Debt Heterogeneity and Investment Responses to Monetary Policy [*]

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Abstract

We study how debt heterogeneity determines firm-level investment responses to monetary policy shocks focusing on the role of debt maturity. We first document that debt heterogeneity in both leverage and maturity significantly affects the responses of firm-level investment to monetary policy shocks: firms who hold more debt and/or hold more long-term debt are less responsive to monetary policy shocks. Evidence from credit ratings and borrowing behavior indicates that the higher default risk embedded in long-term debt plays an essential role. We then develop a heterogeneous firm model with investment, long-term and short-term debt, and default risk to quantitatively interpret these facts. In the model, firms with higher leverage and/or more long-term debt are more likely to default on their external debt and consequently face a higher marginal cost of external finance. As a result, these firms are less responsive in terms of investment to expansionary monetary policy shocks. The effect of monetary policy on aggregate investment, therefore, depends on the joint distribution of firms' leverage and maturity.

Keywords: monetary policy; firm heterogeneity; debt maturity; financial frictions;
JEL Classification: E44, E52, G31

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1 Introduction

Firms have different debt positions which drive their investment decisions. This debt heterogeneity exhibits two characteristics. First, firm debt levels are very heterogeneous. Second, conditional on debt level, firms choose heterogeneous maturity profiles. Given this rich debt heterogeneity across firms, a crucial question is: Does *debt heterogeneity* affect the transmission of monetary policy to corporate investment?

We answer this question both empirically and theoretically. We emphasize how these *debt heterogeneities* in leverage and maturity play essential roles in shaping firm investment responses to monetary policy shocks. Our main empirical finding is that firms with higher leverage and/or more long-term debt invest less following an expansionary monetary policy shock. These firms also have lower credit ratings on their long-term bonds and typically take on less long-term debt in response to monetary expansions. To speak to this evidence, we build a model that allows for firms with rich debt structures: firms can issue both short-term and long-term debt to finance investment. In the model, firms with higher leverage or more long-term debt are less responsive in investment to expansionary monetary policy shocks because their marginal cost of external finance is high. Quantitatively, we replicate our empirical regressions with model-simulated data and recover the heterogeneous investment responses as in the data.

Our empirical work combines monetary policy shocks, measured using high-frequency changes in Federal Funds Futures rates, with firm-level variables from Compustat Quarterly. We focus on how the semi-elasticity of investment with respect to monetary policy shocks depends on firms' financial positions in leverage and maturity. Our estimates show that firms holding more debt (high leverage), and firms holding more long-term debt (long maturity) are significantly less responsive to monetary policy shocks. We also show that these firms also have lower credit ratings on their long-term bonds and take on less long-term debt in response to monetary expansions. All these results show that the potentially higher default risk associated with holding more long-term debts lessens firm responses to monetary policy expansions.

We then develop a model with firm default risk to interpret these facts. The model features heterogeneous firms who face idiosyncratic productivity shocks and invest in capital using either internal funds or external borrowing. Firms can issue both short-term debt and long-term debt as external borrowing. Firms may default on their debt, leading to an external finance risk premium. This lack of commitment is priced into long-term contracts and makes long-term debt issuance more costly. Default is inefficient because it involves deadweight losses when resources are transferred from the defaulted firm to creditors. Thus, the fundamental frictions are similar to Cooley and Quadrini (2001), Hennessy and Whited (2005),or Gomes and Schmid (2010).

The innovation of our model is that we allow firms to issue both short-term debt and long-term debt simultaneously. Short-term debt is less risky for the creditor and thus cheaper for the firm, but must be paid fully in the next period. Long-term debt is only required to be paid off proportionally each period which generates lower rollover costs, but is more costly because of higher future default risk. The continuation value of long-term debt implicitly depends on the firm's actions in future periods. Since firms lack commitment and face idiosyncratic shocks, the value of debt repayment for the creditors depends on the future behavior of firms. As a result, firms trade off between rollover costs and default risk by choosing the debt composition.[1]

The mechanism in our model is as follows. An expansionary monetary policy shock works through two channels. First, it increases the stochastic discount factor of firms since firms are owned by households. This increases the marginal benefit of investment, so all firms would prefer to invest more. Second, it lowers the external borrowing costs to finance investment. However, the effect from the second channel depends on firm financial positions. Because of the higher default risk, especially on long-term debt, firms with high leverage and more long-term debt respond less when there is an expansionary monetary policy shock.

