this section are in the Online Appendix B.1. We omit the firm subscription $j$ in the rest of the section to make the equations more intuitive.

### 4.2.1 Shareholder Value and General Effects of Monetary Policy

We could derive the shareholders' value $V^* \equiv V(b_{t-1}, z_t)$ as the summation of net revenues from debt issuance and capital investment as follows:

$$V^* = \underbrace{\left[ q_{st-1} b_{st} + q_{lt-1}(b_{lt} - b_{t-1}) - \Theta_b \right]}_{\text{Net Debt Issuance Revenue}} + \underbrace{\left[ \frac{1-\tau}{1+r_s} k_t \int_{\bar{\varepsilon}_t}^{\infty} (\varepsilon_t - \bar{\varepsilon}_t) \phi(\varepsilon_t) d\varepsilon_t - k_t \right]}_{\text{Net Capital Investment Revenue}} \tag{9}$$

Given interest rates $r_{st}$ and $r_{lt}$, by choosing its optimal scale of production $k_t$, long-term debt issuance $b_{lt}$, and short-term debt $b_{st}$ for the next period $t$, the firm controls the default threshold $\bar{\varepsilon}_t$ as well as maximizes variable component of shareholder value $V^* \equiv V(b_{t-1}, z_t)$. Since all choices are in period $t$, we omit time subscripts $t$ and $t-1$ going forward.

Monetary policy expansions enter the stock value equation (9) by lowering both the short-term and long-term risk-free real interest rates $\{r_s, r_l\}$, and therefore, increasing bond prices $q_{st-1}$ and $q_{lt-1}$ and stochastic discount factor $1/(1+r_s)$. First, even without considering firms changing their optimal behavior in debt issuance and capital investment, net debt issuance and capital investment revenues increase. This directly increases the shareholder value $V^*$. Second, firms would certainly adjust their optimal behavior in debt issuance and capital investment given the reductions in the marginal cost of debt issuance $q_s$ and $q_l$ and improvement in the marginal return of capital investment (stochastic discount factor) $1/(1+r_s)$.

### 4.2.2 The Role of the Existing Debt $b$

Given the same changes in the short-term rate $r_s$ and the marginal benefit of capital investment $1/(1+r_s)$, different changes in the long-term rate $r_l$ will have different effects on shareholders' value due to firms' best responses conditional on (1) the amount of existing debt $b$ on the optimal new debt issuance $b_s$ and $b_l$ (debt dilution channel), and (2) the debt burden of existing debt $b$ on optimal capital investment $k$ (debt overhang channel), both through $\bar{\varepsilon}$. The more firms could adjust on the margins of $\{k, b_s, b_l\}$, the more shareholders' value would grow. Below, we show the effects of monetary expansions through both channels separately.[9]

Before we dive into the two channels, we would like to show the signs of a few partial derivations regarding how the essential endogenous variables would move with respect to firms' choices of $\{k, b_s, b_l, \bar{\varepsilon}\}$. The partial derivatives are:

$$\frac{\partial q_s}{\partial \bar{\varepsilon}} = -\phi(\varepsilon)\frac{1+c}{1+r_s} < 0, \quad \frac{\partial q_l}{\partial \bar{\varepsilon}} = -\phi(\varepsilon)\frac{1+c+(1-\gamma)Eg\left(b', z'\right)}{1+r_l} < 0, \tag{10}$$

$$\frac{\partial \bar{\varepsilon}}{\partial b_s} = \frac{1+(1-\tau)c}{(1-\tau)k} > 0, \quad \frac{\partial \bar{\varepsilon}}{\partial b_l} = \frac{1+(1-\tau)c - E\frac{\partial V(b',z')}{\partial b_l}}{(1-\tau)k} > 0$$

$$\frac{\partial V(b', z')}{\partial b_l} < 0, \quad \frac{\partial g(b', z')}{\partial b_l} < 0$$

$$\frac{\partial \bar{\varepsilon}}{\partial k} = -\frac{1+(1-\tau)(\text{MPK}+\bar{\varepsilon}-\delta)}{(1-\tau)k} < 0, \quad (\text{if chosen } MPK + \bar{\varepsilon} > \delta)$$

where the signs of the partial derivatives are intuitive: $\frac{\partial q_s}{\partial \bar{\varepsilon}} < 0$ and $\frac{\partial q_l}{\partial \bar{\varepsilon}} < 0$ indicates that higher default risk reduces bond prices, $\frac{\partial \bar{\varepsilon}}{\partial b_s} > 0$ and $\frac{\partial \bar{\varepsilon}}{\partial b_l} > 0$ indicates that more borrowing increases default risk, $\frac{\partial V(b',z')}{\partial b_l} < 0$ indicates high debt level lowers continuation value, $\frac{\partial g(b',z')}{\partial b_l} < 0$ indicates more long-term borrowing reduced future long-term bond prices, and $\frac{\partial \bar{\varepsilon}}{\partial b_s} < 0$ indicates that capital investment also increases default risk.

[9] To keep the analysis tractable, the model only has two states: productivity $z$ and existing debt $b$. We will discuss the role of leverage as the role of existing debt $b$ in the following analysis. In the Online Appendix B.4.4, we show that the predictions in debt level are consistent with regression results in leverage.

The key difference between monetary policy expansions before and after the financial crisis is that they affect the long-term risk-free real interest rates differently. As we will show in Section 4.3 below, long-term rates were substantially more responsive in magnitude to unconventional monetary policy after the crisis than to conventional monetary policy shocks before the crisis. With this empirical fact, we can now evaluate the changing role of leverage in the post-crisis sample through the two key channels: debt dilution and debt overhang.

#### 4.2.3 The Debt Dilution Channel of Monetary Policy

We first evaluate how the level of existing debt affects the transmission of monetary policy to firms' optimal new debt issuance choices and shareholder value through the net debt issuance revenue. As capital choice does not explicitly influence the first-order conditions of debt choices, our analysis is easier here than the debt overhang channel below. We first take the firm's first order conditions on $V^*$ with respect to both debt choices $b_s$ and $b_l$ and insert the partial derivatives of $\frac{\partial q_s}{\partial \bar{\varepsilon}}$ and $\frac{\partial q_l}{\partial \bar{\varepsilon}}$. We can rewrite the short and long-term debt FOCs regarding $b_s$ and $b_l$, respectively, in terms of $\{r_s, r_l, b\}$ to analyze the effects of debt dilution due to $b$ and how it interacts with monetary policy $\{r_s, r_l\}$:

$$\begin{aligned}
&\underbrace{\frac{1}{1+r_s}\left[(1-\Phi(\bar{\varepsilon}))\tau c\right]}_{\text{tax benefit if no default}}\underbrace{-\frac{1}{1+r_s}\left[\frac{\partial \bar{\varepsilon}}{\partial b_s}\phi(\varepsilon)(1+c)\right]b_s-\frac{1}{1+r_l}\left[\frac{\partial \bar{\varepsilon}}{\partial b_s}\phi(\varepsilon)\left(1+c+(1-\gamma)Eg\left(b',z'\right)\right)\right]b_l}_{\text{default cost priced into current bond prices}}\\
&\underbrace{+\frac{1}{1+\mathbf{r_l}}\left[\frac{\partial \bar{\varepsilon}}{\partial b_s}\phi(\varepsilon)\left(1+c+(1-\gamma)Eg\left(b',z'\right)\right)\right]\mathbf{b}}_{\textbf{debt dilution benefit priced into current bond prices}}+\Theta_b'(b_s)=0
\end{aligned} \tag{11}$$

$$\begin{aligned}
&\underbrace{\frac{1}{1+r_l}\left[(1-\Phi(\bar{\varepsilon}))\tau c\right]}_{\text{tax benefit if no default}}\underbrace{-\frac{1}{1+r_s}\left[\frac{\partial \bar{\varepsilon}}{\partial b_l}\phi(\varepsilon)(1+c)\right]b_s-\frac{1}{1+r_l}\left[\frac{\partial \bar{\varepsilon}}{\partial b_l}\phi(\varepsilon)\left(1+c+(1-\gamma)Eg\left(b',z'\right)\right)\right]b_l}_{\text{default cost priced into current bond prices}}\\
&\underbrace{+\frac{1}{1+r_l}(1-\Phi(\bar{\varepsilon}))E\left[(1-\gamma)g\left(b',z'\right)+(1-\gamma)\frac{\partial g\left(b',z'\right)}{\partial b_l}b_l+\frac{\partial V\left(b',z'\right)}{\partial b_l}\right]}_{\text{changes in firm value considering both future bond prices and debt level}}\\
&\underbrace{+\frac{1}{1+\mathbf{r_l}}E\left[\frac{\partial \bar{\varepsilon}}{\partial b_l}\phi(\varepsilon)\left(1+c+(1-\gamma)g\left(b',z'\right)\right)-(1-\Phi(\bar{\varepsilon}))(1-\gamma)\frac{\partial g\left(b',z'\right)}{\partial b_l}\right]\mathbf{b}}_{\textbf{debt dilution benefit priced into current and future bond prices}}+\Theta_b'(b_l)=0
\end{aligned} \tag{12}$$

where $\Theta_b'(b_s)$ and $\Theta_b'(b_l)$ indicates the partial derivative of the issuance costs with respect to $b_s$ and $b_l$, which is not the focus of our discussion. Both short and long-term issuance create the marginal benefits of tax deduction and marginal costs of decreasing bond prices, as the first lines of both equations (11) and (12) indicate. Additionally, long-term debt issuance affects firm value through two channels: changes in future bond prices and adjustments in future debt levels, as shown in the second line of equation (12). Notably, these dynamic effects operate independently of the firm's current debt level $b$.

We focus on the last lines of both equations (11) and (12). Since the marginal return of existing debt, the multiplier of existing debt $b$ on the second line in both FOCs, are positive, we can see that high values of existing debt $b$ can increase both short- and long-term debt issuance $b_s$ and $b_l$. This is the classical debt dilution problem (Bizer and DeMarzo, 1992; Admati et al., 2018; DeMarzo and He, 2021). The marginal effect of existing debt—represented by the coefficient on $b$ in the last line of both FOCs—is positive. This indicates that higher levels of existing debt incentivize increased issuance of both short-term $b_s$ and long-term $b_l$ debt. This exemplifies the classic debt dilution problem. The reason is that the firm does not internalize potential default costs on existing long-term debt while issuing new debt. Moreover, this effect is stronger for long-term debt borrowing because of the additional dilution effects on future bond prices.[10]

In terms of monetary policy, Proposition (1) below summarizes how the debt dilution channel of monetary policy operated before and after the Great Financial Crisis.

**Proposition 1.** ***The Debt Dilution Channel of Monetary Policy***

*(i). Higher existing debt $b$ amplifies the transmission of monetary policy expansions to debt issuance. This effect is even bigger for long-term debt issuance.*

*(ii). Suppose an unconventional monetary expansion post-crisis lowers long-term rate $r_l$ more than a conventional expansion pre-crisis, then higher existing debt $b$ benefits the shareholders more after the crisis through the debt dilution channel above.*

***Proof.*** *(i) and (ii) are derived from the first-order conditions of debt.*

[10]The term $-\frac{1}{1+r_l}(1-\Phi(\bar{\varepsilon}))(1-\gamma)\partial Eg\left(b', z'\right)/\partial b_l$ in the marginal return, which represents the changes in future bond prices of existing debt holders, is positive since $\partial Eg\left(b', z'\right)/\partial b_l < 0$.

