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

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Abstract

We study how leverage determines firm-level responses to monetary policy. Using both high-frequency financial market and quarterly investment data, we find that the role of leverage in monetary transmission changed around the financial crisis of 2007-09. Firms with high leverage were less responsive to monetary policy shocks in the pre-crisis period but have become more responsive since the crisis. The higher responsiveness is driven by firms whose leverage is more dependent on long-term debt, suggesting an outsize role for monetary policy affecting long-term funding conditions since the crisis. We also find suggestive evidence for transmission through changes in monetary policy uncertainty.

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1 Introduction

Since the federal funds rate hit the zero lower bound at the beginning of the financial crisis, the Federal Reserve has relied more on unconventional policy tools like forward guidance and 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.[2] Our main contribution is to show that the role of financing conditions in determining the firm-level response to monetary shocks has *reversed* in the post-crisis sample.

We document this result with three complementary empirical approaches using both high frequency financial market and quarterly real activity data for non-financial firms. For all approaches, we construct monetary policy shocks using high frequency data from futures and Treasury bond markets. Our preferred measure of monetary policy shocks combines unexpected changes in the federal funds target with the change in the 10 year Treasury yield in a narrow window around FOMC announcements. This allows us to parsimoniously capture both conventional and unconventional monetary policy actions.[3]

For our first approach, we combine firm-level characteristics with high frequency data on stock prices. 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. More importantly, since we are interested in the interaction of leverage and monetary shocks, with time fixed effects we can also control for any aggregate factors that could be changing over time.

Given that monetary policy shocks are not predictable, these results have no implications for the *expected direction* of the movement in the stock price of firms with higher (or lower) leverage on FOMC announcement days. However, there is a direct implication for the *expected*

[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 (2018), Jeenas (2018) and Ozdagli (2018).

[2] A notable exception is the paper of Wu (2018), which we discuss below.

[3] This approach is especially important in the post-crisis sample where the federal funds rate is mostly stuck at the zero lower bound. But we also show that using one single policy indicator for both the pre- and post-crisis samples (e.g. the change in the 2 year Treasury rate) confirms our results.

volatility of the stock price. Specifically, we should expect that firms with high leverage will 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. Our second approach involves testing this hypothesis by using high frequency firm-level options data. These options data allow us to construct 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. Markets expected high leverage firms to be less volatile on FOMC announcement days in the pre-crisis sample but more volatile since then.

Our third approach involves using firm-level investment data. Since this measure of real activity is only available quarterly, we aggregate our monetary policy shock measure up to the quarterly level. At this quarterly frequency, there are several factors that could affect firm-level investment other than monetary policy.[4] Nevertheless, these quarterly results confirm the pattern of increasing responsiveness of firms with higher leverage since the financial crisis. There is an ongoing discussion in the literature regarding the longer-run response of investment to monetary policy shocks, see Ottonello and Winberry (2018) and Jeenas (2018). The relatively shorter sample of data since the crisis makes it difficult to do inference on comparing long-run responses in the pre- and post-crisis samples, so in this paper we focus on the contemporaneous response. Our findings for the contemporaneous response of investment in the pre-crisis sample are consistent with both these papers.

Our results hold across a variety of robustness checks, including using alternative measures of leverage, expanding our baseline sample from firms in the S&P 500 to a broader set of firms in the CRSP/Compustat dataset, dropping unscheduled FOMC meetings, using time-by-sector fixed effects and including financial firms in our sample. A natural question is whether our results are driven by the changing behavior of leverage since the crisis. We document that average leverage has only slightly increased since the crisis and that the cross-sectional distribution of leverage is similar in the two samples. Moreover, we show that most firms have not moved around much in the leverage distribution since the crisis and that excluding firms that did move around a lot does not affect our results.

In the next part of the paper we shed light on the mechanism driving our empirical results. There is a growing literature on the transmission of monetary policy and heterogeneity in firm balance sheets. But, as mentioned above, this literature has focused on the pre-crisis period.

[4]Since we use an exogenous measure of monetary shocks and time-fixed effects we are not worried about endogeneity but rather about the loss of precision as a smaller fraction of the firm-level dependent variable will be driven by monetary policy here relative to the high frequency specification.

We start by placing our pre-crisis results in the context of the leading heterogenous firm model of Ottonello and Winberry (2018), which builds on the work of Khan et al. (2016). Within this model, we then discuss potential channels that can rationalize our post-crisis results and provide supporting empirical evidence.

In the Ottonello and Winberry (2018) model there are competing forces affecting how high vs. low leverage firms respond to an expansionary monetary policy shock. The marginal cost curve of a high leverage firm is steeper making it less responsive to monetary policy induced shifts of the marginal benefit curve. However, the expansionary monetary policy shock flattens out the marginal cost curve more because of an increase in the value of collateral and cash flows, making high leverage firms more responsive. In a pre-crisis calibration, Ottonello and Winberry (2018) find that the former effect dominates, implying results that are consistent with our pre-crisis findings. We argue that to reverse this result in the post-crisis sample, an expansionary monetary policy shock must flatten the marginal cost curve substantially more for high leverage firms. A direct testable implication of this hypothesis is that credit spreads for high leverage firms should fall more (relative to low leverage firms) in the post-crisis sample. We provide evidence of this channel by using the credit spread between firms rated BAA relative to those rated AAA. Consistent with the hypothesis, the BAA-AAA spread falls more (in response to an expansionary monetary policy shock) in the post-crisis sample.[5]

Why is it that monetary policy actions flatten the marginal cost curve more and thus compress the yield spread between high leverage and low leverage firms more in the post-crisis sample? Our hypothesis is that longer-term interest rates, and thus firms that are more dependent on long-term funding, have become more sensitive to monetary policy actions in the post-crisis sample. We first document that the nominal and real 10 year Treasury yields respond significantly more to monetary policy shocks in the post-crisis sample. Next, we test if this increased sensitivity is spilling over into long-term funding conditions and contributing to our baseline results. To do this we separate a firm's leverage into two components, one depending on long-term debt and the other on short-term debt. We find that the increased responsiveness since the crisis is largely driven by firms that have a larger share of long-term debt in their leverage. This is consistent with the results of Foley-Fisher et al. (2016) who 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. However, our results suggest that this increased responsiveness to monetary policy is a feature prevalent throughout the post-crisis sample rather than just in response to specific large scale asset purchase episodes.

We also provide some suggestive evidence for the role of another monetary transmission

[5] This result is broadly consistent with the findings of Gilchrist and Zakrajšek (2013) that borrowing costs of riskier firms reacted substantially more to quantitative easing announcements in the post-crisis sample.

channel, namely through changes in uncertainty about future policy decisions. In recent empirical work, Kroencke et al. (2018), Bauer et al. (2019) and Bundick et al. (2017) find that monetary policy uncertainty shocks are likely drivers of term-premium on long rates and general risk-premium in the financial markets. Moreover, Bauer et al. (2019) find that monetary transmission to financial markets through uncertainty has strengthened in the post-crisis sample. We use their uncertainty measure of the changes in the standard deviation of the expected future policy rate, as constructed using high-frequency options data around FOMC announcements. We find that monetary policy uncertainty shocks induce a similar reversal in the sign of the relationship between the firm-level response and leverage. Specifically, in response to uncertainty shocks firms with high-leverage respond less in the pre-crisis sample but more in the post-crisis sample.

Related Literature: Our paper is related to three strands of the literature. The first one identifies firm-level characteristics, particularly financial constraints such as leverage, that are associated with a heterogenous stock market response to monetary policy shocks. Both Ehrmann and Fratzscher (2004) and Ottonello and Winberry (2018) 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. Ozdagli (2018) finds that firms that have higher information frictions are less responsive while Ippolito et al. (2018) find that more financially constrained firms have a stronger response to monetary policy.[6] 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 contribution is to highlight the changing relationship between leverage and stock price response since the financial crisis. We also confirm this changing relationship using both high-frequency options data and quarterly firm-level investment data. Finally, we interpret our findings through a structural model and provide evidence of the mechanism working through long-term funding conditions and monetary policy uncertainty changes.

Our paper also adds to the growing literature on the heterogenous effects of unconventional monetary policy since the crisis. In addition to the Foley-Fisher et al. (2016) paper discussed above, there is some recent work analyzing the heterogenous impact of European Central Bank's (ECB) unconventional policies. Grosse-Rueschkamp et al. (2019) study the effect of ECB's corporate sector purchase program on firm's capital structure, while Daetz et al. (2018) investigate the impact of the ECB's longer-term refinancing operations on corporate

[6] Ippolito et al. (2018) find increased sensitivity using a measure of leverage that only includes bank debt.

investment.

Finally, our paper is related to the literature that explores heterogenous responses of real economic activity to changes in monetary policy. Gertler and Gilchrist (1994), an early influential paper in this literature, notes that sales at small manufacturing firms decrease disproportionately relative to larger manufacturing firms after Romer and Romer tight money dates.[7] They provide evidence that small firms are a proxy for financial constraints, as smaller firms seem to have more difficulty acquiring credit when monetary policy becomes contractionary. More recent papers explicitly attempt to control for financial constraints. Ottonello and Winberry (2018) find that investment spending at firms with higher leverage is less responsive to monetary policy shocks in the quarter of a monetary shock. Dedola and Lippi (2005) show that output of industries in the U.S. and four other OECD countries with higher leverage is less responsive between 4 and 12 quarters after a monetary policy shock. In contrast to those two papers, Jeenas (2019) and Jeenas (2018) find that sales and investment of higher leverage firms are more responsive to monetary policy shocks after approximately 8 quarters. We provide evidence that the contemporaneous effect on higher leverage firms has become larger following the financial crisis. Cloyne et al. (2018) stress the importance of firm age for the investment response to monetary shocks with younger firms being the most responsive. In our analysis the combination of firm- and time-fixed effects effectively control for age and imply that firm age is not driving the changing relationship between leverage and monetary transmission.

The rest of the paper is organized as follows. In the next section we outline the data sources and data variables used in our empirical analysis. Section 3 presents the results from our three main empirical strategies using stock price, options and investment data. Next, in Section 4 we shed some light on the mechanism driving our results. Section 5 provides a variety of robustness checks and Section 6 concludes.

2 Data

This paper uses the daily firm share prices from the CRSP/Compustat Merged Security Daily dataset for July 1991 to December 2017 and firm characteristics from the 1991:Q3 to 2017:Q4 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 a subsample of the firms in the CRSP/Compustat Merged dataset with a dataset

[7]A related literature uses business cycle contractions as the type of shock under investigation rather than monetary shocks, e.g. Kudlyak and Sanchez (2016), Crouzet et al. (2017), Kalemli-Ozcan et al. (2018) and Bustamante (2018).

of firm-level implied volatility from OptionMetrics. This section further describes these three data sources.