We then calibrate our model to match the key features of firms' investment, short-term and long-term debt borrowings, and other characteristics in the U.S. firm-level micro data. We introduce monetary policy as an external series of changes in the real interest rate as in Jeenas (2018).[2] The calibrated model generates empirically consistent firm bond price functions and decision rules for investment and borrowings.

Finally, we estimate our empirical specification on panel data simulated from our model and find that the implied investment responses are within one standard error of their estimates in the data. The quantitative results emphasize the essential role of financial heterogeneity in the transmission of monetary policy shocks to aggregate investment.

Related Literature: This paper contributes to three key strands of literature. First, we contribute to the rapidly expanding literature that studies how the effect of monetary policy varies across heterogeneous firms due to financial frictions. Earlier literature (Gertler and Gilchrist, 1994; Kashyap et al., 1994) shows that smaller (relatively more financially constrained) firms are more responsive to monetary policy shocks than larger firms. Aside from size, more recent literature has started to explore the effects of financial frictions from other sources. For instance, recent studies argue that the firm-level response depends on distance-to-default (Ottonello and

[1] Equilibrium long-term debt prices typically feature a discount relative to short-term debt. The price of debt reflects how much the firm can get when it issues the debt. Thus, a lower price means a higher borrowing cost.

[2] We do not exactly follow the approach of Jeenas (2018) to include a series of changes in the inflation rate. As the inflation is controlled in our empirical analysis, we only focus on the real interest rate to evaluate the effect of monetary policy shocks on firm-level investment.

Winberry (2020)), leverage (Lakdawala and Moreland, 2019; Auer et al., 2019), age (Cloyne et al. (2018)), liquidity (Jeenas (2018)), credit risk (Palazzo and Yamarthy (2020)), bond versus bank lending (Darmouni et al. (2020)), asset pledgeability (Silva (2019)), and creditor rights (Vats (2020)). Our paper explores two new dimensions of financial heterogeneity including debt issuance and debt maturity to study the transmission of monetary policy to firms. We extend the Ottonello-Winberry model to include firm debt maturity profiles and show that maturity heterogeneity is an important source of heterogeneous responses as well.

Second, this paper is related to the dynamic capital structure and investment literature that emphasizes the role of debt maturity. Barclay and Smith Jr (1995) shows that firms with larger information asymmetries, who are presumably more constrained, issue more short-term debt. Almeida et al. (2012) shows that firms whose long-term debt was largely maturing after the crisis cut their investment more than otherwise similar firms. Diamond and He (2014) provides a theoretical explanation that shorter-term debt typically imposes less debt overhang in terms of investment. Crouzet (2016) studies the optimal maturity structure of debt emphasizing the trade-off between short-term refinancing risk and long-term debt overhang. Our model contributes to the literature by incorporating this maturity trade-off into a context with aggregate shocks, especially monetary policy shocks. We show that the debt overhang from holding more long-term debt weakens firm investment responses to monetary expansions.

Finally, this paper is related to the literature studying the role of financial frictions in determining the business cycle dynamics of aggregate investment. Earlier literature (Cooley and Quadrini, 2001; Hennessy and Whited, 2005; Miao, 2005) studies the implications of costly external financing for the cross-sectional and dynamic properties of firm-level and aggregate investment. More recently, Khan et al. (2014) studies the effects of credit shocks in an economy where firms have persistent differences in TFP, capital and debt or financial assets. Gilchrist et al. (2014) and Arellano et al. (2019) study how financial frictions interacting with uncertainty shocks generate substantial output losses. Gomes et al. (2016) develops a heterogeneous agent model with nominal long-term debt, in which inflation risk affects investment and default through a debt overhang channel. The contribution of our paper is to make maturity choice an integral part of the firm's capital structure decision, and thus enrich the realism and heterogeneity of firm financial positions.

Road Map This paper proceeds as follows. Section 2 provides empirical evidence showing that the responses to monetary policy shocks vary across firms, and that the magnitude of the responses depends on firms' financial positions. Section 3 develops a model with firm investment, borrowing, maturity choice and default. Section 4 parameterizes the model, characterizes the mechanism, and reproduces the effects of debt heterogeneity interacting with monetary policy shocks on investment. Finally, Section 5 concludes and discusses further research directions.