Proposition (1) states that a higher existing debt level $b$ strengthens the positive effect of monetary expansion by amplifying the multiplier on the long-term stochastic discount factor $1/(1+r_l)$, thereby enhancing firms' incentives for new debt issuance. The impact differs between conventional and unconventional monetary policy. Both policies intensify the debt dilution channel by increasing the prices of existing bonds through $1/(1+r_l)$, but the unconventional policy has a stronger effect. Let $r_l^u$ and $r_l^c$ denote the effects of unconventional and conventional monetary policy on long-term rates, respectively. As our empirical results show below, unconventional policy reduces long-term rates more than conventional policy, $1/(1+r_l^u) > 1/(1+r_l^c)$, resulting in a stronger multiplier effect on existing debt $b$. This amplification is especially pronounced for long-term debt issuance.

#### 4.2.4 The Debt Overhang Channel of Monetary Policy

We then evaluate how the level of existing debt affects the transmission of monetary policy to firms' optimal capital choices and shareholder value through the net capital investment revenue. The firm's first order condition with respect to capital $k$ is:

$$\frac{\partial \bar{\varepsilon}}{\partial k}\left[b_s \frac{\partial q_s}{\partial \bar{\varepsilon}} + (b_l - b)\frac{\partial q_l}{\partial \bar{\varepsilon}} - \frac{1-\tau}{1+r_s} k[1-\Phi(\bar{\varepsilon})]\right] + \frac{1-\tau}{1+r_s}\int_{\bar{\varepsilon}}^{\infty}(\varepsilon - \bar{\varepsilon})\varphi(\varepsilon)d\varepsilon - 1 = 0$$

where we can plug in the partial derivatives of bond prices $\partial q_s/\partial \bar{\varepsilon}$ and $\partial q_l/\partial \bar{\varepsilon}$ and rewrite the capital FOC in terms of $\{r_s, r_l, b_s, b_l, b\}$ to analyze the effects of debt overhang and how it interacts with monetary policy as follows:

$$\begin{aligned}
&\underbrace{\frac{(1-\tau)}{1+r_s}\int_{\bar{\varepsilon}}^{\infty}(\varepsilon-\bar{\varepsilon})\varphi(\varepsilon)d\varepsilon}_{\text{revenue benefit if no default}} \underbrace{+\frac{(1-\tau)}{1+r_s}\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)[1-\Phi(\bar{\varepsilon})]k}_{\text{revenue benefit of reducing default risk}} \\
&\underbrace{+\frac{1}{1+\mathbf{r_s}}\left[\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)\phi(\varepsilon)\left(1+c\right)\right]\mathbf{b_s} + \frac{1}{1+\mathbf{r_l}}\left[\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)\phi(\varepsilon)\left(1+c+(1-\gamma)Eg\left(b',z'\right)\right)\right]\mathbf{b_l}}_{\text{bond price benefit of reducing default risk}} \\
&\underbrace{-\frac{1}{1+\mathbf{r_l}}\left[\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)\phi(\varepsilon)\left(1+c+(1-\gamma)Eg\left(b',z'\right)\right)\right]\mathbf{b}}_{\textbf{debt overhang cost priced into current and future bond prices}} \quad = 1
\end{aligned} \tag{13}$$

where $\mathbf{b_s} = b_s(z, b, r_s, r_l)$ and $\mathbf{b_l} = b_s(z, b, r_s, r_l)$ are in turn functions of the existing debt level $b$ and monetary policy instruments $\{r_s, r_l\}$.

Our focus is the second and the third lines of equation (13).[11] First, focusing on the third line, we evaluate the effects without considering the increased responses of $b_s$ and $b_l$ to a higher existing level of debt $b$. Since the marginal return of existing debt, the multiplier of existing debt $b$ on the third line is negative, we see that a high value of existing debt $b$ decreases capital investment $k$. This is the classical debt overhang problem (Myers, 1977; Hennessy, 2004; Gomes et al., 2016). The reason is that lower default risk also raises the market value of existing debt through $(-\partial\bar{\varepsilon}/\partial k > 0)$, which the firm does not internalize.

Second, we now take the debt issuance effects into consideration in terms of monetary expansions, that is, the increased responses of $b_s$ and $b_l$ to a higher existing level of debt $b$. According to Proposition 1, the optimal debt issuance choices are increased functions of existing debt $\partial b_s/\partial b > 0$ and $\partial b_l/\partial b > 0$ in response to monetary expansions. Higher $b_s$ and $b_l$ enlarges the positive multiplier on the short- and long-term stochastic discount factor $1/(1 + r_s)$ and $1/(1 + r_l)$ respectively, making a monetary expansion more beneficial to the firm with respect to capital investment. Depending on the magnitudes of the elasticity $\partial b_s/\partial b$ and $\partial b_l/\partial b$ and how much monetary shocks move the long-term rate $r_l$, the above debt issuance effect could mitigate or even dominate the debt overhang effects from existing debt $b$.[12]

Proposition (2) below summarizes how the debt overhang channel of monetary policy operated before and after the crisis.

**Proposition 2.** ***The Debt Overhang Channel of Monetary Policy***

*(i). Without considering the effects of existing debt $b$ on new debt issuance $b_s$ and $b_l$, higher existing debt $b$ dampens the transmission of monetary policy expansions to investment.*

*(ii). Considering the debt dilution effects of existing debt $b$ on new debt issuance $b_s$ and $b_l$, the debt overhang channel above is mitigated or even reversed.*

*(iii). Suppose an unconventional monetary expansion post-crisis lowers the long-term rate $r_l$ more*

[11] The first line is not our focus. Given short-term and long-term bond issuance $b_s$ and $b_l$, increasing capital by one unit is a net equity issuance with unity costs. Meanwhile, it generates future discounted dividends and lowers default risk $(\partial\bar{\varepsilon}/\partial k < 0)$, which induces the benefit of retained discounted capital from non-default.

[12] For instance, ignore short-term debt $b_s$, if an increment $\Delta b$ causes changes in optimal $b_l$ choice for $\Delta b_l = 0.5\Delta b$, then $\Delta(b - b_l) = 0.5\Delta b$, the debt overhang channel is mitigated. Another example would be that an increment $\Delta b$ causes changes in optimal $b_l$ choice for $\Delta b_l > \Delta b$, then the debt overhang channel is reversed.

*than a conventional expansion pre-crisis; then, the mitigation/reversal of the debt overhang problem is stronger for unconventional monetary policy.*

***Proof.*** *(i), (ii), and (iii) are all derived from the first-order conditions of debt and capital.*

Proposition (2) states that the differential impact of conventional and unconventional monetary policy depends on how effectively new debt issuance can mitigate or reverse the debt overhang effects from existing debt. As our empirical analysis below demonstrates, the conventional monetary policy before the crisis induced relatively modest reductions in $r_l$, providing limited incentives for long-term debt issuance. In contrast, unconventional monetary policy after the financial crisis generated substantial declines in $r_l$, making long-term debt issuance significantly more attractive to firms.

#### 4.2.5 Summary of the Predictions Before and After Financial Crisis

Finally, we summarize the model's key predictions about how firms' optimal decisions vary with their initial debt level $b$, contrasting the pre- and post-crisis responses to monetary policy.

**Predictions** In the pre-crisis period, with conventional monetary policy not moving long-term rates substantially, the debt overhang channel dominates, and high debt (leverage) firms are less responsive to monetary policy shocks. The model's predictions change after the crisis if monetary policy has a substantially stronger effect on long-term rates. This makes new debt issuance more attractive to high debt (leverage) firms, and the debt dilution channel mitigates the debt overhang channel. Therefore, assuming that monetary expansions lower long-term rates more in the post-crisis period, the model predicts that firms would increase their debt borrowing, increase capital investment, and higher stock returns of firms with higher debt (leverage) levels. We choose the state variable as debt level $b$ to keep the stylized model analytically tractable.

**Quantification** We also provide a quantification of a full-blown model with realistic features commonly used in the literature. Since the quantification confirms the analytical results above, we leave out the quantitative model to the Online Appendix B.4 and just provide a summary here. The model is calibrated to US firm-level data and is consistent with the predictions of the stylized model but in terms of firm leverage instead of debt level. While the analytical model used the level of debt as the state variable, the quantitative model reproduces the same results using leverage as the state variable.

### 4.3 Empirical Evidence for the Mechanism in the Data

In this section, we provide supporting empirical evidence for the above-mentioned mechanisms in the data.

We start by showing that unconventional monetary policy adopted since the financial crisis has had an outsized effect on long-term *real* rates relative to the pre-crisis period. In Table 4, we regress the (daily) change in the 10 year nominal yield, the 10 year real yield, and the term premium of the 10 year nominal yield on the Swanson (2021) monetary policy shocks. The nominal yields are from Gürkaynak et al. (2007), the real yields from Gürkaynak et al. (2010), and the term premium estimates are from Kim and Wright (2005). The results shows that unconventional monetary policy lowers real long-term yields substantially more than conventional monetary policy. Much of the effect of unconventional monetary policy works through the term premium, consistent with the "portfolio-balance" channel.

To properly assess the magnitude of the effect we provide two versions of the regression with different scaling of the Swanson (2021) shocks. The top panel shows this using our baseline scaling. Recall, that for our baseline results we scaled the FFR shock to have a unit effect on the current month's fed funds futures and the LSAP shock to have a unit effect on the 10-year Treasury yield. To make sure that this scaling is not driving the results in Table 4 we rerun the regression with the unscaled versions of these shocks, which are constructed to have unit standard deviation. These are presented in the bottom panel. Using the estimates from the bottom panel suggests that a one-standard deviation LSAP shock in the post-crisis period lowers the real 10 year yield 4 times as much compared to a one standard deviation FFR shock in the pre-crisis period.

Feeding this result into our model framework generates the predicted changing relationship between leverage and monetary transmission to stock prices documented in Section 3. In doing so, the model mechanism relies on the debt dilution channel getting stronger in the post-crisis period. This generates the testable implication that firms with high leverage should issue relatively more debt in the post-crisis period in response to monetary policy.[13] The other testable implication is that strengthening the debt dilution channel mitigates or even reverses the debt overhang channel. This means that the debt overhang channel, which makes high-leverage firms' investments respond less in the pre-crisis period, should be weakened in the post-crisis period. We test to see if this is the case in the data. In Table 5, we show that both model predictions on debt borrowing and capital investment are indeed the case in the data. Specifically, the interaction coefficient on $D_t^{post}$x $\epsilon_t^m$ x leverage is positive and significant. High-leverage firms increase their capital investment and their debt issuance more in the post-crisis period in response to a monetary policy shock.

# 5 Conclusion

This paper adds to the growing empirical literature on monetary policy and firm-level heterogeneity. Using high-frequency data from the stock market, we show that the role of leverage in explaining firm-level responses to monetary policy shocks has changed since the financial crisis. Before the financial crisis, firms with higher leverage were less responsive to monetary policy shocks. However, after the financial crisis, this relationship *reversed*, with high-leverage firms becoming more responsive to monetary policy shocks.

Using a stylized model of firm financing with both short-term and long-term debt, we highlight two competing channels through which monetary transmission interacts with the firms' existing debt: debt dilution and debt overhang. The relative strength of these channels depends on how monetary policy affects long-term rates. Our empirical evidence shows that unconventional monetary policy shocks in the post-crisis period have had larger effects on long-term rates than conventional policy shocks pre-crisis, strengthening the debt dilution channel and explaining why high-leverage firms have became more responsive. These findings highlight how the shift from conventional to unconventional monetary policy has altered the relationship between corporate financial structure and monetary transmission mechanism.

[13] These results are also consistent with the "gap-filling" framework outlined in Greenwood et al. (2010), and the work of Foley-Fisher et al. (2016) who find that the Federal Reserve's Maturity Extension Program (MEP) in 2011 and 2012 had disproportionate effects on firms with more long-term debt. We have run our results, dropping the quarters containing the two MEP-related FOMC meetings in 2011 and 2012, and find that they are essentially unchanged. Thus, our results indicate that the phenomenon of monetary policy having a bigger effect on firms that are more exposed to long-term debt has been true more generally of Federal Reserve policy since the crisis and not just specific to the MEP.