2.1 Monetary Policy Shocks

To construct our measure of monetary policy shocks, we combine data from fed funds futures and Treasury bond markets. 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. The early work of Kuttner (2001) and Bernanke and Kuttner (2005) used changes in the current month's futures contract. This measure captures any unexpected changes to the target for the fed funds rate. However, in more recent years, the Federal Reserve has been using alternative unconventional policy tools, including large scale asset purchases (quantitative easing) and forward guidance. FOMC announcements that provide information about these unconventional policy actions are not well captured by this measure. This issue has been especially relevant since the fed funds rate hit the zero lower bound in late 2008. Thus we also use the change in longer-term Treasury yields around FOMC announcements to supplement the Kuttner (2001) measure. Specifically, our monetary policy shock ϵ_t^m is defined as

$$\epsilon_t^m = P_{t+\delta_+} - P_{t-\delta_-} \tag{1}$$

where t is the time of the FOMC announcement, P_t is either the implied fed funds rate from the price of the current month's fed funds futures contract or on-the-run Treasury yields, $t + \delta_+$ and $t - \delta_-$ represent 20 minutes after the FOMC announcement and 10 minutes before the FOMC announcement, respectively. For our baseline measure (labeled MP Shock) we combine the change in the current month's futures contract[8] (labeled FFR Shock) and the 10 year Treasury yield by taking the first principal component of these two measures. The idea is to parsimoniously capture both conventional and unconventional monetary policy actions in one tool.[9] Since the scale of this shock is arbitrary, we rescale it to have a unit effect on the 2 year yield. We also present our baseline regressions including both the FFR Shock and the change in the 10 year yield as separate measures of monetary policy shocks.[10] Finally,

[8]Since fed funds futures contracts are based on the average rate for a month, the change in the implied rate needs to be adjusted by $\tau(t) = \frac{\tau_m^n(t)}{\tau_m^n(t) - \tau_m^d(t)}$ where $\tau_m^n(t)$ is the number of days in the month of the announcement and $\tau_m^d(t)$ is the day of the month the announcement occurred

[9]We perform this principal component analysis separately for the pre-crisis and post-crisis periods. The first principal component explains 84% of the variation in these two rates during the pre-crisis sample and 90% of the variation in these two rates during the post-crisis sample.

[10]Since the 10-year rate is a function of shorter-term rates, we first regress it on the short-term rate and use

we also use a single monetary policy indicator in both the samples: the change in the 2 year Treasury yield as recommended by Hanson and Stein (2015). We find that the main results are robust to the choice of monetary policy shock; however, for simplicity, we most frequently report results based on the MP Shock, i.e. the first principal component of changes in the current month's fed funds futures contract and the on-the-run 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 December 2017). The effect of the zero lower bound is clearly apparent. The standard deviation of the FFR Shock measure falls substantially from 9 basis points in the pre-crisis sample to 1 basis point in the post-crisis sample. Even for the two year shock measure the standard deviation falls from 6.5 basis points to 3.5 basis points, reflecting the effective lower bound on Treasury yields starting in late 2011 as reported by Swanson and Williams (2014). However the standard deviation of the 10 year shock measure is roughly similar in the pre- and post-crisis samples, motivating our reliance on this measure to effectively capture monetary policy shocks in the post-crisis period.

2.2 Firm-Level Variables

We use the CRSP/Compustat Merged Fundamentals Quarterly sample beginning in 1991:Q3, as this is the first year where we have a complete record of our monetary policy shock measures. For the baseline results we use the firms in the S&P 500 index and, as is common in the literature, we exclude financial firms (SIC 6000-6999). In the online appendix we include robustness checks expanding the sample to all firms in the CRSP/Compustat dataset and also another check including financial firms in our sample. Our primary measure of interest from Compustat is the firm's leverage ratio. The baseline results use the ratio of debt-to-capital, measured as the sum of debt in current liabilities (Compustat item: DLCQ) and long-term debt (DLTTQ) over the sum of debt in current liabilities, long-term debt and stockholder's equity (SEQQ). We also confirm our results (relegated to the online appendix) using an alternative measure of leverage: debt-to-assets (using the book value of assets (ATQ)). Table 1 displays the summary statistics for these definitions of leverage measured as the 4-quarter rolling average at the firm level.

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 log of quarterly market capitalization and the ratio of current assets to total assets. Including these

the residuals as the orthogonalized measure of the 10-year rate.

controls are intended to capture important characteristics of the firm that could be correlated with both firm leverage and firm performance. Table A.1 in the appendix displays summary statistics of these measures, dividing the sample into firms with above and below average leverage. The construction of these variables follows standard methods in the literature; however, we include these details in the online appendix.[11]

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 December 2017. To ensure sufficient liquidity in the market for options, we make two restrictions to our implied volatility sample. First, we use implied volatility measures for options set to expire in greater than 3 months. Second, we use the 100 most-liquid firms, i.e. the 100 firms with the highest number of days with available data in our sample period. Summary statistics for both these variables are also presented in Table 1.

3 Results

This section presents the main results illustrating how leverage affects 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. Finally, we use quarterly data on firm investment and show that a similar pattern emerges.

3.1 Evidence from firm-level stock returns

We first examine how leverage determines 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 November 2017. We are thus leaving out the crisis period as categorized by July 2008 to July 2009. These dates are commonly used

[11] In Section 3.4 we investigate the impact of monetary policy shocks on firms' quarterly investment. The construction of this investment variable is also detailed in the online appendix.

in the literature due to turbulence in the financial markets and the presence of some asset pricing anomalies, see for example Nakamura and Steinsson (2018).[12]

Our baseline regression takes the following general form

$$s_{i,t} = \alpha_i + \alpha_t + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t} \tag{2}$$

where $s_{i,t}$ is the (daily) return on firm i's share price on FOMC meeting day t,[13] α_i is a firm i fixed effect, α_t is an FOMC meeting day t fixed effect (i.e. a dummy for each time period), $l_{i,t-1}$ is firm i's average leverage (measured as debt-to-capital) for the four quarters preceding the quarter of the FOMC announcement, ϵ_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 ϵ_t^m is not included separately as a regressor because it is subsumed by the 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 quarterly market capitalization and the ratio of current assets to total assets.[14] Since the firm-level characteristics are measured at the quarterly 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 time fixed effect accounts for aggregate shocks common to all the firms on the day of the FOMC announcement. The standard errors reported in the parentheses are calculated using two-way clustering along the time and firm dimensions.[15]

We multiply the monetary policy shock measure by negative one so that an increase in ϵ_t^m corresponds to an expansionary shock. The key parameter in the above specification is β, which captures how the responsiveness of a firm's share price to a monetary policy shock changes based on a firm's leverage ratio. We standardize leverage to be mean zero and unit variance, so β 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.

[12] In the online appendix we show that our results are robust to including the financial crisis dates in the "post-crisis" sample.

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

[14] In the appendix Table A.2 we show that our results are robust to interacting these controls, as well as the firm's sector, with the monetary policy shock.

[15] Our results are robust to using Driscoll-Kraay standard errors instead of two-way clustering.

Table 2 presents the results for firms in the S&P 500 for pre- and post-crisis samples for the three different monetary policy shock measures. Columns 1a and 1b show the results for our first measure (labeled MP shock), which is the first principal component of the change in the current month's fed funds futures contract and the change in the on-the-run 10 year yield. The interaction coefficient of MP shock and leverage (β) is *negative* and significant in the pre-crisis sample but *positive* and significant in the post-crisis sample. Since we use time fixed effects, we cannot estimate the stand-alone effect of the monetary policy shock on firm-level stock returns from this specification. However, we show in appendix Table A.3 that the sign is as expected and implies that a 100 basis point expansionary monetary policy shock leads to an over 6% increase in stock prices.[16] This means that the interaction coefficient of MP shock and leverage shows that firms with higher leverage were *less* responsive to monetary shocks before the crisis and have become *more* responsive since the crisis. Specifically, for a firm that has leverage one standard deviation above the mean, its stock price *falls* by 5.5% more (relative to a firm that has average leverage) in the pre-crisis sample but *increases* by 2.2% more in the post-crisis sample. To formally test that the pre- and post-crisis responses are statistically significantly different from each other we run a specification with triple interactions ($D_t^{post} * \epsilon_t^m * l_{i,t-1}$) where D_t^{post} is a dummy for the post-crisis sample. The lower panel of Table 2 shows that the coefficient on this triple-interaction is positive and statistically significant implying that firms with higher leverage have become significantly *more* responsive to monetary shocks in the post-crisis, relative to the pre-crisis.

Columns 2a and 2b show the results where we include both the change in the current month's fed funds futures contract (FFR shock) and the change in the on-the-run 10 year yield as monetary shocks.[17] In the pre-crisis sample firms with higher leverage are less responsive to a FFR shock while the 10 year shock response is essentially the same for firms regardless of leverage. In the post-crisis sample this relationship changes and the FFR shock has an identical effect for firms across the leverage spectrum whereas firms with higher leverage are now responding more to the 10 year shock. The heterogenous effects of monetary policy worked directly through fed funds rate target changes in the pre-crisis sample but in the post-crisis sample worked through the changes in the 10 year rate. This is not surprising given that the fed funds rate was stuck at the zero lower bound for most of the post-crisis sample and in this period the Federal Reserve used unconventional measures like forward guidance

[16] Recall that the MP shock measure has been scaled to have a unit (100 basis point) effect on the 2 year Treasury yield.

[17] Since the 10 year yield is mechanically a function of the short rate, we first orthogonalize the 10 year yield change with respect to the FFR shock. In other words, we first regress the change in the on-the-run 10 year yield on the FFR shock and use the residual from this regression as our monetary shock measure (labeled "10 yr shock").

and quantitative easing. This result also highlights the convenience of our MP shock measure that parsimoniously captures the joint effect of the FFR shock and the 10 year shock in one variable. Thus we will use the MP shock for most of the results shown below.

Finally, Table 2 shows the results when we use only a single rate as the monetary policy indicator. Columns 3a and 3b show the results using the change in the on-the-run 2 year Treasury yield as the monetary policy shock (labeled "2 yr shock") for both samples. These results confirm the reversal in the relationship. Firms with higher leverage were less responsive to monetary policy shocks in the pre-crisis sample but more responsive in the post-crisis sample. The bottom panel also shows the triple interaction specification using the 2 year rate as the monetary policy indicator. Consistent with the earlier results, this interaction coefficient is positive and statistically significant.

In Section 5 below we conduct a battery of robustness checks. These include using a different leverage measure (debt-to-assets), expanding our S&P 500 sample to all non-financial firms in the CRSP/Compustat dataset, including the crisis dates in the sample, excluding unscheduled FOMC meetings from the sample, using time-by-sector fixed effects, narrowing our panel to firms without any entry or exit from the sample and including financial firms. First, we document some empirical patterns in our baseline leverage measure to show that our results are not being driven by any sudden change in the behavior of leverage since the crisis.