2 Empirical Evidence

This section provides empirical evidence on how firms change their investment when facing an expansionary monetary policy shock, and how the magnitude varies across the firms depending on their financial positions. Section 2.1 describes the data. Section 2.2 shows that high-leverage firms, firms holding more long-term debt, and firms with lower credit ratings on their long-term debt, invest less in response to an expansionary monetary policy shock. Section 2.3 provides further complementary evidence on heterogeneous borrowing behaviors across the firms.

2.1 Data Description

Firm-Level Panel Data: We obtain firm-level data from Compustat Quarterly, which contains quarterly balance-sheet information on publicly listed U.S. firms. The quarterly database has several advantages: quarterly frequency, which is the highest frequency we could obtain at the firm level; a sufficiently long data history, covering the whole period for which we have a monetary policy shock measure; and rich and detailed financial information, giving us the opportunity to extensively control for firm characteristics.[3]

The key variables are investment, leverage, and debt maturity, which are constructed following standard methods. Investment i_{jt} is defined as the ratio of quarterly capital expenditures (*capxy*) to the lag of quarterly property, plant and equipment (*ppentq*) [4]; leverage l_{jt} is defined as the debt-to-asset ratio which is the sum of debt maturing within one year and debt maturing in more than one year (*dlcq+dlttq*) over total assets (*atq*); and net debt borrowing is defined as changes in total debt (Δ *[dlcq+dlttq]*) over total debt (*dlcq+dlttq*); We also define net long-term debt borrowing and net short-term debt borrowing as changes in long-term debt (Δ*dlttq*) and changes in short-term debt (Δ*dlcq*) over total debt (*dlcq+dlttq*) respectively. Finally, debt maturity m_{jt} is constructed as the ratio of debt maturing in more than 1 year (*dlttq*) over total debt

[3]However, it has two shortcomings: it only includes public firms, which excludes private and smaller firms; and detailed debt maturity data is only available in the Fundamentals Annual. Despite these flaws, it covers almost half of U.S. output, and offers substantial variation within and between firms to offer weight to the empirical analysis of these firms.

[4]Because capital expenditures (*capxy*) is a cumulative variable within a fiscal year, for the first fiscal quarter Q1, net investment is properly measured as $capxy_{q1}$. For fiscal quarter Q2, net investment equals $capxy_{q2} - capxy_{q1}$, and so on for Q3 and Q4. We prefer this approach as *capxy* contains many fewer missing values, leaving us with a more complete sample. Second, *capxy* is exactly how much a firm invests in their *ppentq*, avoiding the potential measurement problems from constructing capital series and then taking the log differences as investment.

(*dlcq+dlttq*). The data selection criteria approach follows Almeida et al. (2012). We disregard observations from the financial sector (SICs 6000-6999), non-profit organizations and governmental enterprises (SICs 8000s & 9000s), and utilities (SICs 4900-4999). We drop firm-quarter observations with missing or negative sales, with more than 100% sales or asset growth in a quarter, with cash holdings larger than assets, with capital expenditures or property, plant and equipment larger than total assets, and with potentially mis-measured debt structures (debt greater than total assets). Details of variable construction and sample selection are in the Empirical Appendix A. We present the summary statistics for the sample in Table 1.

Table 1:
KEY STATISTICS FOR FIRM-LEVEL VARIABLES

Statistics	Investment	Leverage	Maturity>1	Borrowing	Borrowing^L	Borrowing^S
Observation	141,306	141,306	141,306	125,380	125,380	125,380
Mean	0.058	0.352	0.842	0.039	0.030	0.009
Median	0.042	0.319	0.917	-.001	-0.016	0.000
Std	0.054	0.190	0.187	0.307	0.282	0.134
Max	0.407	0.954	1.000	12.902	11.677	5.629
75%	0.074	0.462	0.985	0.052	0.029	0.014
25%	0.023	0.206	0.764	-0.044	-0.035	-0.008
Min	-0.052	0.059	0.159	-0.928	-0.921	-0.830

Notes: The data is from Compustat Quarterly. Investment is defined as the ratio of quarterly capital expenditures (changes in *capxy*) to the lag of quarterly property, plant and equipment (*ppentq*). Leverage is defined as the debt-to-assets ratio. Maturity is defined as the ratio of long-term debt to total debt.