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Table 1: Summary Statistics

| | Pre-Crisis | | Post-Crisis | |
|---|---|---|---|---|
| | mean | std. dev. | mean | std. dev. |
| Stock return | 0.23 | 3.03 | 0.08 | 1.92 |
| Leverage (Debt-to-Assets) | 0.26 | 0.15 | 0.28 | 0.17 |
| Leverage (Debt-to-Capital) | 0.39 | 0.22 | 0.42 | 0.24 |
| LT debt share | 0.79 | 0.23 | 0.87 | 0.16 |
| Implied volatility, short maturity | 44.36 | 26.42 | 32.25 | 15.30 |
| Implied volatility, medium maturity | 38.41 | 18.85 | 28.32 | 10.75 |
| Implied volatility, long maturity | 35.93 | 16.00 | 28.75 | 9.71 |
| FFR shock | 0.01 | 0.09 | | |
| FG shock | -0.00 | 0.03 | 0.00 | 0.03 |
| LSAP shock | | | -0.00 | 0.02 |
| Firm observations | 58,673 | | 28,967 | |
| FOMC observations | 152 | | 80 | |

Notes: This table shows summary statistics for stock returns, leverage measures, long-term debt share, implied volatility, and monetary policy shocks. Stock returns and implied volatility are measured daily at the firm level. Leverage is measured quarterly at the firm level. The monetary policy shocks are measured within a 30-minute window around an FOMC announcement. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to June-2019.

Table 2: Response of firm-level stock returns to monetary shocks

| Panel A: | (1a) Pre | (1b) Post | (1c) Diff |
|---|---|---|---|
| $\epsilon_t^m$ (FFR) x Leverage | -2.72* | | |
| | (1.400) | | |
| $\epsilon_t^m$ (LSAP) x Leverage | | 2.15*** | |
| | | (0.640) | |
| $D_t^{post}$ x $\epsilon_t^m$ x Leverage | | | 4.86*** |
| | | | (1.553) |
| Observations | | 59,868 | |
| $R^2$ | | 0.250 | |

| Panel B: | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $D_t^{post}$ x $\epsilon_t^m$ x Leverage | 4.72*** | 4.85*** | 4.10*** | 4.05*** | 5.41*** | 4.71*** |
| | (1.494) | (1.527) | (1.231) | (1.345) | (1.602) | (1.201) |
| $D_t^{post}$ x $\epsilon_t^m$ x Asset Value | 2.53 | | | | | -11.18** |
| | (1.663) | | | | | (5.037) |
| $D_t^{post}$ x $\epsilon_t^m$ x Deprec./Assets | | -2.65** | | | | -2.73** |
| | | (1.330) | | | | (1.261) |
| $D_t^{post}$ x $\epsilon_t^m$ x Firm Age | | | 0.19** | | | 0.21*** |
| | | | (0.078) | | | (0.069) |
| $D_t^{post}$ x $\epsilon_t^m$ x Curr. Asst. Ratio | | | | 2.34* | | 2.97* |
| | | | | (1.346) | | (1.587) |
| $D_t^{post}$ x $\epsilon_t^m$ x Market Cap. | | | | | 5.34** | 12.18** |
| | | | | | (2.056) | (4.734) |
| Observations | 59,868 | 59,868 | 59,868 | 59,868 | 59,868 | 59,868 |
| $R^2$ | 0.250 | 0.250 | 0.253 | 0.250 | 0.250 | 0.257 |

Notes: This table shows results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. In Panel A, $\Upsilon = 0$. In Panel B, $\Upsilon$ is allowed to be non-zero. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3: Regression of firm-level implied volatility leading up to FOMC announcement

| | (1)<br>Short Maturity | (2)<br>Medium Maturity | (3)<br>Long Maturity |
|---|---|---|---|
| Pre-Crisis ($\delta$) | -2.11*** | -1.80*** | -1.39** |
| | (0.810) | (0.677) | (0.622) |
| Post-Crisis ($\delta + \zeta\delta$) | 0.60 | 0.59 | 0.61 |
| | (0.578) | (0.516) | (0.502) |
| Difference ($\zeta\delta$) | 2.71*** | 2.40*** | 1.99*** |
| | (0.834) | (0.698) | (0.644) |
| Observations | 38,468 | 43,178 | 43,888 |
| $R^2$ | 0.623 | 0.767 | 0.781 |

Notes: This table shows results from estimating $ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right)[\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$, where $ivol_{i,t-1}$ is firm-level implied volatility on the day before the FOMC announcement, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $D_t^{post}$ is an indicator for the post-crisis period and $Z_{i,t-1}$ is the baseline vector of firm-level controls including the firm-level stock price at the close of prior trading day. Pre-crisis is Jan-1996 to Jun-2008 (108 obs.) and post-crisis is Aug-2009 to Jun-2019 (80 obs.).The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4: Response of 10 year nominal yield, real yield and term premium to monetary shocks

| Panel A: | 10 year nominal | | 10 year real | | 10 year term premium | |
|---|---|---|---|---|---|---|
| | Pre-Crisis | Post-Crisis | Pre-Crisis | Post-Crisis | Pre-Crisis | Post-Crisis |
| $\epsilon_t^m$ (FFR) | -0.08 | | -0.15*** | | 0.05 | |
| | (0.075) | | (0.056) | | (0.055) | |
| $\epsilon_t^m$ (LSAP) | | -1.71*** | | -1.34*** | | -1.39*** |
| | | (0.251) | | (0.272) | | (0.192) |
| Observations | 152 | 69 | 82 | 69 | 152 | 69 |
| $R^2$ | 0.230 | 0.461 | 0.195 | 0.484 | 0.219 | 0.487 |

| Panel B: | 10 year nominal | | 10 year real | | 10 year term premium | |
|---|---|---|---|---|---|---|
| | Pre-Crisis | Post-Crisis | Pre-Crisis | Post-Crisis | Pre-Crisis | Post-Crisis |
| $\epsilon_t^m$ (FFR) | -0.01 | | -0.01* | | 0.00 | |
| | (0.008) | | (0.006) | | (0.006) | |
| $\epsilon_t^m$ (LSAP) | | -0.04*** | | -0.04*** | | -0.03*** |
| | | (0.005) | | (0.007) | | (0.004) |
| Observations | 152 | 69 | 82 | 69 | 152 | 69 |
| $R^2$ | 0.011 | 0.389 | 0.055 | 0.302 | 0.011 | 0.395 |

Notes: This table shows the results from estimating $\Delta y_t = \alpha_0 + \beta\epsilon_t^m + e_{it}$, where $y_t$ is (daily) change in the 10 year nominal rate, 10-year real rate, or the Kim & Wright 10 year term premium estimate and $\epsilon_t^m$ is the monetary policy shock. The monetary policy shock is normalized so that a positive value represents an expansionary shock. In Panel A, $\epsilon_t^m$ (FFR) is normalized to have a unit effect on mp1 and $\epsilon_t^m$ (LSAP) is normalized to have a unit effect on the intraday 10 year yield. In panel B, both shocks are normalized to have unit standard deviation. Pre-crisis is Jul-1991 to Jun-2008 (153 obs.) and post-crisis is Aug-2009 to Jan-2018 (69 obs.). The 10-year real rate is not available before 1999. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5: Response of investment and borrowing to monetary shocks

| | (1) Investment | (2) Investment | (3) Borrowing | (4) Borrowing |
|---|---|---|---|---|
| $D_t^{post}$ x $\epsilon_t^m$ x Leverage | 2.65* | 3.20** | 39.56** | 36.81* |
| | (1.360) | (1.552) | (18.769) | (19.857) |
| Interactions with Controls | No | Yes | No | Yes |
| Observations | 8,679 | 8,679 | 8,791 | 8,791 |
| $R^2$ | 0.398 | 0.400 | 0.180 | 0.183 |

Notes: Panel A shows results from estimating $\Delta ln(y_{it}) = \left(1+\zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \sum_{n\in N}\beta_{1n} l_{i,t-n-1}\epsilon_{t-n}^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{it}$, where $y_{it}$ is value of firm $i$'s capital stock (Col. 1 and 2) or value of total debt (Col. 3 and 4) in quarter $t$, $\alpha_i$ is a firm $i$ fixed effect, $\alpha_{s,t}$ is a quarter $t$ x sector fixed effect, $l_{it}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the sum of all high-frequency monetary policy shocks (FFR in the pre-crisis and LSAP in the post-crisis) that occur in quarter $t$, $D_t^{post}$ is an indicator for the post-crisis period, $N = [0, 4]$ and $Z_{it-1}$ is a vector of firm-level controls. In columns (1) and (3), $\Upsilon = 0$. The monetary policy shock is normalized to have a unit effect on mp1 in the pre-crisis and a unit effect on the 10 year yield in the post-crisis. A positive value represents an expansionary shock. Sample is non-financial S&P 500 firms with at least 40 quarters of data in the pre-crisis and post-crisis sample for the dependent variable. Pre-crisis is 1991:Q3 to 2008:Q2 and post-crisis is 2009:Q3 to 2019:Q2. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

# Online Appendix for Monetary Policy and Firm Heterogeneity: The Role of Leverage Since the Financial Crisis (Not for Publication)

**Contents**

# A Empirical Appendix

## A.1 Additional Details on Data Construction and Summary

**Data Construction** We construct the firm sample in three steps.

First, we create our investment variable using the following standard steps:

1. Flag the first date that a firm reports its gross capital stock, i.e., the level of the gross plant, property, and equipment (Compustat: ppegtq). This date must also have the necessary information to compute the change in the net capital stock: Compustat variable ppentq reported for quarter $t+1$ and either quarter $t$ or $t-1$.

2. Interpolate any missing net investment values (ppentq) using the average of ppentq in quarters $t+1$ and $t-1$.

3. Create the capital stock beginning with the first reported gross capital stock from step #1. Then, update the following periods using the change in the net capital stock. If missing values of the net capital stock cannot be interpolated in step #2, then begin the process over with the next non-missing gross capital stock.

4. Create the quarterly intensive investment measure as the log change in the created capital stock series.

5. To remove the effect of outliers, we drop the top and bottom 0.5% of values.

Next, we define our control variables using the Compustat item names as follows:

- Ratio of current assets to total assets: $\frac{actq}{atq}$.
- Year-over-year real sales growth: log change in real $saleq$, relative to 4-quarter lagged real $saleq$. We use the quarterly price index from the BEA NIPA Table 1.3.4. Price Indexes for Gross Value Added by Sector (Non-Farm Business Index) to create all real variables.
- Firm size: log of real $atq$.
- Price-to-cost margin: $\frac{saleq-cogsq}{saleq}$.
- Receivables-minus-payables to sales: $\frac{rectq-apq}{saleq}$.
- Depreciation to assets: $\frac{dpq}{atq}$.
- Firm age: computed as the number of years since the firm first appeared in the Compustat database.
- Market capitalization: log of $cshoc$ multiplied by $prccd$.
- Fiscal quarter: $fqtr$.

Finally, the data is cleaned using the standard criteria:

- Keep only firms incorporated in the US ($FIC =$"$USA$").

- Drop firm-quarters with acquisitions greater than 5% of assets.
- Drop firm-quarters with assets or liabilities at or below zero or missing shareholder's equity ($SEQQ$).
- Drop firm-quarters that violate the accounting identity (Assets = Liabilities + Equity) by more than 10% of book value of assets.
- Winsorize leverage at 1% and 99% values and LT debt at 5% and 95% values.
- Drop firm-quarters with LT debt share greater than 1.