3.2 Leverage in the pre- and post-crisis samples

The results of differential responsiveness in the pre- versus post-crisis samples raise some natural questions about the behavior of leverage in the two samples. Has average leverage changed since the crisis? How does the cross-sectional distribution of leverage compare across the two samples? Has there been any "churning" of firms from low leverage in one sample to high-leverage in the other sample? Importantly, do these patterns play a role in driving the results? In this section we tackle these issues in order.

First, from Table 1 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 0.41 in the post-crisis sample relative to a mean of 0.38 in the pre-crisis sample.[18] Similarly the standard deviation of leverage is also roughly the same across the two samples. Figure 1 shows the distribution of leverage 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

[18]The fact that leverage is increasing a little on average for all firms in the post-crisis sample is not a concern because our results are driven by how firm response is different across the leverage distribution.

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. These results are presented in the online appendix. As one would expect with the patterns from Table 1 and Figure 1 we find these results are very similar to our baseline results.

We further investigate whether firms have moved around in the 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 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 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. the ones that are not close to the 45 degree line. In the appendix Table A.4, we present our baseline results excluding firms which lie more than 1 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 movement of firms across the leverage distribution does not explain the difference in transmission of monetary policy through firm leverage following the financial crisis.

Next, we show this pattern of high leverage being related to less responsiveness before the financial crisis and more responsiveness afterwards is also evident using firm-level options data.

3.3 Evidence from firm-level options data

Given that monetary policy shocks are not predictable, our results from Section 3.1 have no implications for the *expected direction* of the movement in the stock price of firms with higher (or lower) leverage on FOMC announcement days. However, there is a direct implication for the *expected volatility* of the stock price of firms with higher (or lower) leverage. Specifically, we should expect that in the pre-crisis period high leverage firms should be less volatile on FOMC announcement days but more volatile in the post-crisis sample. In this section, using options data we indeed find strong evidence for this pattern.

We construct firm-level measures of expected volatility 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. Specifically, for each firm we use the implied volatility of the expected stock return, based on firm-level options prices. To assure the options in our sample are sufficiently liquid, we restrict the sample to those options set to expire in one quarter or longer. Even with this restriction, on any given trading day there exist many firms with missing implied volatility data. Thus, for the following specification, we will use the the most recent day (within the previous three trading days) in which an S&P 500 firm has a non-missing value for its implied volatility.[19]

Using this implied volatility measure 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. Specifically we run the following regression

$$ivol_{i,t-1} = \alpha_i + \alpha_t + \delta l_{i,t} + \beta l_{i,t-1} D_t^{post} + \Gamma Z_{i,t-1} + e_{i,t} \tag{3}$$

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-capital) 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 December 2017, $Z_{i,t-1}$ contains a variety of firm-level controls,[20] α_i is a firm fixed effect and α_t is a time-fixed effect. The combination of the firm- and time-fixed effect allows us to control for factors that are firm specific (but fixed over time) and aggregate patterns that affect the level of the firm-specific implied volatility measure. Due to the data availability of options data, our sample runs from January 1996 to December 2017.

The estimates are presented in Table 3 with two-way clustered standard errors along the firm and time dimension. Column 1 does not include any firm-level controls, while column 2 adds the full list of firm-specific controls listed above. For both columns, the coefficient on leverage (δ) is negative and significant: In the pre-crisis sample firms with higher leverage had lower levels of expected volatility on the day before the FOMC announcement. But the coefficient on the interaction of leverage and the post-crisis dummy (β) is positive and significant: Relative to the pre-crisis sample, leverage is more positively associated with implied volatility in the post-crisis sample. In the post-crisis sample, expected volatility is roughly one-quarter of a standard deviation higher for a firm that has leverage one standard deviation

[19] Our results are very similar if we instead choose not to impute any of the missing implied volatility data

[20] 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.

above the mean. Moreover, the size of the total effect in the post-crisis sample ($\delta + \beta$) is positive and significant, as shown by p-values in the table. 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.

The results from Table 3 are also robust to using the alternative measures of leverage (debt-to-assets and debt-to-equity), putting in time-sector fixed effects, excluding unscheduled FOMC meetings from the sample, including the crisis dates in the post-crisis period or including financial firms in the sample. These results are discussed in Section 5.

In summary, the firm-level options data confirm the reversal in the relationship between leverage and monetary policy announcements since the financial crisis. Moreover, our options-based variable is measuring *expected* volatility as captured on the day before the FOMC announcement. The change in the sign of the relationship between this expected volatility and leverage implies that participants in the financial markets have internalized the change in relationship since the crisis that we estimated with stock returns in Section 3.1. Next, we provide evidence for this changing relationship using firm-level investment data.

3.4 Evidence from investment data

In this section we corroborate the evidence from the stock market using firm-level variables on economic activity from Compustat. Specifically we explore the response among S&P 500 firms of firm-level investment and sales to monetary policy shocks. We focus in the main text on the investment response, relegating our sales growth results to the online appendix. Our baseline empirical specification is the following:

$$\Delta ln(y_{it}) = \alpha_i + \alpha_t + \sum_{n \in N} \beta_{1,n} l_{i,t-n-1} \epsilon^m_{t-n} + \beta_{2,n} l_{i,t-n-1} \epsilon^m_{t-n} D^{post}_{t-n} + \Gamma' Z_{i,t-1} + e_{it} \quad (4)$$

where y_{it} is the value of either firm i's real sales revenue or capital stock in quarter t, α_i is a firm i fixed effect, α_t is a quarter t fixed effect, l_{it} is firm i's leverage ratio, ϵ^m_t is the sum of all high-frequency monetary policy shocks that occur in quarter t, D^{post}_t is an indicator for the post-crisis period, $Z_{i,t-1}$ is a vector of firm-level controls (lagged by one quarter) and e_{it} is the residual.[21] For the specification with investment as the dependent variable, $N = [0, 12]$. Due to the strong seasonality of sales data, $N = \{0, 4, 8, 12\}$ for the specification with sales

[21] $Z_{i,t-1}$ also contains each of the n lags of the firm's leverage ratio and the respective interactions with the lagged post-crisis dummy. As with the stock market specification, the monetary policy shock ϵ^m_t is subsumed by the time fixed effect. The same is true of the post-crisis dummy and its interaction with the monetary policy shock.

growth as the dependent variable.

The key parameters in the above specification are $\beta_{1,0}$ and $\beta_{2,0}$, which estimate how the responsiveness of the real variable, y_{it}, to a contemporaneous quarterly monetary policy shock differs based on a firm's leverage ratio in the pre-crisis and post-crisis, respectively. Since we standardize l_{it} to be mean zero and unit variance, these parameters can be interpreted as the additional increase in a firm's quarterly sales or investment in response to an expansionary monetary shock by moving from an average leverage ratio to one standard deviation above the average leverage ratio. As in the results discussed above, we multiply the monetary policy shock measure by negative one so that an increase in ϵ_t^m corresponds to an expansionary shock.

We control for factors in $Z_{i,t-1}$ that could potentially affect both a firm's leverage ratio and the quarterly growth in the firm's sales or capital stock. For regressions with investment as the dependent variable, $Z_{i,t-1}$ includes the log of the book value of assets, the ratio of current assets to total assets, the ratio of sales revenue to the (net) capital stock and the year-over-year real sales growth. These controls are intended to capture the size of the firm and its liquidity/cash flow, both of which should increase a firm's ability to finance investment expenditures. For regressions with sales growth as the dependent variable, $Z_{i,t-1}$ includes the log of the book value of assets and the ratio of current assets to total assets. Since the monetary policy shocks occur throughout the quarter and the firm-level variables are measured at the quarterly level, leverage and the controls are lagged to ensure they are predetermined at the time of the monetary policy shocks. We also include a dummy for the fiscal quarter in all specifications, to account for differences across firms due to different positions in their fiscal year. This is particularly important for sales, which displays a strong seasonal trend based on fiscal quarter. Since we are using panel data, we are able to include firm and time fixed effects. The firm fixed effect accounts for permanent characteristics of changes in firm i's sales or capital stock that are not captured by our controls. The time fixed effect accounts for aggregate shocks common to all the firms in quarter t. The standard errors reported in the parentheses are calculated using two-way clustering along the time and firm dimensions. Finally, to ensure that the firm fixed effect is not endogenous, we only keep firms in the sample that have at least 40 observations with non-missing sales or investment data in either the pre- or post-crisis sample.

Table 4 shows the contemporaneous response of investment with the results for sales provided in the online appendix. These results are consistent with the pattern emerging from the stock price and implied volatility results. In the pre-crisis sample, the interaction between the monetary policy shock and leverage is negative and significant, while the interaction is positive and significant in the post-crisis sample. Our finding that investment is less responsive to a contemporaneous monetary policy shock in the pre-crisis period matches the main finding of Ottonello and Winberry (2018).[22] Specifically, during the pre-crisis period, a firm with leverage one standard deviation above average experiences an increase in investment 3.71% *less* than a firm with average leverage during the quarter in which an expansionary monetary policy shock occurs. In the post-crisis period, a high-leverage firm would experience an increase in investment 7.86% *more* than a firm with average leverage.

In section 5 below we discuss further robustness checks of these results, including using time-sector fixed effects, adding more controls and expanding the sample beyond S&P 500 firms. Before detailing these tests, we now turn to a discussion of potential mechanisms behind the empirical findings we have presented up to this point.

4 Mechanism

We began by showing that there has been a change in the relationship between firm leverage and monetary transmission. Specifically, using both high frequency stock market data and quarterly economic activity variables we showed that high leverage firms were less responsive in the pre-crisis sample but more responsive in the post-crisis sample. In this section we shed some light on the mechanism underlying the change in this relationship.

In the post-crisis sample, with the fed funds rate stuck at the zero lower bound, the Federal Reserve has leaned more on unconventional monetary policy actions like large scale asset purchases and forward guidance. While there is a large literature on the channels of unconventional policy transmission, there is very little work that studies the heterogeneous transmission through the balance sheets of non-financial firms. In this section we start with the recent heterogeneous firm general equilibrium model of Ottonello and Winberry (2018) (OW hereafter) who study the transmission of conventional monetary policy (in the pre-crisis sample) through firm balance sheets. Within this framework, we discuss a channel that can rationalize our post-crisis findings and provide supporting empirical evidence for it. Next, we dig deeper to understand this channel and show that long rates have become more sensitive to monetary policy shocks in the post-crisis sample. Thus a monetary policy induced change in long rates could have outsize spillover effects on financing conditions for firms who rely

[22] Jeenas (2018) finds that higher leverage firms become more responsive than lower leverage firms several quarters after a monetary policy shock in the pre-crisis period. In contrast, Ottonello and Winberry (2018) do not find a differential effect by leverage beyond the contemporaneous quarter. Ottonello and Winberry (2018) contains a lengthy discussion of the methodological differences between these two papers. Due to limited amount of data in the post-crisis sample, it is difficult to discern any statistically significant differences in the long-term response between the pre- and post-crisis samples. We find that the clearest change from the pre- to the post-crisis occurs in the contemporaneous sensitivity of investment due to differences in firm leverage. Thus we choose to focus on these results here.

more on longer term funding. Consistent with this story, we find that our baseline results are driven by firms whose leverage is more dependent on long-term debt. Finally, we provide some suggestive evidence for an additional channel of monetary transmission to firm balance sheets since the crisis, namely through changes in uncertainty about future monetary policy decisions.