Monetary Policy Shocks: The main difficulty in measuring monetary policy shocks is that most of the variation in the Federal Funds rate is driven by the Federal Reserve's endogenous response to aggregate economic conditions. As a result, it is challenging to measure exogenous monetary policy shocks. We identify shocks using the high-frequency event-study approach pioneered by Cook and Hahn (1989). This high-frequency identification imposes fewer assumptions to identify shocks than the VAR approach in Christiano et al. (2005) or the narrative approach in Romer and Romer (2004). We use high-frequency data on Federal Funds futures contracts and identify monetary shocks using changes in the traded rate of Federal Funds futures in a narrow time window around FOMC press releases. By examining a narrow window around the announcement, this ensures that the only relevant shock during the time period (if any) is the monetary policy shock.

Following Gürkaynak et al. (2005), Gorodnichenko and Weber (2016) and Wong (2016), we construct our monetary policy shocks x_t^m as:

$$\Delta_t^m = \tau(t) \times (ffr_{t+\Delta_+} - ffr_{t-\Delta_-}) \tag{1}$$

where t is the time of a monetary announcement and ffr_t is the implied Federal Funds rate from a current-month Federal Funds futures contract at time t. We focus on a window of Δ_- = fifteen minutes before the announcement and Δ_+ = forty-five minutes after the announcement, as well as a tighter window of Δ_- = ten minutes before the announcement and Δ_+ = twenty minutes after the announcement. $\tau(t) = \frac{\tau^n(t)}{\tau^n(t)-\tau^d(t)}$ is the adjustment for the timing of the announcement within the month, which accounts for the fact that Federal Funds Futures pay out based on the average effective rate over the month. $\tau^d(t)$ denotes the day of the meeting in the month and $\tau^n(t)$ is the number of days in the month. Our shock series begins in January 1990, when the Federal Funds futures market opened. Since the 30-day Federal Funds Rate hit the zero lower bound in December 2008, this high-frequency shock measure has subsequently exhibited little fluctuation. We cut the sample off in 2008 to avoid zero-lower bound issues.[5]

To match our quarterly firm-level data in Compustat, we sum up the identified shocks within the same quarter to generate a quarterly measure of the shock series from the first quarter in 1990 to the last quarter in 2008. The statistics are summarized in Table 2. $\Delta^{m,30}$ denotes the high frequency shock measure using a 30 minute window (10 minutes before the announcement and 20 minutes after the announcement), $\Delta^{m,60}$ denotes the high frequency shock measure using a 60 minute window (15 minutes before the announcement and 45 minutes after the announcement), $\Delta^{m,tight}$ denotes $\Delta^{m,30}$ aggregated to a quarterly series, and $\Delta^{m,wide}$ denotes $\Delta^{m,60}$ similarly aggregated. The differences between the two measures are quite small for all statistics, which suggests that the market is very efficient in adjustment to FOMC announcements. Using the tight window measure, for example, the average monetary policy shock is -4.6 basis points. The minimum is -45.9 basis points in Q4 1991, while the maximum is 17.2 basis points in Q2 2003. In the regression analysis, we always flip the sign of monetary policy shocks so positive monetary policy shocks imply monetary stimulus.

2.2 Heterogeneous Investment Responses to Monetary Policy

We first empirically test how the investment decisions of firms respond to monetary policy shocks given their debt structure including both their levels (leverage) and maturity structures of debt.

A. Baseline Regression

[5]See Gilchrist et al. (2015). The 30-day Federal Funds Rate hit the zero lower bound following the FOMC press release on December 25, 2008. There were no more FOMC press releases within that quarter. Therefore, we truncated the data series at Q4 2008. The Federal Funds Rate has since remained within the effective zero lower bound and therefore does not capture the responses of the market to changes in the stance of monetary policy.

Table 2: Statistics of Monetary Policy Shocks

Statistics	$\Delta^{m,30}$	$\Delta^{m,60}$	$\Delta^{m,tight}$	$\Delta^{m,wide}$
Observation	175	175	76	76
Mean	-0.022	-0.0217	-0.046	-0.0457
Median	0	0	-0.0025	0
Std	0.0906	0.0925	0.122	0.1284
Max	0.163	0.152	0.172	0.162
Min	-0.4667	-0.463	-0.459	-0.479

Note: Among the 175 announcements, there are 23 unscheduled meeting announcements other than the 8 regularly scheduled meetings per year. Excluding these unscheduled meeting announcements does not make a qualitative difference to the results.