**Summary Statistics** Table A.1 provides the summary statistics of firm characteristics.

Table A.1: Summary Statistics of Firm Characteristics

| | mean | std. dev. |
|---|---|---|
| Current to Total Assets Ratio | 0.62 | 0.20 |
| Log Year-Over-Year Real Sales Growth, % | 3.74 | 21.45 |
| Log of Real Total Assets | 9.05 | 1.12 |
| Price-to-Cost Margin | 0.39 | 0.23 |
| Receivables minus Payables to Sales | 0.24 | 0.48 |
| Depreciation to Assets | 0.01 | 0.01 |
| Firm Age | 36.54 | 17.01 |
| Log of Market Capitalization | 15.98 | 1.32 |
| Tobin's q | 2.20 | 1.46 |
| Observations | 87,640 | |

Notes: The table shows summary statistics for the firm-level characteristics. All variables (excluding market capitalization) are measured quarterly at the firm level. Market capitalization is measured on the day prior to the FOMC meeting. The sample is non-financial firms in the S&P 500 between Jul-1991 and Jun-2019, excluding the financial crisis dates of Jul-2008 to Jul-2009.

## A.2 Robustness Checks for the Main Results

### A.2.1 Leverage in the Pre- and Post-crisis Samples

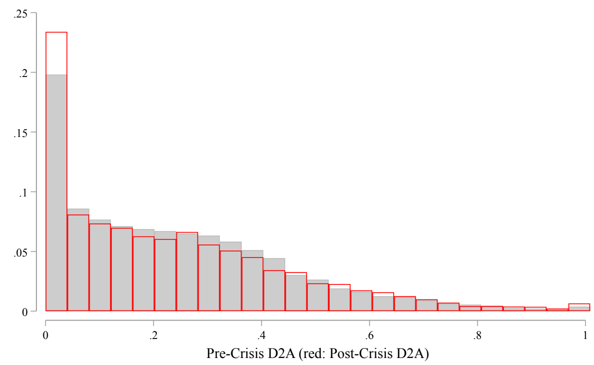
We first start by considering whether the firms that had high leverage in the pre-crisis also had high leverage in the post-crisis sample. This is potentially important because a systematic migration of less-sensitive firms toward lower leverage or more-sensitive firms toward higher leverage in the post-crisis period could, for instance, create an illusion of changed transmission mechanisms. However, we find that there is remarkable stability in the leverage distribution across the two periods, with only modest increases in average leverage post-crisis. We also demonstrate that our main findings are not driven by firms that substantially changed their leverage position. Figure A.1 below shows the distribution of leverage pre-crisis and post-crisis and how they correlate with credit ratings pre-crisis and post-crisis. We provide a discussion as follows.

First, from Table 1 in the main paper, we can see that leverage is, on average, only slightly higher in the post-crisis sample. For example, our baseline measure of leverage, debt-to-capital, has a mean of 0.42 in the post-crisis sample relative to a mean of 0.39 in the pre-crisis sample. Similarly the standard deviation of leverage is also roughly the same across the two samples. Figure A.1 shows the leverage distribution in the two samples where we have taken the firm-specific average for each sample. The grey shaded bars show the histogram for the pre-crisis sample, while the red transparent bars show the post-crisis histogram. While there is a little more mass toward the right in the post-crisis sample (and a little more toward the left in the pre-crisis sample), the distribution is quite similar in the two samples. In our baseline results presented in Section 3.1 we standardized our leverage measure by using the full sample mean and standard deviation of leverage. We have also tried using the pre-crisis mean and standard deviation to standardize our leverage measure (see Appendix Table A.3). As one would expect with the patterns from Table 1 and Figure A.1, we find these results are very similar to our baseline results.

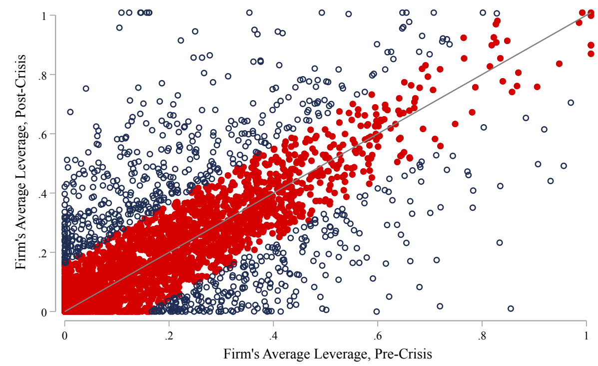
We further investigate whether firms have moved around in the leverage distribution in the two samples. Given the stability of the leverage distribution in the two samples, it is still possible that our results are driven by i) less-sensitive firms that had high leverage in the pre-crisis sample but switched to having lower leverage in the post-crisis sample and ii) more-sensitive firms with low leverage in the pre-crisis sample but switched to having higher leverage in the post-crisis sample. To this end, Figure A.1 displays a scatter plot of the firm-specific average leverage in the post-crisis sample versus the average in the pre-crisis sample. If firms' leverage across the two samples is similar, we should expect the points in the scatter plot to cluster around the 45-degree line. Figure A.1 does, in fact, show this pattern. We also investigate whether our results are driven by the firms that did change their leverage noticeably, i.e., those that are not close to the 45-degree line. In Appendix Table A.2, we present our baseline results excluding firms with more than one standard deviation away from the 45-degree line. The table confirms that our baseline stock market results are robust to excluding these outliers. This suggests that the movement of firms across the leverage distribution does not explain the difference in the transmission of monetary policy through firm leverage following the financial crisis.

Figure A.1

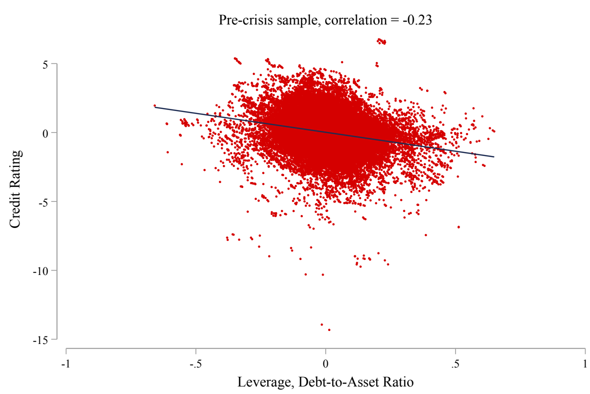
(a) Distribution of Firm Leverage



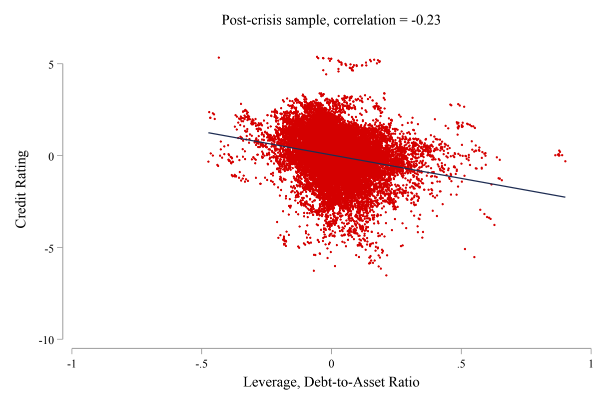

(b) Firm Leverage: Post vs. Pre




(c) Conditional Correlation of Credit Rating and Leverage: Pre-Crisis




(d) Conditional Correlation of Credit Rating and Leverage: Post-Crisis




Notes: Panel (a) plots the histogram of the quarterly firm leverage (measured as debt-to-assets), averaged across the pre-crisis (grey, shaded) and post-crisis (red, transparent) samples. Panel (b) plots the scatter plot of quarterly firm leverage (measured as debt-to-assets) averaged across the post-crisis versus the average in the pre-crisis sample. Firms below one standard deviation from the 45-degree line are shown in hollow circles. Panels (c) and (d) plot the residuals from regressing the firm's S&P long-term credit rating on our set of control variables against the residuals from regressing the firm's 4-quarter rolling leverage on a set of control variables. For all figures, pre-crisis is Jul-1991 to Jun-2008, post-crisis is Aug-2009 to Jun-2019, and the sample is non-financial firms in the S&P 500 on the date of FOMC announcement.

### A.2.2 Excluding Outliers in Terms of Firm Leverage

We present our baseline results excluding firms that lie more than one standard deviation away from the 45-degree line of Figure A.1. The table confirms that our baseline stock market results are robust to excluding these outliers. This suggests that the movement of firms across the leverage distribution does not explain the difference in monetary policy transmission through firm leverage following the financial crisis. Table A.2 shows the results.

Table A.2: Robustness of baseline results to removing pre vs. post outliers

| | (1)<br>Firm Share Price<br>MP shock x Leverage | (2)<br>Implied Volatility<br>Leverage |
|---|---|---|
| Pre-Crisis | -1.98** | -0.85 |
| | (0.870) | (0.647) |
| Post-Crisis | 2.35** | 0.70 |
| | (1.023) | (0.710) |
| Difference | 4.33*** | 1.56* |
| | (1.349) | (0.894) |
| | | |
| Observations | 49,330 | 35,004 |
| $R^2$ | 0.266 | 0.788 |

Notes: Column (1) is the result from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right)[\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. We exclude 94 firms with a change in leverage from pre-crisis to post-crisis greater than one standard deviation. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.3 Standardization of Firm Leverage Measure

In our baseline results, we standardized our leverage measure by using the full sample mean and standard deviation of leverage. We have also tried using the pre-crisis mean and standard deviation to standardize our leverage measure. As one would expect with the patterns from Figure A.1, we find these results shown in Table A.3 are very similar to our baseline results.

Table A.3: Robustness of baseline results with pre-crisis standardization of leverage

| | (1)<br>Firm Share Price<br>MP shock x Leverage | (2)<br>Implied Volatility<br>Leverage |
|---|---|---|
| Pre-Crisis | -2.44** | -1.36** |
| | (0.964) | (0.610) |
| Post-Crisis | 2.18*** | 0.59 |
| | (0.676) | (0.492) |
| Difference | 4.61*** | 1.95*** |
| | (1.176) | (0.631) |
| | | |
| Observations | 59,868 | 43,888 |
| $R^2$ | 0.257 | 0.781 |

Notes: Column (1) is the result from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right) [\alpha_i + \alpha_{s,t} + \beta l_{i,t-1} \epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized (using the pre-crisis period) to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right) [\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.4 Alternative Leverage Measure: Debt-to-Capital

In our baseline results, we choose our leverage measure using the debt-to-asset measure, which is widely used among many papers, including Ottonello and Winberry (2020). We have also tried using another measure that is also quite commonly used, debt-to-capital ratio; we find these results shown in Table A.4 are very similar to our baseline results.

Table A.4: Robustness of baseline results to an alternative measure of leverage: Debt-to-Capital

| | (1)<br>Firm Share Price<br>MP shock x Leverage | (2)<br>Implied Volatility<br>Leverage |
|---|---|---|
| Pre-Crisis | -2.62*** | -0.98* |
| | (0.877) | (0.542) |
| Post-Crisis | 2.25*** | 0.81* |
| | (0.693) | (0.472) |
| Difference | 4.86*** | 1.79*** |
| | (1.110) | (0.590) |
| Observations | 59,868 | 43,888 |
| $R^2$ | 0.257 | 0.781 |

Notes: Column (1) is the result from estimating $s_{i,t} = \left(1+\zeta D_t^{post}\right)[\alpha_i+\alpha_{s,t}+\beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1}+\Gamma' Z_{i,t-1}+\Upsilon\epsilon_t^m Z_{i,t-1}]+e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage (measured as debt-to-capital) normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i+\left(1+\zeta D_t^{post}\right)[\alpha_{s,t}+\delta l_{i,t-1}+\Gamma' Z_{i,t-1}]+e_{i,t}$. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.5 Sample Composition Pre-Crisis and Post-Crisis

Third, we show that our stock market results are not driven by a change in the sample composition between the pre-crisis and post-crisis periods. We rerun our stock market specification, limiting the sample to only those firms that entered Compustat prior to 1993 and remained in the sample through at least 2017, and the results closely match our baseline results. In our baseline specification, we excluded the crisis period from July 2008 to July 2009. We show that our results are similar when we include the crisis dates in the post-crisis sample. Higher leverage firms are less responsive in the pre-crisis period and more responsive in the post-crisis period. This shows that our main results are not caused by certain firms entering or exiting the sample, e.g., firms that did not survive the financial crisis. Table A.5 shows the results.