4.1 Ottonello & Winberry channels of monetary transmission

The canonical theoretical framework to understand the transmission of monetary policy through firm balance sheets is the financial accelerator model of Bernanke et al. (1999). The essential feature of the models in this vein is the existence of some financial friction in the borrower-lender relationship. For our purposes, the key question is what this framework implies for the heterogenous firm response to monetary policy. In the literature, the theoretical predictions of how firm balance sheet characteristics affect monetary transmission are ambiguous. Bernanke et al. (1999) did extend their baseline model to a heterogenous (two-firm) case. With their preferred calibration they find that firms that have a larger external finance premium respond more strongly to monetary policy shocks. Building on the work of Khan et al. (2016), OW extend the Bernanke et al. (1999) framework to allow for a richer structure of heterogeneity (including firm-specific productivity and capital quality shocks) and firm default. Contrary to Bernanke et al. (1999), they find that firms with higher leverage are less responsive to monetary policy. Moreover, they confirm their results using an empirical analysis for the pre-crisis sample. These OW results are consistent with our empirical results shown above for the pre-crisis sample. If we start with the OW model as our baseline model for the pre-crisis sample, is it possible to explain our post-crisis results in this framework? Below we summarize their model in brief and layout the key mechanisms from their model to understand this issue.

The OW model has firms that can invest in capital by borrowing or using internal funds and generates default in equilibrium. They embed this heterogeneous firm setup into a standard New Keynesian sticky-price framework to study the effects of monetary policy. To understand the relevant mechanism of monetary transmission, we reproduce a key first-order condition from their model. For a given level of productivity (z), the first order condition for the optimal choice of a firm's investment (k') and borrowing (b') is given by[23]

$$\left(q_t - \varepsilon_{R,k'}\left(z,k',b'\right)\frac{b'}{k'}\right)\frac{R_t^{\text{sp}}\left(z,k',b'\right)}{1-\varepsilon_{R,b'}\left(z,k',b'\right)} = \frac{1}{R_t}\mathbb{E}_t\left[\text{MRPK}_{t+1}\left(z',k'\right)\right]$$

The left hand side represents the marginal cost of capital and is a product of two terms. The first one is the price of capital net of the elasticity of the lender's rate schedule with respect to investment ($\varepsilon_{R,k'}\left(z,k',b'\right)$). An extra unit of investment costs q_t but it adds to the firm's collateral and thus lowers the interest rate charged by lenders. The second term is how borrowing costs change with investment. $R_t^{sp}\left(z,k',b'\right)$ is the firm-specific rate $R_t(z,k',b')$ (relative to the risk-free rate R_t). This is scaled by one minus the elasticity of the debt price schedule ($1-\varepsilon_{R,b'}\left(z,k',b'\right)$) with respect to borrowing, which captures the idea that an increase in borrowing makes the firm riskier and thus makes lenders charge a higher premium. Graphically (as can be seen in Figure 2), the marginal cost schedule (as a function of capital accumulation) is flat for low levels of capital as the firm has enough cash on hand to not be perceived as risky. After a certain cutoff point, the marginal cost curve slopes upward as the higher level of borrowing required to fund the capital increases the riskiness of firms. The right hand side represents the marginal revenue product of capital discounted by the risk-free rate. Graphically, the marginal benefit schedule is represented by a standard downward sloping curve due to diminishing returns to capital.

What is the effect of an expansionary monetary policy shock in this framework? By lowering the risk-free rate, an expansionary shock lowers the discount rate and thus shifts the marginal benefit curve up and to the right.[24] An expansionary shock has three effects on the marginal cost curve. First, it shifts up the curve because an increase in the demand for investment leads to an increase in the price of capital. Next, this shock extends the flat part of the marginal cost curve because it increases the firm's cash on hand and decreases the amount the firm needs to borrow to finance a given amount of investment. Finally, it flattens the upward sloping part of the curve because the firm's collateral is worth more and thus reduces the loss to the lender in case of default. These can be seen in Figure 2.

[23]We have omitted two terms that capture the marginal benefit of investment from this first order condition. The first one is $\frac{1}{R_t}\frac{\text{Cov}_t\left(\text{MRPK}_{t+1}\left(z',k'\right),1+\lambda_{t+1}\left(z',k',b'\right)\right)}{\mathbb{E}_t\left[1+\lambda_{t+1}\left(z',k',b'\right)\right]}$ which is the covariance between the return to capital and the firm's shadow value of resources. The second one is given by $\frac{1}{R_t}v_t^0\left(\underline{z}_{t+1}\left(k',b'\right)\right)g\left(\underline{z}\left(k',b'\right)\right)\left(\frac{\partial z_{t+1}\left(k',b'\right)}{\partial k'}-\frac{\partial z_{t+1}\left(k',b'\right)}{\partial b'}\right)$ and captures how more investment affects a firm's default probability. OW find that these two terms do not play a major role and we have thus omitted them for convenience.

[24]There are also general equilibrium effects due to changes in the price of output, capital and wages which in the OW calibration further shift out the marginal benefit curve.

How do firms with high and low leverage react differently to monetary policy shocks? In this framework there are competing channels which make it theoretically ambiguous whether a high or low leverage firm will respond more. For a high-leverage firm, the upward sloping part of the marginal cost curve is steeper and thus this will make it less responsive to monetary policy induced shifts of the marginal benefit curve. On the other hand, a high leverage firm's marginal cost curve will flatten more in response to an expansionary monetary shock, making it more responsive. In the OW calibration they find that the former effect dominates and thus a high leverage firm is less responsive to monetary policy shocks. This case is highlighted in the top row of Figure 2. So how can we explain our results of higher sensitivity for high leverage firms in the post-crisis sample using this framework?

Theoretically, there are three possible ways in which this can happen. In the post-crisis sample we would need that i)the marginal benefit curve shifts more for high leverage firms in response to a monetary shock or ii)the slope of the marginal cost curve is more flat (on average, not in response to monetary shocks) for high leverage firms (relative to low leverage firms) or iii) the slope of the marginal cost curve flattens more in response to a monetary shock for high leverage firms and that this increased flattening is enough to outweigh the relative steepness of high leverage firms.

We argue that the first two explanations are less plausible and provide evidence that the third explanation is likely at play. Regarding the first explanation, the shift of the marginal benefit curve is driven by changes in the discount rate. It is unlikely that discount rates for high leverage firms respond differentially in the post-crisis samples.[25] The second explanation would require that in the post-crisis sample high leverage firms are perceived to be less risky than low-leverage firms. In other words, the credit spread charged by lenders (relative to the risk-free rate) to high leverage firms would increase less as these firms take on more borrowing. First, recall that in Figure1 above we have shown that a firm's leverage position is fairly stable across the two samples. Moreover, Figure 1 shows that the correlation of leverage with measures of firm riskiness are stable across the pre- and post-crisis samples. This rules out the unlikely scenario that our results are being driven by the high leverage firms somehow becoming less risky in the post-crisis sample.

This leaves us with the third explanation. This requires that an expansionary monetary policy shock would flatten the marginal cost curve of high leverage firms more (relative to low leverage firms). Additionally this increased flattening would have to be large enough to overcome the relative steepness of the marginal cost curve for high leverage firms. From the first-order condition above, the marginal cost curve flattening more would imply that the

[25]There are also general equilibrium effects that work through the price of output goods, capital and wages but these are also unlikely to respond differentially for high leverage firms in the post-crisis sample.

credit spread charged by the lender (relative to the risk-free rate) to a high leverage firm falls more (relative to a low leverage firm) in response to an expansionary monetary shock. We can see this readily from the bottom row of Figure 2. This figure shows in the post-crisis sample that even though the slope of a high leverage firm is unconditionally steeper than a low leverage firm, it flattens more in response to an expansionary monetary shock to make the desired change in investment higher for high leverage firms.

This explanation provides a simple testable implication: the credit spread (relative to the risk-free rate) of high leverage firms should fall more in response to an expansionary monetary shock in the post-crisis sample. While we do not have access to high-frequency firm-level bond yields, we use bond indices that group together firms with similar risk profiles. Specifically, we use the Moody's bond yields index on firms rated AAA and those rated BAA.[26] Recall that Figure 1 showed that there is a negative and significant correlation between leverage and credit rating in both the pre- and post-crisis samples. Our hypothesis then is that the spread between the BAA yield and risk free rate falls more in the post-crisis sample relative to the spread between the AAA yield and the risk-free rate. Or alternatively, the BAA-AAA yield spread should fall more in the post-crisis sample. We test the hypothesis using the following regression

$$\Delta ln(y_t) = \alpha_0 + \alpha_1 D_t^{post} + \delta \varepsilon_t^m + \beta D_t^{post} \varepsilon_t^m + e_{it} \tag{5}$$

where y_t is the Moody's BAA-AAA bond yield spread, D_t^{post} is a dummy for the post-crisis period and ε_t^m is the monetary policy shock. The results presented in Table 5 show that indeed this is the case. In the pre-crisis sample, this bond spread response to monetary policy is small and not statistically significant. However, in the post-crisis sample the bond spread response is negative and significant at the 10% level. In response to an expansionary monetary policy shock that lowers the two year rate by 1%, the BAA-AAA bond spread falls 20% more in the post-crisis sample. We interpret this as suggestive evidence that monetary policy shocks are flattening the marginal cost curve more for firms with higher leverage in the post-crisis sample, thus driving their increased responsiveness. Overall, this result is consistent with the work of Gilchrist and Zakrajšek (2013) who find using credit default swap data that QE announcements reduced the cost of insuring against default risk more for higher risk firms.

4.2 Transmission through changes in long-term funding conditions

Why is it that monetary policy actions flatten the marginal cost more and thus compress the yield spread between high leverage and low leverage firms more in the post-crisis sample? The

[26]Over 70% of the firms in our sample are rated BAA or higher.

explanation that we pursue in this subsection relies on the fact that long rates have become more sensitive to monetary policy in the post-crisis sample and thus monetary shocks can potentially affect financing conditions more for firms that rely on long-term funding.