Specification Our baseline empirical specification is:

$$i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st} \tag{2}$$

where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, X_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1} and maturity m_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j and γ_{qs} are firm fixed effects and quarter-sector fixed effects, respectively. And finally, γ_t are time fixed effects to absorb all aggregate shocks. Since controlling for γ_t completely absorbs the variations in $\boldsymbol{\alpha}\Delta_t^m$, in order to compare the heterogeneous effects in $\boldsymbol{\beta}'$ to the average effect $\boldsymbol{\alpha}$[6], we shut down the time fixed effects in some regressions. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level.

The firm-level and aggregate-level controls control for factors that may simultaneously affect investment and financial positions but which are outside the scope of our model. The firm fixed effects capture permanent differences in investment behavior across firms, and quarter-sector fixed effects capture differences in how sectors are exposed to aggregate shocks and seasonality. We flip the sign and normalize the monetary policy shock by dividing by *-25 basis points*, therefore the coefficients $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}'$ can be interpreted as the average and heterogeneous effects with respect to a conventional monetary policy expansion.

[6]We take out the sample mean of leverage and maturity, so $\boldsymbol{\alpha}$ reflects the average effect for an average firm with average leverage and an average maturity. The comparison between $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}'$ is intuitive. For instance, $\frac{\boldsymbol{\beta}'}{\boldsymbol{\alpha}} \times \Delta leverage$ is the heterogeneous effect measured as a percentage of having $\Delta leverage$ relative to an average firm.

Results Table 3 shows the results. From Column (1) to Column (4), we do not control for the time fixed effect, so we can compare the heterogeneous effect relative to the average effect. First, Column (1) shows the average response. A conventional unit tightening of monetary policy shock reduces the corporate investment rate by 0.18%. Column (2) and Column (3) show the heterogeneous responses depending on firms' leverage and debt maturity, respectively. Column (4) puts both leverage and maturity together. Both coefficients of the interaction terms between monetary shocks and leverage and maturity are significantly negative, showing that the firms with higher leverage and longer debt maturity are less responsive to the expansionary monetary policy shocks.

Table 3:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY

i_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.185**	0.186**	0.187**	0.188**	—
	(0.073)	(0.073)	(0.074)	(0.074)	—
$\Delta_t^m \times lev_{j,t-1}$		-0.315*		-0.296*	-0.297*
		(0.168)		(0.166)	(0.165)
$\Delta_t^m \times mat_{j,t-1}$			-0.302**	-0.281*	-0.331***
			(0.147)	(0.143)	(0.115)
N	104737	104737	104737	104737	104737
adj. R^2	0.365	0.365	0.365	0.365	0.373
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	—
Time FE	No	No	No	No	Yes

Notes: This table reports the results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, X_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1} and maturity m_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. And finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

In Column (5), we replace the aggregate controls with time fixed effects in order to validate the heterogeneous effects of a monetary shock though the average effect is not available anymore. The magnitudes of the coefficients do not change much and are still significant. Therefore, we focus on Column (4) for quantitative interpretations. For firms one standard deviation higher than average in leverage ($sd_{lev} = 0.190$) or maturity ($sd_{mat} = 0.187$) , this effect is reduced by

0.084% (0.44 × 0.190) or 0.047% (0.25 × 0.187), respectively. Compared to the average effect of 0.188%, a standard deviation higher in leverage or maturity generates 45% (0.084%/0.188%) or 25% (0.047%/0.188%) less investment, respectively. These results indicate that the investment responses of firms to monetary policy shocks differs significantly depending on their corporate debt structure.