Table A.5: Robustness of baseline results with consistent sample of firms

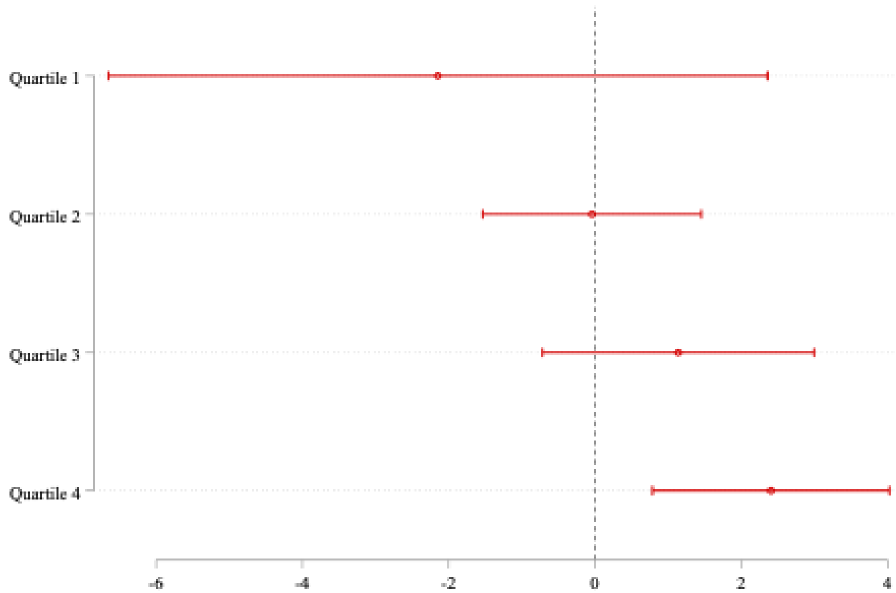
| | (1) Firm Share Price MP shock x Leverage | (2) Implied Volatility Leverage |
|---|---|---|
| Pre-Crisis | -1.66** | -0.34 |
| | (0.778) | (0.744) |
| Post-Crisis | 2.04* | 0.77 |
| | (1.227) | (0.658) |
| Difference | 3.70*** | 1.11* |
| | (1.358) | (0.668) |
| Observations | 23,019 | 17,648 |
| $R^2$ | 0.283 | 0.758 |

Notes: Column (1) is the result from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right)[\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement that entered Compustat prior to 1993 and remained in the sample through at least 2017. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.6 Non-S&P 500 Compustat Firms

We show that our main result qualitatively holds for non-S&P 500 firms and is statistically significant for those non-S&P 500 firms with the highest market capitalization. This is consistent with the evidence that stock prices incorporate news faster for bigger firms, which are tracked more closely by market analysts and traders. We chose to focus on the S&P 500 because it is an objective way to choose our sample. Figure A.2 shows the results.

Figure A.2: Stock response of non-S&P 500 Compustat firms by market capitalization




Notes: This figure plots the difference, by market capitalization quartile, between the pre-crisis and post-crisis interaction of leverage and the monetary policy shock, i.e. $\beta_{2,1}$, $\beta_{2,2}$, $\beta_{2,3}$ and $\beta_{2,4}$ from the following regression: $s_{i,t} = \alpha_t + I(q)_{i,t}(\alpha_{i,q} + \beta_{1,q} l_{i,t-1}\epsilon_t^m + \beta_{2,q} l_{i,t-1}\epsilon_t^m D_t^{post} + \gamma_{1,q} D_t^{post} + \gamma_{2,q}\epsilon_t^m + \gamma_{3,q}\epsilon_t^m D_t^{post} + \delta_{1,q} l_{i,t-1} + \delta_{2,q} l_{i,t-1} D_t^{post}) + \Gamma' Z_{i,t-1} + e_{i,t}$, where $I(q)_{i,t}$ is an indicator for the market capitalization quartile $q$ to which firm $i$ belongs to on FOMC day $t$, $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield) and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008 (153 obs.) and post-crisis is Aug-2009 to Jun-2019 (80 obs.). The sample is non-financial Compustat firms not listed in the S&P 500 on the date of the FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.7 Including the Periods of Financial Crisis

In our baseline results, we consider a pre-crisis sample ranging from July 1991 to June 2008 and a post-crisis sample from August 2009 to June 2019. We are thus leaving out the crisis period as categorized by July 2008 to July 2009. In Table A.6 below, we present the results by including the crisis dates in the post-crisis sample. The coefficients show that including the financial crisis dates does not materially change the results.

Table A.6: Robustness of baseline results to including financial crisis period

| | (1)<br>Firm Share Price<br>MP shock x Leverage | (2)<br>Implied Volatility<br>Leverage |
|---|---|---|
| Pre-Crisis | -0.92** | -1.63*** |
| | (0.440) | (0.588) |
| Post-Crisis | 0.58 | 0.32 |
| | (0.710) | (0.512) |
| Difference | 1.50* | 1.94*** |
| | (0.834) | (0.568) |
| | | |
| Observations | 62,305 | 46,728 |
| $R^2$ | 0.269 | 0.798 |

Notes: Column (1) is the result from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR prior to 2009 and LSAP beginning in 2009) and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right)[\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Dec-2008, and post-crisis is Jan-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.8 Including Only Scheduled FOMC Meetings

Unscheduled FOMC meetings can affect financial markets differently from regularly scheduled meetings, as unscheduled meetings typically occur in times of economic turmoil. The unscheduled meetings are also instances in which the Federal Reserve is more likely to release information about economic fundamentals, for example, Lakdawala and Schaffer (2019). Thus, we want to ensure our results are not driven by these unscheduled meetings. This issue only arises in the pre-crisis sample, with 16 unscheduled meetings, while our post-crisis sample has none. Table A.7 shows the results. Excluding the unscheduled meetings gives results that are quite similar to the baseline case.

Table A.7: Robustness of baseline results with scheduled FOMC meetings only

| | (1)<br>Firm Share Price<br>MP shock x Leverage | (2)<br>Implied Volatility<br>Leverage |
|---|---|---|
| Pre-Crisis | 0.17 | -1.31** |
| | (0.721) | (0.621) |
| Post-Crisis | 2.22*** | 0.63 |
| | (0.671) | (0.494) |
| Difference | 2.05** | 1.94*** |
| | (1.006) | (0.663) |
| | | |
| Observations | 56,568 | 42,067 |
| $R^2$ | 0.230 | 0.779 |

Notes: Column (1) is the result from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right) [\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \left(1 + \zeta D_t^{post}\right) [\alpha_{s,t} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Dec-2008, and post-crisis is Jan-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

#### A.2.9 Using Information Effect Robust Shocks in Lakdawala (2019)

There may still be a concern that even on regularly scheduled FOMC meetings, the high-frequency monetary policy shocks contain a substantial information component. To address this concern, we first use forecast data, following the approach in Lakdawala (2019), to cleanse the monetary policy shock of any information effect. Table A.8 shows the results. These results confirm that this issue does not drive our baseline results.

Table A.8: Robustness of stock return results to info-robust shocks

| | (1a) Pre | (1b) Post | (1c) Diff |
|---|---|---|---|
| $\epsilon_t^m$ (FFR) x Leverage | -2.70** | | |
| | (1.119) | | |
| | | | 4.72*** |
| | | | (1.597) |
| $\epsilon_t^m$ (LSAP) x Leverage | | 2.02* | |
| | | (1.141) | |
| Observations | | 55,189 | |
| $R^2$ | | 0.256 | |

Results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. The monetary policy shock is cleansed of information effects (as in Lakdawala (2019)). Pre-crisis is Jul-1991 to Jun-2008 and post-crisis is Aug-2009 to Dec-2017. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.10 Using Information Effect Robust Shocks in Bauer and Swanson (2023)

There may still be a concern that even on regularly scheduled FOMC meetings, the high-frequency monetary policy shocks contain a substantial information component. To address this concern, we then use the Bauer-Swanson orthogonal shocks, following the approach in Bauer and Swanson (2023), to cleanse the monetary policy shock of any information effect. Table A.9 shows the results. These results confirm that this issue does not drive our baseline results.

Table A.9: Response of firm-level stock returns to Bauer-Swanson monetary shocks

| | (1a)<br>Pre | (1b)<br>Post | (1c)<br>Diff |
|---|---|---|---|
| $\epsilon_t^m$ (Bauer-Swanson) x Leverage | -1.89* | 1.00** | 2.90** |
| | (1.061) | (0.466) | (1.126) |
| Observations | | 59,868 | |
| $R^2$ | | 0.250 | |

Notes: This table shows results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. As in Bauer and Swanson (2023), the monetary policy shock is normalized to have a unit effect on ED4, and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.11 Controlling for the Fama-French Excess Returns

Our results also hold with Fama-French factors. In Table A.10 below, we show that our baseline specification while controlling for three factors: i) firm-specific beta, ii) size as captured by the firm's market capitalization on the day before the FOMC announcement, and iii)firm-level book to market.

Table A.10: Response of firm-level stock returns to monetary policy shocks: Controlling for Fama-French characteristics

| | (1a)<br>Pre | (1b)<br>Post | (1c)<br>Diff |
|---|---|---|---|
| $\epsilon_t^m$ (FFR) x Leverage | -1.64*** | | |
| | (0.519) | | |
| $\epsilon_t^m$ (LSAP) x Leverage | | 2.45*** | |
| | | (0.907) | |
| Pre- vs. post-crisis | | | 4.09*** |
| | | | (1.126) |
| Observations | | 57,903 | |
| $R^2$ | | 0.275 | |

Notes: This table shows results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right) [\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls (including book-to-market ratio and firm betas). The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.2.12 Alternative Measure of Stock Returns

Our results also hold with an alternative measure of stock returns using the open-to-close price differences. We show the results in Table A.11 below.

Table A.11: Response of firm-level stock returns (open-to-close) to monetary shocks

| | (1a) Pre | (1b) Post | (1c) Diff |
|---|---|---|---|
| $\epsilon_t^m$ (FFR) x Leverage | -1.05 | | |
| | (0.647) | | |
| $\epsilon_t^m$ (LSAP) x Leverage | | 2.14*** | |
| | | (0.597) | |
| Pre- vs. post-crisis | | | 3.19*** |
| | | | (0.801) |
| Observations | | 31,195 | |
| $R^2$ | | 0.430 | |

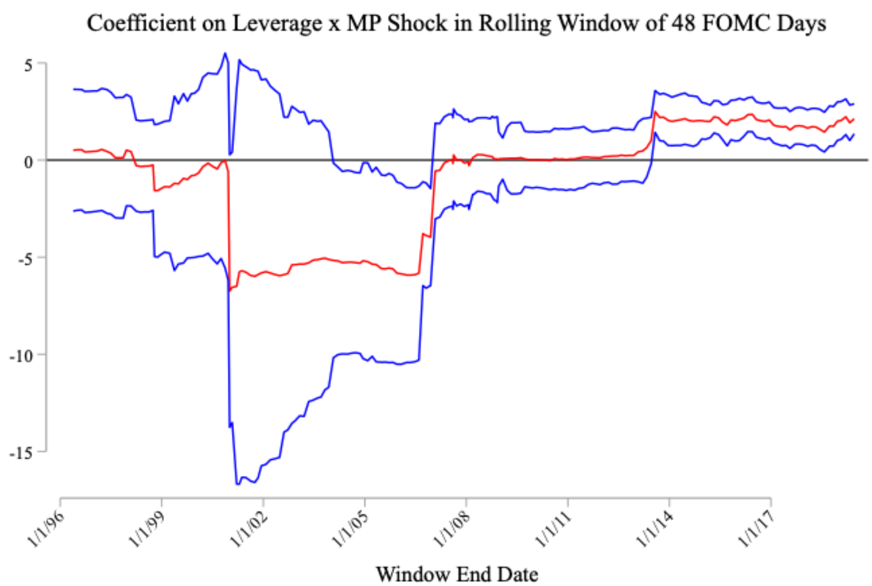
Notes: This table shows results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return (measured from open-to-close), $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

## A.3 Additional Empirical Results

### A.3.1 Timing of the Change in Responsiveness

We answer whether the change in responsiveness could have occurred before or after the financial crisis. Using rolling window estimates, we show that the shift in responsiveness occurred sharply around early 2009, with the leverage-monetary policy interaction remaining consistently negative before and positive after this point. Figure A.3 shows the results.