It is well established in the literature that monetary policy has substantial effects on long-term rates. Gürkaynak et al. (2005) showed this for nominal rates and more recently Hanson and Stein (2015) showed this even for real rates. We first document that both nominal and real long-term rates (and term premium estimates commonly used in the literature) have become more sensitive to monetary policy shocks in the post-crisis sample.

In Table 6 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 monetary policy shock. 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 table shows our baseline measure (MP shock) in Panel A and the 2 year shock in Panel B. An expansionary 2 year shock lowers all three: nominal yield, real yield and the term premium of the 10 year bond. Importantly, the fall in these three variables is substantially larger in the post-crisis sample.[27] The difference between the pre- and post-crisis coefficients is also statistically significant for the real yield and term premium response. In response to a 100 basis point reduction in the 2 year rate, the real yield (term premium) falls by 33 (21) basis points in the pre-crisis sample but by 101 (63) basis points in the post-crisis sample. Thus the real yield and the term premium on the 10 year Treasury bond are three times as sensitive to monetary policy shocks in the post-crisis sample relative to the pre-crisis sample. Recall that our baseline measure combines the fed funds rate target shocks with the 10 year shocks; thus, it is not straightforward to interpret the regressions reported in Panel A. But, we include them for completeness and moreover these results confirm the findings from the 2 year rate regressions.

These results suggest that monetary policy may be having an outsize effect on long-term funding conditions in the post-crisis sample. This could translate into a bigger effect on firms that are more reliant on long-term funding, for example through the "gap-filling" framework outlined in Greenwood et al. (2010). Foley-Fisher et al. (2016) find some supporting evidence of this channel by studying the Federal Reserve's Maturity Extension Program (MEP) in 2011 and 2012. They find that MEP had disproportionate effects on firms that had more long-term debt. The relevant question for us is whether firms whose leverage is driven more by long-term debt are driving our results regarding the changing relationship since the crisis. To test this mechanism we focus on a long-term component of our overall leverage measure. Our baseline leverage measure (debt-to-capital) is defined as leverage $= \frac{\text{debt}}{\text{debt + equity}}$. We now define LT

[27] These results are consistent with the pattern documented in Hanson et al. (2017).

leverage $= \frac{\text{LT debt}}{\text{debt + equity}}$ where LT debt is defined as all debt maturing in more than one year. We separate firms as having high LT leverage (top two-thirds of the LT leverage distribution) and low LT leverage (bottom third of the LT leverage distribution). Then we run our baseline regressions separately for these two groups in the pre- and post-crisis samples.

The results are presented in Table 7. The first two columns (1a and 1b) show the baseline regressions for the firms classified as "High LT leverage" and the next two columns (2a and 2b) show them for the "Low LT Leverage" firms. For the high LT leverage firms, we get the same flip in the sign of the interaction coefficient as the baseline results, with a negative and significant coefficient in the pre-crisis sample but a positive and significant coefficient in the post-crisis sample. For the low LT leverage firms, the coefficient is negative and significant in the pre-crisis sample but insignificant and essentially zero in the post-crisis sample. Thus, in the post-crisis sample, our baseline results of high leverage firms being more responsive to monetary policy shocks is driven by firms whose leverage is more dependent on long-term debt. This is consistent with the interpretation that in the post-crisis sample monetary policy affects firms that are more exposed to funding using long-term instruments. Moreover, these results are consistent with the work of Foley-Fisher et al. (2016) who studied the MEP program. We have run our results dropping the two MEP related FOMC meetings in 2011 and 2012 and find that they are essentially identical to those reported in Table 7. 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.

4.3 Transmission through monetary policy uncertainty changes

In the previous subsection we provided some evidence that firms with leverage more dependent on long-term debt were more responsive to monetary policy shocks in the post-crisis sample. Here we explore another channel through which monetary policy actions since the crisis could have had heterogenous effects, namely the uncertainty channel.

There is a growing literature that highlights the role of changes in policy uncertainty as a channel of monetary transmission.[28] Moreover, Bauer et al. (2019) and Kroencke et al. (2018) highlight the growing importance of this uncertainty channel in the post-crisis sample. To investigate the role of this channel we use the high-frequency market-based measure of monetary policy uncertainty developed by Bauer et al. (2019). They use options on Eurodollar futures to get a model-free estimate of the standard deviation of the expected interest rate

[28] See the recent work of Creal and Wu (2017), Husted et al. (2017), Bauer et al. (2019), Kroencke et al. (2018) and Bundick et al. (2017)

at horizons of 0.5 year, 1 year, 1.5 years and 2 years. We construct a single series by taking the first principal component of these four measures.[29] We will use the (daily) change in this principal component measure on FOMC days as the monetary policy uncertainty shock (labeled "MPU shock").

First, we explore the effect of this monetary policy uncertainty measure on firm-level stock returns and whether high leverage firms respond differentially. We estimate the following regression

$$s_{i,t} = \alpha_i + \alpha_t + \beta l_{i,t-1}\epsilon_t^{mpu} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t} \quad (6)$$

where we have replaced the monetary policy shock from our baseline specification in Equation 2 with the MPU shock (ϵ_t^{mpu}). Because of the limited availability of the uncertainty measure, our sample starts in January 1994. The MPU shock is scaled so that a positive number reflects a lowering of uncertainty ("an expansionary shock"). Table 8 shows the regression results for the pre- and post-crisis sample. In the pre-crisis sample the interaction coefficient of leverage and MPU shock is negative but small in magnitude and statistically insignificant: in the pre-crisis sample, leverage did not play a role in firms' stock price response to uncertainty shocks. However, this coefficient is positive and statistically significant in the post-crisis sample: in the post-crisis sample firms with higher leverage are more responsive to monetary policy uncertainty shocks.[30]

We also find some additional evidence for the heterogenous effects of the monetary policy uncertainty shocks using firm-level implied volatility constructed from options data. We find that the change in the expected volatility of firm-level stock returns responds significantly to monetary uncertainty shocks. Moreover, this transmission is stronger for high leverage firms in the post-crisis sample. Specifically, we estimate the following regression

$$\Delta ivol_{i,t} = \alpha_i + \alpha_t + \beta_1 l_{i,t-1}\epsilon_t^{mpu} + \beta_2 D_t^{post} l_{i,t-1}\epsilon_t^{mpu} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t} \quad (7)$$

where $\Delta ivol_{i,t}$ is the (daily) change in firm-level implied volatility on FOMC days, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, $l_{i,t-1}$ is leverage, ϵ_t^{mpu} is the monetary policy uncertainty shock, D_t^{post} is a dummy for the post-crisis period and $Z_{i,t-1}$ is a vector of firm-level controls containing the firm's share price change, real sales growth, size, price-to-cost margin, receivables-minus-payables to sales, depreciation to assets, age, log(market cap), current assets

[29] The estimates for the 1.5 year and 2 year horizons are not available for the entirety of our sample. Thus, we perform separate principal component analyses on three subsamples, partitioned by the number of measures available.

[30] One issue with this uncertainty measure is that it is only available at a daily frequency. Since our monetary policy shock is constructed at a higher frequency, it is not straightforward to compare the relative contribution of our baseline monetary policy shocks versus the monetary policy uncertainty shocks.

to total assets and an indicator for current fiscal quarter. Table 9 shows that β_1 is positive and significant. Since the baseline effect of a reduction in uncertainty is to reduce expected volatility, a positive β_1 implies that expected volatility fell less on FOMC days in response to reduced uncertainty for firms with high leverage in the pre-crisis sample. In other words, in the pre-crisis sample an FOMC announcement that lowered uncertainty would translate into a smaller reduction in expected future volatility for a firm with high leverage. But the estimate of β_2 is negative and significant. This suggests that this relationship changes after the crisis. In the post-crisis sample, the response of a firm with high leverage to uncertainty shocks is more negative, i.e. high leverage firms are more responsive to reductions in uncertainty.

5 Robustness Checks

We start by documenting the robustness of our three different empirical approaches to using an alternative definition of leverage: debt-to-assets. Debt-to-assets is widely used in the literature to measure firm leverage, e.g. Whited and Wu (2006) find that Compustat firms with a higher debt-to-assets ratio are more financially constrained. Table A.5 shows that these results using debt-to-assets confirm the baseline results. Our baseline results use the four-quarter moving average of debt-to-capital[31]; however, one could be concerned that this smooths out meaningful, higher-frequency variations in leverage. In Table A.6, we show that our results are robust to using the one-quarter lagged version of our leverage measure.

Next, we tackle the concern that our results may be driven by different sectors being more or less responsive to monetary policy shocks. To account for this we include a sector by FOMC day fixed effect, rather than just an FOMC day fixed effect. In Table A.7, we show that the significance and magnitude of our baseline results are not meaningfully affected.

As a further robustness check, we expand our sample beyond S&P 500 firms. One main difference between the S&P 500 sample and a full CRSP/Compustat sample is that firms in the expanded sample enter and exit much more frequently, as well as have more missing data values. To limit the effects of changes in sample composition amongst the full CRSP/Compustat sample, we keep only those firms that are present in our entire sample period. These results are displayed in Table A.8. We see that our baseline results are robust to broadening our sample to include more than just S&P 500 firms.[32]

[31] To be consistent with Ottonello and Winberry (2018), our baseline investment table uses the one-quarter lagged debt-to-capital ratio. We show in the online appendix, as well as Table A.7, that our investment results become stronger in terms of magnitude and significance when using the four-quarter moving average of the debt-to-capital ratio.

[32] Due to the limited availability of expected volatility data for firms outside the S&P 500, we include only our stock market and investment results.

The online appendix contains several more robustness checks. First, we present the results when we include the crisis dates in the post-crisis sample. The coefficients show that including the financial crisis dates does not materially change the results. Second, we show that our stock market results are not driven by a change in the composition of the sample between the pre-crisis and post-crisis periods. In the online appendix we rerun our baseline stock market specification, limiting the sample to only those firms with non-missing data for all 221 FOMC days in our sample. Despite losing approximately 75% of our sample to this restriction, the results qualitatively match our baseline results: 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.

FOMC meetings that are unscheduled can have effects on financial markets that are different from regularly scheduled meetings as the 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, see for example Lakdawala and Schaffer (2019). Thus we want to make sure that our results are not driven by these unscheduled meetings. This issue only arises in the pre-crisis sample which has 16 unscheduled meetings, while our post-crisis sample has none. The online appendix shows the regression results excluding the unscheduled meetings. These results are quite similar to the baseline case. 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 use forecast data (following the approach in Lakdawala (forthcoming)) to cleanse the monetary policy shock of any information effects. These results, also shown in the online appendix, confirm that our baseline results are not driven by this issue. Finally, we show in the online appendix that including financial firms in our sample does not affect our results.