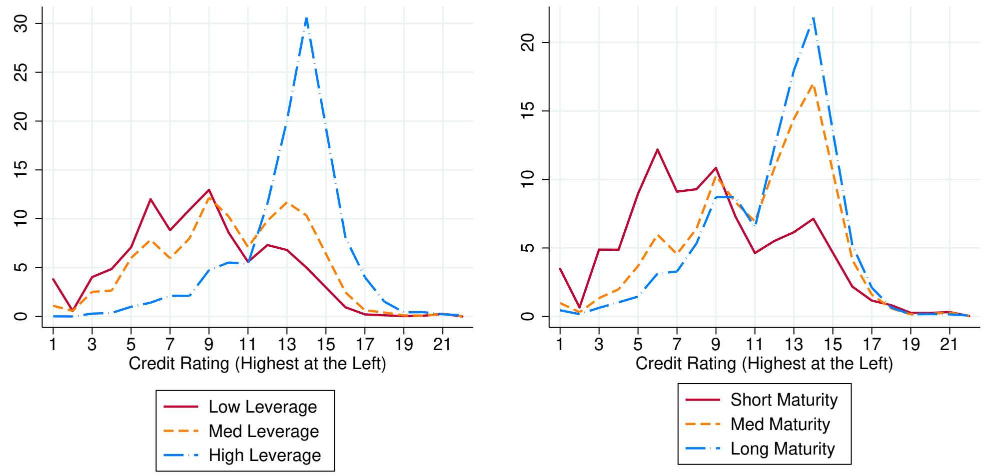
Robustness In the empirical appendixes A.3 and A.4, we provide robustness checks with respect to both monetary policy shocks and firm characteristics. For robustness checks based on the monetary shock measure, we check two different alternatives: an alternative measure using the 60-minute window shocks and an alternative measure by smoothed aggregation as in Ottonello and Winberry (2020) which uses a weighted aggregation of shocks across quarters. For robustness checks of the financial positions measures, we explore the permanent components of leverage and maturity, the transitory components of leverage and maturity, and the heterogeneity among firms in many other dimensions. For heterogeneity among firms in other dimensions, we focus on *size* using total assets, sales, and revenue, *earning status* using sales growth, profitability, and earning volatility, and *liquidity* using cash and net equity issuance. These additional results and robustness checks uniformly suggest that the results of the baseline estimation in Table 3 are robust.

B. Evidence from Credit Ratings

We argue that the heterogeneous responses by leverage and maturity are at least partially driven by firm heterogeneity in default risk. To provide evidence on how default risk affects the effect of monetary policy, we employ the credit ratings of corporate bonds from Standard & Poor. Credit ratings are only available for long-term bonds. The data is from 1990 to 2008, with monthly credit ratings for most U.S. listed firms. Corporate bonds are graded into 22 groups from AAA+ (the highest) to SD (selective default, the lowest). We merge this with our sample described in the baseline specification, resulting in 39,084 firm-quarter observations.

First, we show that firm heterogeneity in leverage and maturity is linked to credit ratings. Figure 1 plots the distribution of firm credit ratings for three equally divided groups by their leverage and maturity. The left panel shows the distribution of credit ratings of firms grouped into low, medium, and high leverage categories. Most of the high leverage firms are concentrated in the right tail with worse credit ratings around Grade BB (Grade 14). This pattern remains for the three groups by maturity, among which the long maturity group also has credit ratings concentrated around Grade BB. In contrast, the credit ratings of both the low leverage and low maturity groups have a peak around Grade AA- (Grade 6). We also show in Table 4 that there are negative relationships between credit rating and both leverage and maturity after controlling for all other firm-level characteristics as in baseline specification (2).

Figure 1:
Credit Rating Distributions over Leverage and Maturity



(a).By Leverage (b).By Maturity

Notes: This figure shows the relationships between leverage, maturity, and credit rating. Both leverage and maturity are equally divided into *Low*, *Medium*, and *High* three groups. Lower number on the x-axis indicates a better credit rating, and lower default risk. Number 1 corresponds to credit rating of AAA+ and number 22 corresponds to credit rating of SD (Selective Default).

Second, we show that firms with high credit ratings invest more in response to monetary policy shocks. We extend the regression in the baseline specification (2) by adding the long-term bond credit ratings into $X_{j,t-1}$ vector. Since the sample is smaller and there is not too much variation across time, we use an indicator if a firm's long-term bonds are rated above AA: $Rating_{j,t-1} \geq AA$. This indicator reflects whether a firm's long-term bond is more risky, which is highly correlated with both the level of leverage and more importantly maturity.