Figure A.3: Interaction coefficient of leverage and monetary shock from rolling regression




Notes: This figure plots the coefficient $\beta_1$ estimated within a rolling window of 48 FOMC days using the specification: $s_{i,t} = \alpha_i + \alpha_t + \beta_1 l_{i,t-1}\epsilon_t^m + \delta_1 l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day $\times$ sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock (FFR in the pre-crisis and LSAP in the post-crisis) and $Z_{i,t-1}$ is a vector of firm-level controls. The sample is non-financial firms in S&P 500 on the FOMC announcement day. The date of the plotted coefficient refers to the final FOMC day within the window. 90% confidence intervals are plotted and calculated using the two-way clustered (by firm and FOMC day) standard errors. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock.

### A.3.2 The Average Effects of Monetary Shocks

Since we use time fixed effects in the main regressions, we cannot estimate the stand-alone effect of the monetary policy shock on firm-level stock returns from this specification. Table A.12 shows the average effects of monetary shocks when we shut down the time fixed effects. First, we find our main results on the interaction between monetary policy shocks and leverage remain robust.

Table A.12: Robustness of stock return results without time fixed effects

| | (1a)<br>Pre | (1b)<br>Post | (1c)<br>Diff |
|---|---|---|---|
| $\epsilon_t^m$ (FFR) | 5.17*** | | |
| | (1.625) | | |
| $\epsilon_t^m$ (LSAP) | | -2.39 | |
| | | (7.691) | |
| Pre- vs. post-crisis | | | -7.56 |
| | | | (7.863) |
| $\epsilon_t^m$ (FFR) x Leverage | -3.35* | | |
| | (1.717) | | |
| $\epsilon_t^m$ (LSAP) x Leverage | | 4.21*** | |
| | | (1.275) | |
| Pre- vs. post-crisis | | | 7.56*** |
| | | | (2.148) |
| Observations | | 60,075 | |
| $R^2$ | | 0.043 | |

Results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_s + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008 and post-crisis is Aug-2009 to Dec-2017. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

### A.3.3 Distinguishing Short-term and Long-term Leverage

In Table A.13, we show the results where we simultaneously include short-term and long-term leverage (and interaction with monetary policy) in our baseline specification. The results are consistent with our theory centralized around the essential role of long-term debt post-crisis. Before the financial crisis, both short-term and long-term leverage hindered firms' responses to monetary shocks because of debt overhang problems. After the financial crisis, the unconventional monetary policy moved the long-term rate much more than the short-term rate; therefore, debt dilution effects from the existing long-term debt dominated the debt overhang problems, and we have the reversal results. Short-term leverage has the same sign but is less/not significant because the short-term rates are moving much less or even not moving at all. We see these results as consistent with our main mechanism.

Table A.13: Response of firm-level stock returns to monetary shocks: LT vs. ST leverage

| | (1a) Pre-Crisis | (1b) Post-Crisis |
|---|---|---|
| $\epsilon_t^m$ (FFR) x ST Leverage | -1.82*** | |
| | (0.549) | |
| $\epsilon_t^m$ (FFR) x ST Leverage | -2.01*** | |
| | (0.738) | |
| $\epsilon_t^m$ (LSAP) x ST Leverage | | 1.01 |
| | | (0.967) |
| $\epsilon_t^m$ (LSAP) x LT Leverage | | 2.05*** |
| | | (0.790) |
| Observations | 59,868 | |
| $R^2$ | 0.257 | |

Notes: Results from estimating $s_{i,t} = \left(1 + \zeta D_t^{post}\right)[\alpha_i + \alpha_{s,t} + \beta_1 l_{i,t-1}^{ST} \epsilon_t^m + \delta_1 l_{i,t-1}^{ST} + \beta_2 l_{i,t-1}^{LT} \epsilon_t^m + \delta_2 l_{i,t-1}^{LT} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1}] + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, $\alpha_i$ is a firm fixed-effect, $\alpha_t$ is an FOMC day x sector fixed-effect, $D_t^{post}$ is an indicator for the post-crisis period, $l_{i,t-1}^{ST}$ ($l_{i,t-1}^{LT}$) is four-quarter moving average short-term (long-term) leverage normalized to have mean 0 and variance 1, $\epsilon_t^m$ is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. The pre-crisis (post-crisis) monetary policy shock is normalized to have a unit effect on mp1 (the 10 year yield), and a positive value represents an expansionary shock. Pre-crisis is from Jul-1991 to Jun 2008, and post-crisis is from Aug 2009 to Dec-2017. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

# B Theoretical Appendix

## B.1 Characterization of the Stylized Model in Section 4.2

### B.1.1 Equilibrium Firm Policy

We recursively solve the equilibrium firm policy in the steady state and transition periods following unexpected monetary policy shocks. At the center of the policy is a Bellman equation of the continuation value function $V_t(b_t, z_{t+1})$, which is

$$V_{t-1}\left(b_{jt-1}, z_{jt}\right) = \max\left\{-\tilde{e}_{jt-1} + \frac{1}{1+r_s}\int_{\bar{\varepsilon}_{jt}}^{\infty}[n_{jt} + EV_t\left(b_{jt}, z_{jt+1}\right)]\varphi(\varepsilon)d\varepsilon\right\} \tag{14}$$

where $\tilde{e}_{jt-1} \equiv n_{jt-1} + e_{jt-1} \geq \underset{\sim}{e}$ is defined as a choice variable and $\underset{\sim}{e}$ is the redefined upper bound of equity issuance. In equilibrium, a firm maximizes shareholder value subject to creditors' bond prices and aggregate paths of real interest rates. The value $V_{t-1}\left(b_{jt-1}, z_{jt}\right)$ can be computed recursively. We omit all the $j$ and $t$ subscriptions, the firm chooses policies $\{\tilde{e_{-1}}, k, l, b_s, b_l\}$ to solve the following optimization problem

$$\begin{aligned}
V(b_{-1}, z_t) = & \max_{\left\{\begin{array}{c} k, l, \tilde{e_{-1}} \geq \underset{\sim}{e} \\ b_s, b_l \end{array}\right\}} -\tilde{e_{-1}} + \frac{1}{1+r_s}\int_{\bar{\varepsilon}}^{\infty}\left[n + EV\left(b, z_{+1}\right)\right]\varphi(\varepsilon)d\varepsilon \\
\text{s.t.: } & n = k - b_s - \lambda b_l + (1-\tau)\left[y + \varepsilon k - wl - \delta k - f - c\left(b_s + b_l\right)\right] \\
& y = zk^{\theta}l^{\nu} \\
& n(\bar{\varepsilon}) + (1-\kappa)EV\left(b, z_{+1}\right) = 0 \\
& k = \tilde{e} + b_s q_{s,-1} + \left(b_l - b\right)q_{l,-1} - \Theta(b_s, b_l, b) \\
& b = (1-\lambda)b_l \\
& q_{s,-1} = \frac{1}{1+r_s}[1-\Phi(\bar{\varepsilon})](1+c) \\
& q_{l,-1} = \frac{1}{1+r_l}[1-\Phi(\bar{\varepsilon})]\left[\gamma + c + (1-\gamma)Eg\left(b, z_{+1}\right)\right]
\end{aligned}$$

### B.1.2 Derive the Variable Continuation Value $V^*$

In the firm's problem (14), the variable component of shareholder value at time $t-1$ to be maximized is $V(b_{t-1}, z_t)$ in terms of three choice variables: $\{k_t, b_{st}, b_{lt}\}$ which consequently determines the default cutoff $\bar{\varepsilon}_t$. Since the beginning of the period, net worth $n_{t-1}$ is predetermined, and firms' optimal choices have no effect on it; we can focus only on $V(b_{t-1}, z_t)$. Combining the firm's problem (14) with its constraints (4), (5), (6), (7), and (8).

To derive the continuation stock value equation (9), we first combine the *ebita* equation and net worth equation and apply them to the definition of $\bar{\varepsilon}$ equation below

$$ebita_{jt} \equiv y_{jt} + \varepsilon_{jt}k_{jt} - wl_{jt} - \delta k_{jt} - f \tag{15}$$

$$n_{jt} = k_{jt} - b_{jst} - \lambda b_{jlt} + (1-\tau)\left[ebita_{jt} - c\left(b_{jst} + b_{jlt}\right)\right] \tag{16}$$

$$\bar{\varepsilon}_{\mathbf{jt}}: \quad n_{jt}(\bar{\varepsilon}_{jt}) + EV_t\left(b_{jt}, z_{jt+1}\right) = 0, \quad \text{default if } \varepsilon_{jt} < \bar{\varepsilon}_{jt} \tag{17}$$

to get the cutoff equation (18) below as

$$\begin{aligned}(1-\tau)\bar{\varepsilon}_{jt}k_{jt} = & -k_{jt} + b_{jst}(1+(1-\tau)c) + b_{jlt}(\lambda + (1-\tau)c) \\ & -(1-\tau)\left[y_{jt} - wl_{jt} - \delta k_{jt} - f\right] - EV_t\left(b_{jt}, z_{jt+1}\right)\end{aligned} \tag{18}$$

We then combine the reformulated equity equation with the capital equation below

$$\tilde{e}_{jt-1} \equiv n_{jt-1} + e_{jt-1} \geq \underset{\sim}{\tilde{e}} \tag{19}$$

$$k_{jt} = n_{jt-1} + e_{jt-1} + b_{jst}q_{jst-1} + \left(b_{jlt} - b_{jt-1}\right)q_{jlt-1} - \Theta_b \tag{20}$$

to get the reformulated equity equation (21)

$$\tilde{e}_{jt-1} = k_{jt} - b_{jst}q_{jst-1} - \left(b_{jlt} - b_{jt-1}\right)q_{jlt-1} + \Theta_b \tag{21}$$

Finally, apply equations (18) and (21) to equation (14) and omit all $j$, we have

$$V_{t-1}(b_{t-1}, z_t) = \underbrace{\Big[q_{st-1}b_{st} + q_{lt-1}(b_{lt} - b_{t-1}) - \Theta_b\Big]}_{\text{Net Debt Issuance Revenue}} + \underbrace{\left[\frac{1-\tau}{1+r_s}k_t\int_{\bar{\varepsilon}_t}^{\infty}(\varepsilon_t - \bar{\varepsilon}_t)\phi(\varepsilon_t)d\varepsilon_t - k_t\right]}_{\text{Net Capital Investment Revenue}}$$

## B.2 Derive the First Order Conditions

Assuming $\Theta_b = \eta(b_s + b_l - b)^2$ and have $b_l - b > 0$, we would have the FOCs as below. In the paper, we shortcut to have $\Theta_b'(b_s)$ or $\Theta_b'(b_l)$ as the partial derivatives.