6 Conclusion

In this paper we add to the growing empirical literature on monetary policy and firm-level heterogeneity. Using both high frequency data from the stock market and lower frequency investment data we show that the role of leverage in transmitting monetary policy shocks has changed since the financial crisis. Before the financial crisis a firm with higher than average leverage was less responsive to monetary policy shocks. However, after the financial crisis this relationship has reversed so that firms with higher leverage are now more responsive to monetary policy shocks. We interpret our pre-crisis results through a structural model and provide suggestive evidence for a mechanism that can rationalize our post-crisis results. Since the crisis, long rates have become more sensitive to monetary policy shocks suggesting increased sensitivity of long-term funding conditions to monetary policy. Consistent with this story, we show that our baseline results of increased responsiveness since the crisis are driven by firms whose leverage is more dependent on long-term debt. Finally, we also provide some suggestive evidence that monetary transmission related to leverage works in part through an uncertainty channel, where FOMC announcements change the market's perceived uncertainty about future policy actions.

Our results have potentially important implications for the aggregate effects of monetary policy. Focusing on the pre-crisis sample, Ottonello and Winberry (2018) find that monetary policy is less effective in the aggregate when there is a bigger share of riskier firms in the economy. Our estimates from the post-crisis sample indicate that this relationship has reversed in the last decade. This suggests two important avenues for future research. First developing general equilibrium models with firm heterogeneity that also allow a role for unconventional monetary policy will help us understand the aggregate transmission of monetary policy since the crisis. Second, we think that further exploring empirical strategies to tease out the state-dependent effects of monetary policy based on firm balance sheets is a promising area for future research.

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Table 1: Summary Statistics

	Pre-Crisis		Post-Crisis	
	mean	std. dev.	mean	std. dev.
Stock return	0.240	3.001	0.162	1.935
Leverage (Debt-to-Capital)	0.381	0.216	0.414	0.231
Leverage (Debt-to-Assets)	0.251	0.149	0.276	0.162
Leverage (Debt-to-Equity)	0.985	3.846	1.208	3.538
Implied volatility	34.799	14.378	27.846	9.453
MP shock	-0.007	0.035	-0.002	0.023
FFR shock	-0.020	0.094	-0.003	0.012
10 year shock	0.001	0.040	-0.002	0.035
2 year shock	-0.007	0.065	-0.006	0.035

The table shows summary statistics for stock returns, leverage measures, monetary policy shocks and implied volatility. 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. Sample is non-financial firms in S&P 500 on date of FOMC announcement. Pre-crisis is Jul-1991 to Jun-2008 and post-crisis is Aug-2009 to Dec-2017.

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

Panel A:	(1a) Pre-Crisis	(1b) Post-Crisis	(2a) Pre-Crisis	(2b) Post-Crisis	(3a) Pre-Crisis	(3b) Post-Crisis
Leverage (Debt-to-Capital)	0.006	0.009	0.006	0.011	-0.026	0.006
	(0.039)	(0.026)	(0.039)	(0.027)	(0.038)	(0.025)
MP shock x Leverage	-5.466*	2.223***				
	(3.186)	(0.573)				
FFR shock x Leverage			-2.050*	-0.368		
			(1.187)	(1.382)		
10 yr shock x Leverage			0.265	1.470***		
			(1.203)	(0.368)		
2 yr shock x Leverage					-1.205	0.915**
					(0.848)	(0.366)
Observations	48,143	24,584	48,143	24,584	48,143	24,584
R^2	0.181	0.341	0.181	0.341	0.177	0.341
Firm controls	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes

Panel B:	Full Sample	Full Sample
D_t^{post} x MP shock x Leverage (Debt-to-Capital)	7.706**	
	(3.269)	
D_t^{post} x 2 yr shock x Leverage (Debt-to-Capital)		2.107**
		(0.929)
Observations	72,733	72,733
R^2	0.206	0.203
Firm controls	yes	yes
Firm FE	yes	yes
Time FE	yes	yes

Panel A shows results from estimating $s_{i,t} = \alpha_i + \alpha_t + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Panel B shows results for $s_{i,t} = \alpha_i + \alpha_t + \beta_1 l_{i,t-1}\epsilon_t^m + \beta_2 l_{i,t-1}\epsilon_t^m D_t^{post} + \delta_1 l_{i,t-1} + \delta_2 l_{i,t-1} D_t^{post} + \Gamma' Z_{i,t-1} + e_{i,t}$ where D_t^{post} is an indicator for the post-crisis period. Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered 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)	(2)
Leverage	-1.02**	-0.75*
	(0.442)	(0.414)
Post-Crisis x Leverage	2.30***	1.81***
	(0.403)	(0.370)
Observations	47,131	42,635
R^2	0.759	0.786
Firm FE	yes	yes
Time FE	yes	yes
Firm controls	no	yes

Null Hypothesis	p-value	
leverage + post x leverage = 0	0.001	0.003

Results from estimating $ivol_{i,t-1} = \alpha_i + \alpha_t + \delta l_{i,t} + \beta l_{i,t-1} D_t^{post} + \Gamma Z_{i,t-1} + e_{i,t}$, where $ivol_{i,t-1}$ is firm-level implied volatility on the day before the FOMC announcement, α_i is a firm fixed-effect, α_t is an FOMC day 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 firm-level stock price at close of prior trading day. Pre-crisis is Jan-1996 to Jun-2008 (108 obs.) and post-crisis is Aug-2009 to Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4: Contemporaneous response of firm-level investment to monetary shocks

	Investment
MP shock_t x Leverage_{t-1}	-3.71**
	(1.596)
D_t^{post} x MP shock_t x Leverage_{t-1}	7.86***
	(2.885)
Observations	19,755
R^2	0.146
Firm controls	yes
Firm FE	yes
Time FE	yes

Results from estimating
$\Delta ln(y_{it}) = \alpha_i + \alpha_t + \sum_{n \in N} \beta_{1n} l_{i,t-n-1} \epsilon_{t-n}^m + \beta_{2n} l_{i,t-n-1} \epsilon_{t-n}^m D_{t-n}^{post} + \Gamma' Z_{i,t-1} + e_{it}$, where y_{it} is value of firm i's capital stock in quarter t, α_i is a firm i fixed effect, α_t is a quarter t fixed effect, l_{it} is one-quarter lagged leverage normalized to have mean 0 and variance 1, ϵ_t^m is the sum of all high-frequency monetary policy shocks that occur in quarter t, D_t^{post} is an indicator for the post-crisis period, $N = [0, 12]$ and Z_{it-1} is a vector of firm-level controls. The monetary policy shock is normalized to have a unit effect on the 2 year yield and 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 or post-crisis sample for the dependent variable. Pre-crisis is 1991:Q3 to 2008:Q2 and post-crisis is 2009:Q3 to 2017:Q4. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5: Response of Bond Yield Spread to Monetary Policy Shock

	BAA - AAA spread
MP Shock	1.034
	(4.447)
Post-Crisis x MP Shock	-20.414*
	(12.211)
Observations	221
R^2	0.021

Results from estimating $\Delta ln(y_t) = \alpha_0 + \alpha_1 D_t^{post} + \delta \epsilon_t^m + \beta D_t^{post} \epsilon_t^m + e_{it}$, where y_{it} is BAA-AAA bond yield spread, D_t^{post} is a dummy for the post-crisis period and ϵ_t^m is the monetary policy shock. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6: 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
MP Shock	-0.19	-1.77***	-0.40**	-1.89***	0.12	-1.45***
	(0.228)	(0.319)	(0.157)	(0.415)	(0.168)	(0.323)
Observations	153	68	83	68	153	68
R^2	0.012	0.311	0.104	0.352	0.010	0.309
Null Hypothesis	p-value		p-value		p-value	
D_t^{post} x MP shock = 0	0.000		0.001		0.000	

Panel B:	10 year nominal		10 year real		10 year term premium	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
2 yr shock	-0.42***	-0.71***	-0.33***	-1.01***	-0.21***	-0.63***
	(0.077)	(0.244)	(0.066)	(0.216)	(0.051)	(0.203)
Observations	153	68	83	68	153	68
R^2	0.205	0.121	0.226	0.248	0.103	0.142
Null Hypothesis	p-value		p-value		p-value	
D_t^{post} x 2 yr shock = 0	0.268		0.003		0.044	

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 ϵ_t^m is the monetary policy shock. The monetary policy shock is normalized so that a positive value represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008 (153 obs.) and post-crisis is Aug-2009 to Dec-2017 (68 obs.). The 10-year real rate is not available prior to 1999. The p-values for each panel are for a full sample estimation of the interaction coefficient $D_t^{post} * \epsilon_t^m$, where D_t^{post} is a dummy for the post-crisis period. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 7: Response of firm-level stock returns (by high/low long-term leverage)

	High LT Leverage		Low LT Leverage	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
	(1a)	(1b)	(2a)	(2b)
MP shock x Leverage	-2.738*	1.826**	-12.611*	0.245
	(1.475)	(0.867)	(6.444)	(1.668)
Observations	32,238	18,817	15,901	5,766
R^2	0.183	0.350	0.231	0.342
Firm controls	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Time FE	yes	yes	yes	yes

Results from estimating $s_{i,t} = \alpha_i + \alpha_t + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t}$ separately for firms classified as "High (Low) LT Leverage" that are in the top two-thirds (bottom third) of the long-term (LT) leverage distribution, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, α_t is a time fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and $Z_{i,t-1}$ is a vector of firm-level controls. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8: Response of firm-level stock returns to monetary policy uncertainty shocks

	Pre-Crisis	Post-Crisis
MPU Shock x Leverage	-0.117	0.852*
	(0.897)	(0.438)
Observations	39,684	24,584
R^2	0.187	0.341
Firm controls	yes	yes
Firm FE	yes	yes
Time FE	yes	yes

Results from estimating $s_{i,t} = \alpha_i + \alpha_t + \beta l_{i,t-1}\epsilon_t^{mpu} + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is the firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, $l_{i,t-1}$ is 4-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^{mpu} is monetary policy uncertainty shock (positive value means a decrease in uncertainty) and $Z_{i,t-1}$ is a vector of firm-level controls. Pre-crisis is Feb-1994 to Jun-2008 (125 obs.) and post-crisis is Aug-2009 to Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

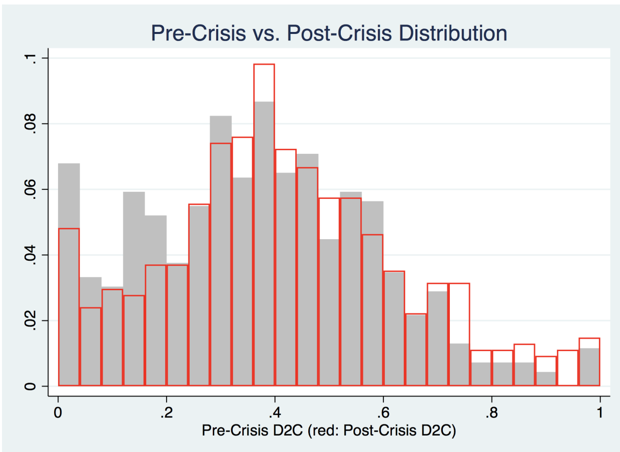
Table 9: Response of Firm-Level Implied Volatility to MPU Shock