**Debt FOCs** The firm's first order condition on $V^*$ with respect to $b_s$ and $b_l$ are

$$\frac{1-\Phi(\bar{\varepsilon})}{1+r_s}\tau c + \frac{\partial\bar{\varepsilon}}{\partial b_s}\left[b_s\frac{\partial q_s}{\partial\bar{\varepsilon}} + (b_l - b)\frac{\partial q_l}{\partial\bar{\varepsilon}}\right] - 2\theta_b\left(b_s + b_l - b\right) = 0$$

$$\begin{aligned}\frac{1-\Phi(\bar{\varepsilon})}{1+r_l}E\left[\tau c + (1-\gamma)\left(g\left(b', z'\right) + (b_l - b)\frac{\partial g\left(b', z'\right)}{\partial b_l}\right) + \frac{\partial V\left(b', z'\right)}{\partial b_l}\right] \\ + \frac{\partial\bar{\varepsilon}}{\partial b_l}\left[b_s\frac{\partial q_s}{\partial\bar{\varepsilon}} + (b_l - b)\frac{\partial q_l}{\partial\bar{\varepsilon}}\right] - 2\theta_b\left(b_s + b_l - b\right) = 0\end{aligned}$$

Given long-term debt choice $b_l$, we can rewrite the short-term debt FOC in terms of $\{r_s, r_l, b\}$ to analyze the effects of debt dilution and how it interacts with monetary policy:

$$\begin{aligned}-2\theta_b b_s + \frac{1}{1+r_s}\left[(1-\Phi(\bar{\varepsilon}))\tau c - \frac{\partial\bar{\varepsilon}}{\partial b_s}\phi(\varepsilon)(1+c)b_s\right] \\ + \left[\frac{1}{1+r_l}\left[\frac{\partial\bar{\varepsilon}}{\partial b_s}\phi(\varepsilon)\left(1 + c + (1-\gamma)Eg\left(b', z'\right)\right)\right] + 2\theta_b\right](b - b_l) = 0\end{aligned} \tag{22}$$

Given short-term debt choice $b_s$, we can rewrite the long-term debt FOC in terms of $\{r_s, r_l, b\}$ to analyze the effects of debt dilution and how it interacts with monetary policy:

$$
\begin{aligned}
&-2\theta b_s - \frac{1}{1+r_s}\left[\frac{\partial \bar{\varepsilon}}{\partial b_l}\phi(\varepsilon)(1+c)b_s\right] + \frac{1}{1+r_l}E\left[(1-\Phi(\bar{\varepsilon}))\left(\tau c + (1-\gamma)g\left(b', z'\right) + \frac{\partial V\left(b', z'\right)}{\partial b_l}\right)\right] \\
&+\left[\frac{1}{1+r_l}E\left[\frac{\partial \bar{\varepsilon}}{\partial b_l}\phi(\varepsilon)\left(1+c+(1-\gamma)g\left(b', z'\right)\right) - (1-\Phi(\bar{\varepsilon}))(1-\gamma)\frac{\partial g\left(b', z'\right)}{\partial b_l}\right] + 2\theta_b\right](b-b_l) = 0
\end{aligned}
\tag{23}
$$

We then rearrange the above two FOCs to get the paper's equations (11) and (12).

**Capital FOCs** The firm's first order condition with respect to capital $k$ is:

$$
\frac{\partial \bar{\varepsilon}}{\partial k}\left[b_s\frac{\partial q_s}{\partial \bar{\varepsilon}} + (b_l - b)\frac{\partial q_l}{\partial \bar{\varepsilon}} - \frac{1-\tau}{1+r_s}k[1-\Phi(\bar{\varepsilon})]\right] + \frac{1-\tau}{1+r_s}\int_{\bar{\varepsilon}}^{\infty}(\varepsilon - \bar{\varepsilon})\varphi(\varepsilon)d\varepsilon - 1 = 0
$$

where we can plug in the partial derivatives of bond prices $\partial q_s/\partial \bar{\varepsilon}$ and $\partial q_l/\partial \bar{\varepsilon}$ and rewrite the capital FOC as

$$
\begin{aligned}
\frac{1}{1+r_s}&\left[\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)\phi(\varepsilon)\left(1+c\right)b_s + (1-\tau)\left[\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)k[1-\Phi(\bar{\varepsilon})] + \int_{\bar{\varepsilon}}^{\infty}(\varepsilon-\bar{\varepsilon})\varphi(\varepsilon)d\varepsilon\right]\right] \\
&- \frac{1}{1+r_l}\left[\left(-\frac{\partial \bar{\varepsilon}}{\partial k}\right)\phi(\varepsilon)\left(1+c+(1-\gamma)\mathbb{E}g\left(b', z'\right)\right)\right](b-b_l) - 1 = 0
\end{aligned}
\tag{24}
$$

We then rearrange the above FOC to get the paper's equation (13).

### B.3 Full-blown Quantitative Model

The stylized model has many abstractions to be analytically more intuitive. However, it quantitatively omits many important components, including productivity progress, exogenous exit risk, recovery value, details of the issuance costs, etc. In this appendix section, we lay down a full-blown model and quantify it using US data.

**Firm's Production, Productivity Progress, and Entry/Exit** Each firm $j$ produces using capital $k$ and labor $l$ with decreasing returns to scale production function $y_{it} = z_{it}k_{it}^{\theta}l_{it}^{\nu}, \theta + \nu < 1$, where $z_{it}$ is the persistent idiosyncratic productivity shock for firm $i$ that follows distribution $p(z_{it}|z_{it-1})$. Earnings before interest and taxes are $ebita_{it} \equiv y_{jt} + \varepsilon_{jt}k_{jt} - wl_{it} - \delta k_{it} - f$ where $\varepsilon_{it}$ is a firm-specific capital quality shock, $\delta$ is the depreciation rate, and $f$ is a fixed cost of operation. There are three sources of idiosyncratic uncertainty. Productivity $z_{it}$ is persistent and follows a Markov process. The capital quality shock $\varepsilon_{it}$ is i.i.d. normal with mean zero and $\sigma_{\epsilon}$. It is realized after production has taken place in period $t$. Finally, firms face exogenous exit risk $\kappa$. Exiting firms (both default and exogenous) are replaced by mass $M$ free-entry firms with the initial lowest productivity $z_e$ and zero starting debt. Productivity $z_{it}$ is drawn from a ladder $Z = \{z_1 = z_e, z_2, ...z_J\}$ where the support of the natural logarithm of $z_{it}$ is evenly spaced on the interval $[-\sigma_z, +\sigma_z]$. Surviving firms with last period productivity $z_{it-1} = z_j$ draws next period productivity $z_{it} = z_j$ with probability $\rho_z$ and $z_{it} = \min(z_{j+1}, z_J)$ otherwise. We omit subscript $i$ going forward to save notations.

**Firm's Finance** The firm can finance capital with equity and short-term and long-term debt at the end of the period $t-1$. Let $b_{st}$ and $b_{lt}$ denote the issuance of short-/long-term debt and $b_{t-1}$ denote the stock of outstanding long-term debt at the end of period $t-1$. Short-term debt is a one-period contract. For long-term debt, we assume that a fraction $\lambda$ of the long-term principal is paid back in every period while the remaining $(1-\lambda)$ remains outstanding. There are issuance costs for debt. These issuance costs are flotation fees for new debt issues and bank fees. The debt issuance cost is $\Theta_b = \theta_b (b_s + \max\{b_l - b, 0\})^2$, where $\theta_b$ capture issuance cost. Coupon payments $c$ are tax-deductible. The firm can also finance its capital stock by injecting equity. Let $n_{t-1}$ be the net worth, and let $e_{t-1}$ denote net equity issuance at the end of period $t-1$. A negative value of $e_{t-1}$ indicates a net dividend payment from the firm to shareholders. Capital in period $t$ is given by $k_t = n_{t-1} + e_{t-1} + b_{st}q_{st-1} + (b_{lt} - b_{t-1}) q_{lt-1} - \Theta(b_{st}, b_{lt}, b_{t-1})$. Firm earnings are taxed at rate $\tau$. The stock of net worth in period $t$ after production and repayment of debt is $n_t = k_t - b_{st} - \lambda b_{lt} + (1-\tau) [ebita_t - c (b_{st} + b_{lt})]$. Shareholders are protected by limited liability, so they are free to default. A defaulting firm exits the economy. In addition to this, there is exogenous exit risk. With probability $\kappa$, a non-defaulting firm exogenously leaves the economy. We assume default and exogenous firms have zero value to show the mechanism more straightforwardly.

**Firm's Recursive Problem** Firms maximize shareholder value, the expected present value of net cash flows to shareholders. They discount cash flows at the short-term risk-free rate $r_s$. The shareholder value of a continuing firm at the end of period $t$ can be written as the sum of net worth and a continuation value: $n_t + V_t (b_t, z_{t+1})$, where $b_t$ is the remaining outstanding debt $b_t = (1-\lambda)b_{lt}$. Because there are no equity issuance costs, net worth $n_{it}$ does not influence the optimal firm policy, and the continuation value $V_t (b_t, z_{t+1})$.

We describe the firm problem starting from the default decision at the end of period $t$. The idiosyncratic capital quality shock $\varepsilon_t$ has been realized, but future firm productivity $z_{t+1}$ is still uncertain. If the firm does not default, the expected shareholder value is $(1-\kappa) [n_t + \mathbb{E}V_t (b_t, z_{t+1})]$, where the expectation $\mathbb{E}$ is taken over future firm productivity $z_{t+1}$ and $\kappa$ is exogenous exit risk.

There exists a unique threshold realization $\bar{\varepsilon}_t$ which sets expected shareholder value to zero: $n_t(\bar{\varepsilon}_t) + (1-\kappa)\mathbb{E}V_t(b_t, z_{t+1}) = 0$. Firm default if $\varepsilon_t < \bar{\varepsilon}_t$.

At the end of the period of $t-1$, the firm chooses its corporate policies: current period finance and next period production $\{e_{t-1}, b_{st}, b_{lt}, k_t, l_t\}$. The firm anticipates that shareholder value will be positive if $\varepsilon_t$ is higher than the threshold value $\bar{\varepsilon}_t$ and zero otherwise. Given a net worth $n_{t-1}$, existing debt $b_{t-1}$, and productivity $z_t$, a firm solves:

$$n_{t-1} + V_{t-1}(b_{t-1}, z_t) = \max\left\{-e_{t-1} + \frac{1}{1+r_s}\int_{\bar{\varepsilon}_t}^{\infty}[n_t + (1-\kappa)\mathbb{E}V_t(b_t, z_{t+1}) - \kappa b_t \mathbb{E}q_{lt}]\varphi(\varepsilon)d\varepsilon\right\} \quad (25)$$

**Creditor's Problem** Creditors are perfectly competitive and break even on expectations for both short- and long-term bonds $\{b_{st}, b_{lt}\}$ given the corresponding risk-free rates at different maturities $\{r_s, r_l\}$. At the steady state without monetary shocks, all interest rates and coupons are equal ($r^* = c = r_s = r_l$). They buy firm bonds $b_{st}$ and $b_{lt}$ at the end of the period $t-1$. If the firm does not default in period $t$, short-term creditors receive $(1+c)b_{st}$, and long-term creditors are paid $(\gamma + c)b_{lt}$. In case of default, they receive $(1-\xi)\underline{n_t}$, where $\xi$ is the proportional cost of a fire sale and $\underline{n_t} = k_t + (1-\tau)ebita_t$ is the firm's value without repaying. Short- and long-term debt have equal seniority. The break-even price of short-term debt is

$$q_{st-1} = \frac{1}{1+r_s}\left[\left[1-\Phi(\bar{\varepsilon}_t)\right](1+c) + \frac{1-\xi}{b_{st}+b_{lt}}\int_{-\infty}^{\bar{\varepsilon}_t}\underline{n_t}\phi(\varepsilon)d\varepsilon\right] \quad (26)$$

where $1-\Phi(\bar{\varepsilon}_t)$ is the probability that $\varepsilon_t > \bar{\varepsilon}_t$. The price of short-term debt depends on firm behavior at time $t$, in particular on the risk of default $\Phi(\bar{\varepsilon}_t)$. In contrast, the price of long-term debt also depends on the future market value of long-term debt $q_{lt+1} = g_{t+1}(b_t, z_{t+1})$:

$$q_{lt-1} = \frac{1}{1+r_l}\left[\left[1-\Phi(\bar{\varepsilon}_t)\right](\gamma + c + (1-\gamma)\mathbb{E}g_t(b_t, z_{t+1})) + \frac{1-\xi}{b_{st}+b_{lt}}\int_{-\infty}^{\bar{\varepsilon}_t}\underline{n_t}\phi(\varepsilon)d\varepsilon\right] \quad (27)$$

where if the firm does not default in period $t$, it repays a fraction $\gamma$ of the outstanding debt plus the coupon $c$. A fraction $1-\gamma$ of the debt remains outstanding while the future price of long-term debt $q_{lt} = g_t(b_t, z_{t+1})$ depends on future firm behavior.

**Equilibrium Firm Policy** We recursively solve the equilibrium firm policy in the steady state and transition periods following unexpected monetary policy shocks. At the center of the policy is a Bellman equation of the continuation value function $V_t(b_t, z_{t+1})$. The key idea is to rewrite the firms' problem as

$$V_{t-1}(b_{t-1}, z_t) = \max\left\{-\tilde{e}_{t-1} + \frac{1}{1+r_s}\int_{\bar{\varepsilon}_t}^{\infty}[n_t + (1-\kappa)\mathbb{E}V_t(b_t, z_{t+1}) - \kappa b_t \mathbb{E}q_{lt}]\varphi(\varepsilon)d\varepsilon\right\} \quad (28)$$

where $\tilde{e}_{t-1} \equiv n_{t-1} + e_{t-1} \geq \underline{\tilde{e}}$ is defined as a choice variable and $\underline{\tilde{e}}$ is the redefined upper bound of equity issuance. The above bond prices, capital and net worth accumulation rules, and production technologies are the constraints.

**Numerical Solution** In terms of numerical solution, we solve the model in a partial equilibrium fashion, focusing on firms' decisions. More specifically, we follow the backward induction method in Hatchondo and Martinez (2009) and Jungherr and Schott (2020) to solve the continuation value function $V_t(b_t, z_{t+1})$, firm policies $\{e_{t-1}, b_{st}, b_{lt}, k_t, l_t\}$ and bond prices $\{q_{st-1}, q_{lt-1}\}$ recursively starting from a final date. We iterate backward for the steady-state equilibrium until all prices and quantities converge. Then, we use the first-period equilibrium allocation as the steady-state equilibrium of the infinite-horizon economy. We solve the equilibrium wage as if there is a representative household whose utility function is $ln(\sum(y_t - i_t)) - (\sum l_t)^3/3$. For the transition equilibrium, we take the wage as given and use a shooting method to solve backward the value and policy functions starting from the steady-state equilibrium and then simulate the steady-state distribution following the "MIT" monetary policy shocks in Ottonello and Winberry (2020). In both types of monetary expansions, we have $r_{st+1} = \rho_r r_{st} + \Delta r_s$ and $r_{lt+1} = \rho_r r_{lt} + \Delta r_l$, where $\rho_r$ is the persistence of monetary policy shocks. Our modification is that given the same magnitude of changes in the short rate $\Delta r_s$, the difference between conventional monetary expansions and unconventional expansions is substantial, $|\Delta r_l^c| < |\Delta r_l^u|$.

## B.4 Quantification of the Model Mechanism

We quantify the above full-blown model using U.S. firm-level data and responses of Treasury yields to monetary policy shocks. The model generates predictions that are consistent with our main empirical evidence and evidence on the mechanism channels.

### B.4.1 Parameterization

The model is calibrated at a quarterly frequency. There are two groups of parameters for the stationary equilibrium and a third group for the transitional equilibrium. The first group is assigned, the second group is chosen jointly to match data moments in the stationary equilibrium, and the third group matches monetary policy shocks, which we will explain in the next subsection. Table A.14 below lists all parameters and moments.

Table A.14: Parameterization and Targeted Moments

| Fixed Parameters | Notation | Value | Fixed Parameters | Notation | Value |
|---|---|---|---|---|---|
| Discount factor | $1/(1+r_s^*)$ | 0.99 | Coupon rate | $c$ | $r_s^*$ |
| Capital coefficient | $\theta$ | 0.250 | Labor coefficient | $\nu$ | 0.500 |
| Exogenous exit rate | $\kappa$ | 0.017 | Capital depreciation rate | $\delta$ | 0.025 |
| Corporate income tax rate | $\tau$ | 0.400 | Long-term debt repayment rate | $\lambda$ | 0.050 |
| Monetary shock persistence | $\rho_r$ | 0.500 | Productivity persistence | $\rho_z$ | 0.965 |
| **Fitted Parameters** | **Notation** | **Value** | **Fitted Parameters** | **Notation** | **Value** |
| Capital quality shock volatility | $\sigma_\varepsilon$ | 0.627 | Fixed cost of operation | $f$ | 0.303 |
| Debt issuance cost | $\theta_b$ | 0.004 | Fire sale cost | $\xi$ | 0.900 |
| Support of productivity shock | $\sigma_z$ | 0.290 | CMP/UMP shock to short rate | $\Delta r_s$ | -25bps/4 |
| CMP shock to long rate | $\Delta r_l^c$ | -4bps/4 | UMP shock to long rate | $\Delta r_l^u$ | -34bps/4 |
| **Targeted Moments** | **Data** | **Model** | **Targeted Moments** | **Data** | **Model** |
| Leverage (%) | 32.8 | 32.6 | Long-term debt share (%) | 66.9 | 66.4 |
| Investment rate (%) | 6.2% | 6% | Default rate (%) | 0.6 | 0.6 |
| Long-term credit spread | 2.5% | 2.4% | $\Delta$ Short-term Treasury yield | -25bps | -25bps |
| $\Delta$ long-term Treasury yield (CMP) | -4bps | -4bps | $\Delta$ long-term Treasury yield (UMP) | -34bps | -34bps |

In the first group, the steady state stochastic discount factor $1/(1 + r_s^*)$ is 0.99. Also, in the steady state, $c = r_s^* = r_l^*$ holds, so firms have no incentive to arbitrage from short- and long-term positions without considering monetary policy shocks. Following Gomes and Schmid (2010), we set the decreasing returns to scale parameter $\alpha$ to 0.65. The capital depreciation rate is set to 2.5%

per quarter. We set the long-term debt repayment rate to 0.05 to match the maturity of long-term debt of 5 years. The corporate income tax rate is 0.4 as in Gomes et al. (2016). We set the productivity parameters, exogenous firm exit rate, and monetary shock persistency following Ottonello and Winberry (2020). In the second group, we target an average investment rate of 6.2% and a mean quarterly default rate of 0.6%, as estimated in a survey of businesses by Dun and Bradstreet. We target a mean leverage ratio of about 33%, as reported in Crouzet and Mehrotra (2020). We target a mean long-term debt share of 67%, as in the data.

### B.4.2 Monetary Expansions Move Long-term Rates More Post-Crisis

We first calibrate the monetary policy shocks roughly according to our empirical findings. Specifically, we first match the magnitude of the on-impact changes in the short-term real interest rate of $\Delta r_s$ of $-25bps$ to changes in the short-term rates, regardless of conventional or unconventional monetary policy shocks, in the third group of parametrization. This is not exactly true because the short rate did not move after-crisis. However, we make this assumption since we want to demonstrate the difference only from the long-term rate. The shocks then last with the persistence of $\rho_r$. We then match the corresponding changes in the 10-year Treasury yield to the on-impact long-term real interest rate changes to the same shocks in the short-term rates as our empirical findings. A conventional expansion shock will change the long-term rate by $\Delta r_l^c = -0.15 * 25bps \simeq -4bps$, and an unconventional expansion shock will change the long-term rate by $\Delta r_l^c = -1.34 * 25bps \simeq -34bps$. We then rescale all the monetary policy shocks to quarterly frequency.

### B.4.3 High-leverage Firms Hold More Long-term Debt

We then provide the quantitative model results that are consistent with the data that high-leverage firms hold more long-term debt. In the model simulated firm sample in the steady state, we find a high positive correlation between leverage and long-term debt share of about 0.71. This is consistent with the model mechanism such that high-leverage firms tend to rollover more long-term debt to reduce the debt issuance costs.

Table A.15: Untargeted Correlation between Leverage and Long Share

| Data | Model |
|---|---|
| **0.30** | **0.71** |

### B.4.4 Regression Results in the Quantitative Model

Finally, we validate the main results and the mechanisms in Section 4.3 to show the changing role of leverage and the two channels of monetary policy shocks through leverage. We first simulate a firm sample under two scenarios. In the first scenario, 5000 firms (with entry and exit) stayed in the steady state by 50 quarters, were hit by a conventional monetary shock in the 51-quarter, and then converged back to their steady state in 50 quarters. In the second scenario, 5000 firms (with entry and exit) stayed in the steady state by 50 quarters, were hit by an unconventional monetary shock in the 51-quarter, and then converged back to their steady state in 50 quarters. We then pick 15 quarters pre-shock and 10 quarters post-shock. Therefore, we have a total of about 5000 firms for 25 quarters for both episodes. For half of the observations, there are no monetary policy shocks; for half of the observations, there are monetary policy shocks with decreasing effects departing from the on-hit quarters. We then run the following regression, which is the same as the main empirical regression:

$$y_{i,t} = \alpha_i + \alpha_t + \beta_1 l_{i,t-1}\epsilon_t^m + \beta_2 D_t^{post} l_{i,t-1}\epsilon_t^m + \delta_1 l_{i,t-1} + \delta_2 D_t^{post} l_{i,t-1} + e_{i,t} \tag{29}$$

where $y_{i,t}$ is the dependent variable of firm $i$, $\alpha_i$ is a firm $i$ fixed effect, $\alpha_t$ is the time fixed effect, $D_t^{post}$ is a dummy that turns on for the post-crisis sample, $l_{i,t-1}$ is firm $i$'s lagged leverage (measured as debt-to-capital), and $\epsilon_t^m$ is the monetary policy shock.

We run the regression for stock returns to show the main results and for debt borrowing and capital investment to show the two channels. As we did for the main empirical regressions, all three measures are in percentage changes. The results are in Table A.16 below; we do not show the significance level since it is model simulated regressions. The results are consistent with our empirical findings either with the triple interaction between $D_t^{post}$, $\epsilon_t^m$, and other firm-level variables or without. The relative magnitudes are also consistent with our empirical findings: the coefficient for borrowing is the largest, the coefficient for investment is the smallest, and the coefficient for stock return lies in between.

Table A.16: Model Regression Results: Post-Crisis vs Pre-Crisis

| | (1) Investment | (2) Investment | (3) Borrowing | (4) Borrowing | (5) Stock Return | (6) Stock Return |
|---|---|---|---|---|---|---|
| $D_t^{post} \times l_{i,t-1} \times \epsilon_t^m$ | 0.053 | 0.029 | 1.226 | 0.419 | 0.743 | 9.436 |
| Interactions with Controls | No | Yes | No | Yes | No | Yes |
| $N$ | 72185 | 72185 | 72185 | 72185 | 72185 | 72185 |
| adj. $R^2$ | 0.151 | 0.175 | 0.520 | 0.532 | 0.174 | 0.177 |