	Full Sample
MPU Shock x Leverage	1.01**
	(0.398)
Post-Crisis x MPU Shock x Leverage	-1.15***
	(0.331)
Observations	9,965
R^2	0.367
Firm FE	yes
Time FE	yes
Firm controls	yes

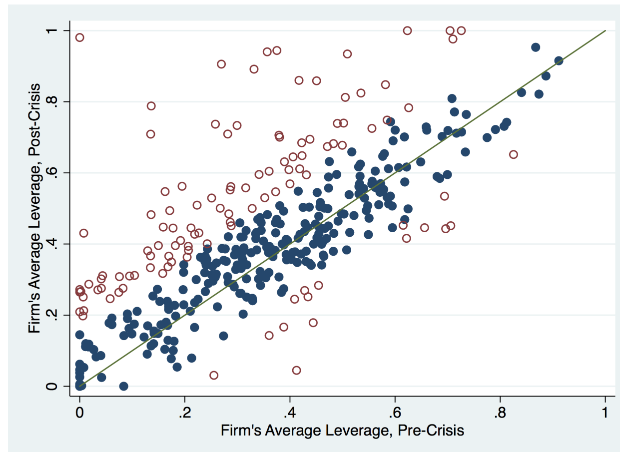
Result from estimating
$\Delta ivol_{i,t} = \alpha_i + \alpha_t + \beta_1 l_{i,t-1}\epsilon_t^{mpu} + \beta_2 D_t^{post} l_{i,t-1}\epsilon_t^{mpu} + \delta l_{it-1} + \Gamma' Z_{i,t-1} + e_{i,t}$, where $ivol_{it}$ is the firm-level implied volatility, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, l_{it-1} is 4-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^{mpu} is monetary policy uncertainty shock (positive value means a decrease in uncertainty)and Z_{it-1} is a vector of firm-level controls. Pre-crisis is Jan-1996 to Jun-2008 (108 obs.) and post-crisis is Aug-2009 to Dec-2017 (68 obs.). Sample is Liquid 100 non-financial firms. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Figure 1

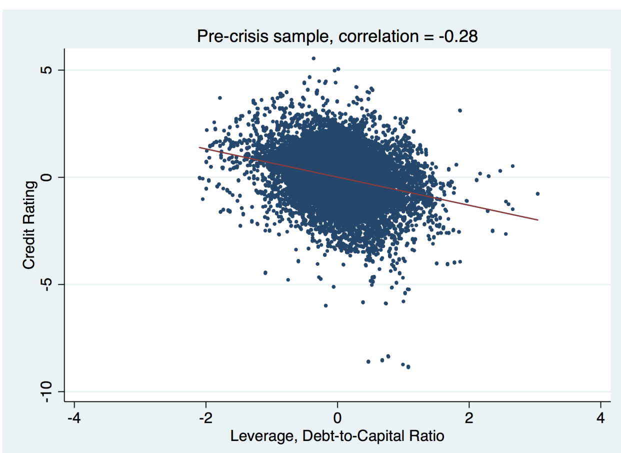
(a) Distribution of Firm Leverage



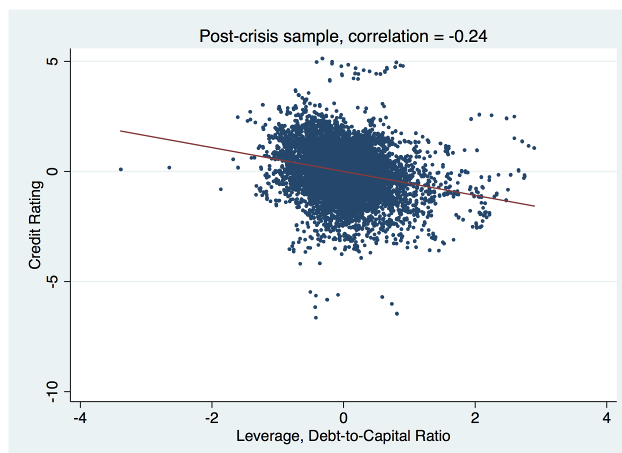
(b) Firm Leverage: Post vs. Pre



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

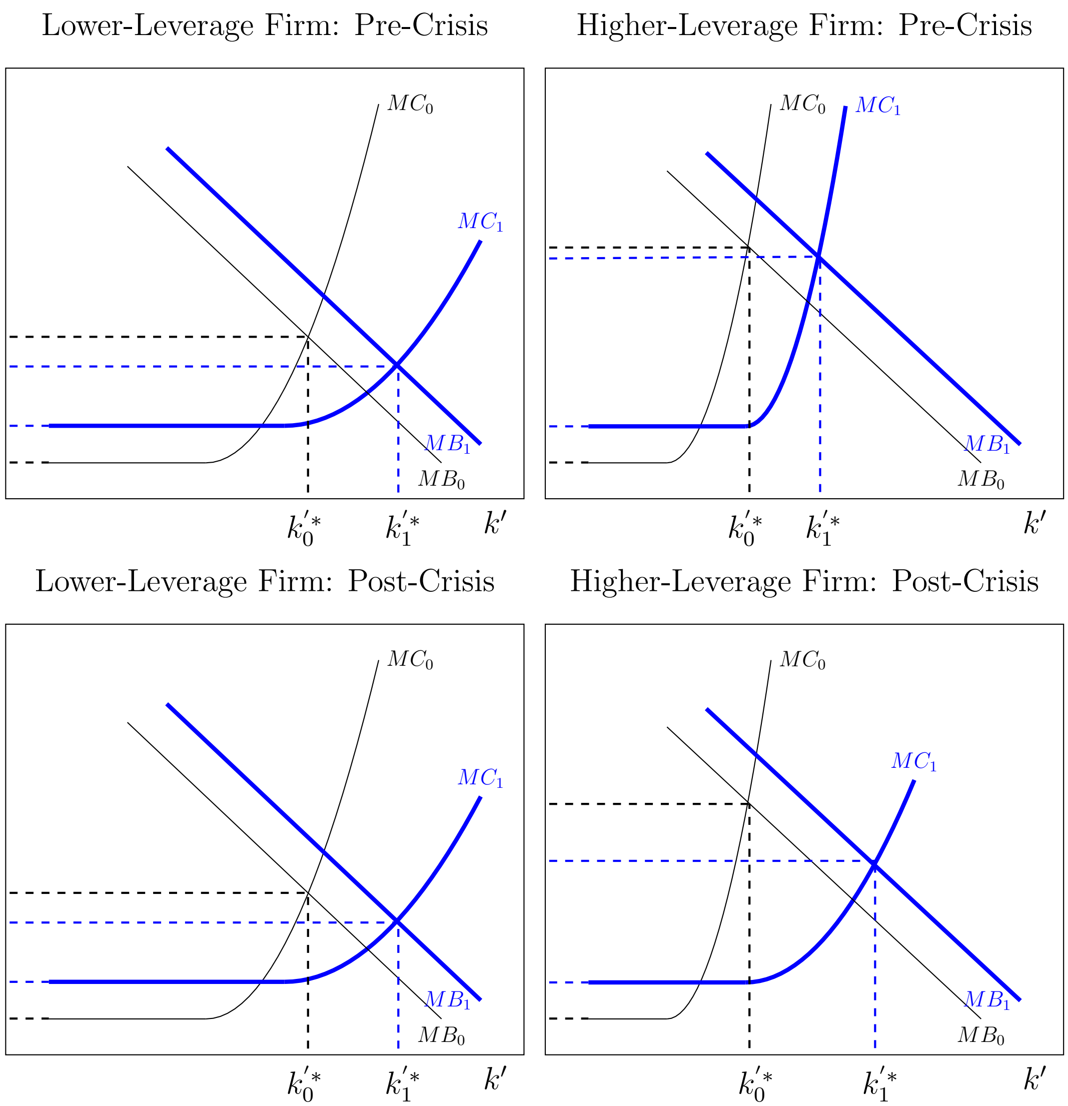


(d) Conditional Correlation of Credit Rating and Leverage: Post-Crisis



Panel (a) plots the histogram of the quarterly firm leverage (measured as debt-to-capital), 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-capital) averaged across the post-crisis versus the average in the pre-crisis sample. Firms further than one standard deviation from the 45-degree line are shown in red. Panels (c) and (d) plot the residuals from regressing firm's S&P long-term credit rating on our set of control variables against the residuals from regressing firm's 4-qtr 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 Dec-2017 and the sample is non-financial firms in the S&P 500 on date of FOMC announcement.

Figure 2: Effects of an expansionary monetary policy shock



Appendix

Table A.1: Summary Statistics of Firm Characteristics

	Low Leverage		High Leverage	
	mean	std. dev.	mean	std. dev.
Leverage (Debt-to-Capital)	0.211	0.120	0.562	0.146
Firm age	31.52	14.18	37.62	13.03
Book value of assets ($, millions)	15,577	36,128	21,613	47,465
Market capitalization ($, millions)	24,623	51,290	18,898	37,891
Real sales growth (%, YoY)	4.424	21.029	2.010	21.858
Price-to-cost margin	0.439	0.246	0.353	0.221
Receivables-minus-payables to sales	0.268	0.368	0.245	0.677
Depreciation to assets	0.012	0.007	0.011	0.006
Current assets to total assets	0.451	0.185	0.298	0.172

The table shows summary statistics for the firm-level controls. The sample is divided into firms below ("Low Leverage") and firms above ("High Leverage") the sample mean debt-to-capital ratio. All variables are measured quarterly at the firm level. Sample is non-financial firms in the S&P 500 between Jul-1991 and Dec-2017, excluding the financial crisis dates of Jul-2008 to Jul-2009.

Table A.2: Response of firm-level stock returns to monetary shocks w/ control interactions

	(1a) Pre-Crisis	(1b) Post-Crisis
MP shock x Leverage	-3.665**	1.001**
	(1.786)	(0.437)
MP shock x Current to total assets	13.676*	-4.722
	(8.058)	(4.593)
MP shock x Real sales growth	0.004	0.021
	(0.044)	(0.064)
MP shock x Firm size	2.792	0.776
	(1.769)	(1.668)
MP shock x Price-to-cost margin	5.369	2.314
	(6.225)	(4.384)
MP shock x Rec-minus-Pay to sales	0.488	-1.669**
	(1.040)	(0.769)
MP shock x Depreciation-to-Assets	176.975	-62.448
	(177.487)	(122.824)
MP shock x Firm age	-0.236	0.055
	(0.181)	(0.050)
MP shock x Market capitalization	-2.217	-1.204
	(1.636)	(2.068)
MP shock x 1st fiscal quarter	-3.209	2.206
	(4.643)	(1.719)
MP shock x 2nd fiscal quarter	-0.595	-0.291
	(2.199)	(2.362)
MP shock x 3rd fiscal quarter	1.993	-1.774
	(3.344)	(2.794)
Observations	47,872	24,516
R-squared	0.184	0.343
Firm controls	yes	yes
Firm FE	yes	yes
Time FE	yes	yes

Results from estimating $s_{it} = \alpha_i + \alpha_t + \beta l_{it-1}\epsilon_t^m + \delta l_{it-1} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, l_{it-1} is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and Z_{it-1} is a vector of the baseline firm-level controls and firm's sector (and their interactions with the MP shock). The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table A.3: Response of firm-level stock returns to monetary shocks: Without a time fixed effect

	(1)	(2)	(3)
MP shock	6.943*		
	(3.912)		
Post-Crisis x MP shock	-0.829		
	(7.333)		
FFR shock		2.369	
		(1.990)	
10 yr shock		5.936***	
		(2.144)	
Post-Crisis x FFR shock		6.896	
		(10.656)	
Post-Crisis x 10 yr shock		-2.636	
		(4.593)	
2 yr shock			6.639***
			(2.243)
Post-Crisis x 2 yr shock			7.483
			(5.373)
Observations	76,599	76,599	76,599
R^2	0.021	0.027	0.038
Firm controls	yes	yes	yes
Firm FE	yes	yes	yes
Time FE	no	no	no

Results from estimating $s_{it} = \alpha_i + \beta\epsilon_t^m + \delta\epsilon_t^m D_t^{post} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is firm-level daily stock return, α_i is a firm fixed-effect, ϵ_t^m is the monetary policy shock, D_t^{post} is an indicator for the post-crisis period and Z_{it-1} is a vector of firm-level controls. The monetary policy shock is normalized to have a unit effect on the 2 year yield and a positive value represents an expansionary shock. Sample is Jul-1991 to Dec-2017 with post-crisis sample of Aug-2009 to Dec-2017. Sample is non-financial firms in S&P 500 on the date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table A.4: Response of firm-level stock returns to monetary shocks (Pre. vs. Post 1SD leverage outliers removed)

	(1a) Pre-Crisis	(1b) Post-Crisis	(2a) Pre-Crisis	(2b) Post-Crisis	(3a) Pre-Crisis	(3b) Post-Crisis
Leverage (Debt-to-Capital)	0.015	0.001	0.015	0.001	-0.022	-0.013
	(0.047)	(0.051)	(0.048)	(0.052)	(0.051)	(0.052)
MP shock x Leverage	-5.709*	4.428***				
	(3.365)	(1.010)				
FFR shock x Leverage			-2.170*	0.462		
			(1.232)	(1.078)		
10 yr shock x Leverage			-0.683	2.855***		
			(1.241)	(0.658)		
2 yr shock x Leverage					-1.625	2.254***
					(0.999)	(0.599)
Observations	22,731	13,699	22,731	13,699	22,731	13,699
R-squared	0.205	0.382	0.205	0.382	0.202	0.381
Firm controls	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes

Results from estimating $s_{it} = \alpha_i + \alpha_t + \beta l_{it-1}\epsilon_t^m + \delta l_{it-1} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, l_{it-1} is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and Z_{it-1} is a vector of firm-level controls. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. We exclude 111 firms with a change in leverage from pre-crisis to post-crisis greater than 1 standard deviation and 485 firms without an observation in either the pre- or post-crisis sample. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table A.5: Robustness of baseline results to alternative measure of leverage: Debt-to-Assets

	(1a)	(1b)	(2)	(3)
	Firm Share Price		Expected Volatility	Investment
	Pre-Crisis	Post-Crisis	Pre & Post	Pre & Post
Leverage (Debt-to-Assets)	0.004	-0.009	-0.94**	-5.59*
	(0.034)	(0.026)	(0.412)	(3.014)
MP shock x Leverage	-4.732*	2.159***		-12.94***
	(2.850)	(0.542)		(4.315)
D_t^{post} x Leverage			1.87***	1.97
			(0.365)	(4.710)
D_t^{post} x MP shock x Leverage				25.26***
				(6.701)
Observations	48,169	24,594	42,655	19,441
R^2	0.180	0.341	0.786	0.147
Firm controls	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Time FE	yes	yes	yes	yes

Columns (1a) and (1b) are the results from estimating $s_{it} = \alpha_i + \alpha_t + \beta l_{it-1}\epsilon_t^m + \delta l_{it-1} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, l_{it-1} is four-quarter moving average debt-to-assets normalized to have mean 0 and variance 1 , ϵ_t^m is the monetary policy shock and Z_{it-1} is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_t + \delta l_{i,t} + \beta l_{i,t-1} D_t^{post} + \Gamma Z_{i,t-1} + e_{i,t}$. Column (3) is the result from estimating $\Delta ln(y_{it}) = \alpha_i + \alpha_t + \sum_{n\in N} \beta_{1n} l_{i,t-n-1}\epsilon_{t-n}^m + \beta_{2n} l_{i,t-n-1}\epsilon_{t-n}^m D_{t-n}^{post} + \Gamma' Z_{i,t-1} + e_{it}$, where y_{it} is the value of firm i's capital stock in quarter t. The monetary policy shock is normalized to have a unit effect on the 2 year yield and a positive value represents an expansionary shock. The pre-crisis sample is Jul-1991 to Jun-2008 (153 obs.) and post-crisis is Aug-2009 to Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table A.6: Robustness of baseline results to alternative measure of leverage: 1-quarter lagged debt-to-capital

	(1a)	(1b)	(2)	(3)
	Firm Share Price		Expected Volatility	Investment
	Pre-Crisis	Post-Crisis	Pre & Post	Pre & Post
Leverage (Debt-to-Capital)	0.014	0.012	-0.58	0.88*
	(0.040)	(0.029)	(0.385)	(0.483)
MP shock x Leverage	-4.990	2.127***		-3.78**
	(3.058)	(0.599)		(1.601)
D_t^{post} x Leverage			1.75***	-1.02
			(0.362)	(0.656)
D_t^{post} x MP shock x Leverage				7.12**
				(2.804)
Observations	48,895	24,928	43,255	18,488
R^2	0.181	0.341	0.786	0.160
Firm controls	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Time FE	yes	yes	yes	yes

Columns (1a) and (1b) are the results from estimating $s_{it} = \alpha_i + \alpha_t + \beta l_{it-1}\epsilon_t^m + \delta l_{it-1} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is the firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, l_{it-1} is one-quarter lagged leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and Z_{it-1} is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_t + \delta l_{i,t} + \beta l_{i,t-1} D_t^{post} + \Gamma Z_{i,t-1} + e_{i,t}$. Column (3) is the result from estimating $\Delta ln(y_{it}) = \alpha_i + \alpha_j t + \sum_{n \in N} \beta_{1n} l_{i,t-n-1}\epsilon_{t-n}^m + \beta_{2n} l_{i,t-n-1}\epsilon_{t-n}^m D_{t-n}^{post} + \Gamma' Z_{i,t-1} + e_{it}$, where y_{it} is the value of firm i's capital stock in quarter t. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table A.7: Robustness of baseline results to time-sector FE

	(1a)	(1b)	(2)	(3)
	Firm Share Price		Expected Volatility	Investment
	Pre-Crisis	Post-Crisis	Pre & Post	Pre & Post
Leverage (Debt-to-Capital)	0.001	0.007	-0.58	-2.08*
	(0.037)	(0.027)	(0.408)	(1.114)
MP shock x Leverage	-4.628*	1.461***		-3.94**
	(2.762)	(0.549)		(1.718)
D_t^{post} x Leverage			1.90***	2.97
			(0.368)	(2.616)
D_t^{post} x MP shock x Leverage				7.02**
				(3.212)
Observations	47,737	24,450	42,468	19,323
R^2	0.225	0.401	0.810	0.181
Firm controls	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Time-Sector FE	yes	yes	yes	yes

Columns (1a) and (1b) are the results from estimating $s_{it} = \alpha_i + \alpha_{jt} + \beta l_{it-1}\epsilon_t^m + \delta l_{it-1} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is firm-level daily stock return, α_i is a firm fixed-effect, α_{jt} is a sector j by FOMC day fixed-effect, l_{it-1} is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and Z_{it-1} is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{jt} + \delta l_{i,t} + \beta l_{i,t-1} D_t^{post} + \Gamma Z_{i,t-1} + e_{i,t}$. Column (3) is the result from estimating $\Delta ln(y_{it}) = \alpha_i + \alpha_{jt} + \sum_{n\in N} \beta_{1n} l_{i,t-n-1}\epsilon_{t-n}^m + \beta_{2n} l_{i,t-n-1}\epsilon_{t-n}^m D_{t-n}^{post} + \Gamma' Z_{i,t-1} + e_{it}$, where y_{it} is the value of firm i's capital stock in quarter t. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Sample is non-financial firms in S&P 500 on date of FOMC announcement. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table A.8: Robustness of baseline results to full CRSP/Compustat sample: No firm entry/exit

	(1a)	(1b)	(2)
	Firm Share Price		Investment
	Pre-Crisis	Post-Crisis	Pre & Post
Leverage (Debt-to-Capital)	-0.004	0.046	-1.06***
	(0.038)	(0.054)	(0.258)
MP shock x Leverage	-2.336**	1.905**	-1.66
	(1.071)	(0.825)	(1.034)
D_t^{post} x Leverage			-0.25
			(0.390)
D_t^{post} x MP shock x Leverage			3.23*
			(1.747)
Observations	75,545	38,324	78,665
R^2	0.081	0.232	0.087
Firm controls	yes	yes	yes
Firm FE	yes	yes	yes
Time FE	yes	yes	yes

Columns (1a) and (1b) are the results from estimating $s_{it} = \alpha_i + \alpha_t + \beta l_{it-1}\epsilon_t^m + \delta l_{it-1} + \Gamma' Z_{it-1} + e_{it}$, where s_{it} is firm-level daily stock return, α_i is a firm fixed-effect, α_t is an FOMC day fixed-effect, l_{it-1} is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the monetary policy shock and Z_{it-1} is a vector of firm-level controls. Column (2) is the result from estimating $\Delta ln(y_{it}) = \alpha_i + \alpha_j t + \sum_{n \in N} \beta_{1n} l_{i,t-n-1}\epsilon_{t-n}^m + \beta_{2n} l_{i,t-n-1}\epsilon_{t-n}^m D_{t-n}^{post} + \Gamma' Z_{i,t-1} + e_{it}$, where y_{it} is the value of firm i's capital stock in quarter t. The monetary policy shock is normalized to have a unit effect on the 2 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 Dec-2017 (68 obs.). Sample is non-financial firms in the CRSP/Compustat sample for the entire sample period. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$