Table 5 reports the results when adding long-term bond credit ratings. First, the average effect of monetary policy stimulus on firm investment is positive and consistent across all regressions, however, the point estimate changes slightly because the sample shrunk by two-thirds and the mean of credit rating was not adjusted accordingly. In row two, we see that the marginal effect of higher credit ratings indicates significantly more investment following an expansionary monetary policy shock. However, the explanatory power of leverage and especially maturity is reduced. Since the credit ratings are only for long-term debt, which reflects the higher default risk embedded within the maturity measure of a firm's long-term debt share, the explanatory power of the maturity measure is reduced. All these results indicate that the higher default risk stemming from having more long-term debt is hindering firms' responses to monetary expansions.

Table 4:
Debt Heterogeneity and Credit Ratings

Credit Rating	(1)	(2)	(3)
$lev_{j,t}$	3.81***		3.88***
	(12.73)		(12.87)
$mat_{j,t}$		0.87***	1.03***
		(3.25)	(4.21)
N	39084	39084	39084
R^2	0.060	0.060	0.060
Firm Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

Notes: This table reports the results of the following specification: $\text{Credit Rating}_{jt} = \beta_0' X_{jt} + \gamma_z' Z_{jt} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where Credit Ratings are from Grade AAA+ (Grade 1) to Grade Selective Default (Grade 22) and a higher number means a higher default risk. X_{jt} includes both leverage and maturity, Z_{jt} is a vector of firm-level controls, γ_j, γ_{qs}, and γ_t are firm fixed effects, quarter-sector fixed effects, and time fixed effects. t statistics in parentheses. Significance level: * p<0.1, ** p<0.05, *** p<0.01

2.3 Heterogeneous Borrowing Responses to Monetary Policy

We then test how firm borrowing behavior responds to monetary policy shocks given their corporate debt structure including both leverage and debt maturity. The empirical specification is the same as the baseline specification equation (2), except for replacing the dependent variables with Δb_{jt} (changes in debt).

Total Borrowing In Table 6, we report the results from estimating regression equation (2) with the dependent variable being firm-level borrowing Δb_{jt}. We find that an expansionary monetary policy shock boosts firms' borrowing, but there is no significant evidence for heterogeneous responses for firms with different leverage or maturity. Column (1) shows that a 25 bps monetary policy expansion increases firm borrowing by 0.48%. Column (2) to (5) show that there is no significant evidence showing that firms with different leverage or debt maturity structures borrow differently following a monetary policy shock.

Long versus Short To further explore the potential heterogeneous responses in terms of borrowing, we decompose debt borrowing Δb_{jt} into long-term debt borrowing Δb_{jt}^L, and short-term debt borrowing Δb_{jt}^S. Interestingly, we find heterogeneous responses for firms when we look at long-term debt and short-term debt separately. In Table 7, we report the results from estimating equation (2) with the dependent variable being either long-term debt Δb_{jt}^L or short-term debt Δb_{jt}^S

Table 5:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY
BY LONG-TERM BOND CREDIT RATINGS

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.180***	0.107*	0.139*	—
	(0.056)	(0.062)	(0.071)	—
Δ_t^m x $\{Rating_{j,t-1} \geq AA\}$		0.284***	0.209***	0.225***
		(0.069)	(0.066)	(0.069)
$\Delta_t^m \times lev_{j,t-1}$			-0.466*	-0.436*
			(0.253)	(0.252)
$\Delta_t^m \times mat_{j,t-1}$			-0.088	-0.140
			(0.247)	(0.227)
N	38997	38997	38997	38997
adj. R^2	0.468	0.468	0.468	0.476
Firm FE	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	—
Time FE	No	No	No	Yes

Notes: This table reports the results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, X_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including lagged leverage l_{jt-1}, lagged maturity m_{jt-1}, and a lagged indicator if the firm's credit rating is good, $Rating_{j,t-1} \geq AA$. Z_{jt-1} is a vector of lagged firm-level controls, including total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. Finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

in Panel (A) and Panel (B), respectively. We show that an average firm borrows roughly 0.40% more long-term debt following a monetary expansion. However, they do not increase short-term debt borrowing.

We then compare the heterogeneous effects across the firms. Panel (A) shows that firms with longer maturity profiles are statistically significantly less responsive in taking on long-term debt. A one standard deviation increase in maturity (0.187) lowers long-term debt borrowing by 0.56% (0.187*3.005). Combined with the coefficient of Δ_t^m, a firm with almost exclusively long-term debt would not take on any more new long-term debt. Panel (B) shows that firms with higher leverage and longer maturity would take on much more short-term debt given a monetary expansion. As the average response is not significant, we cannot compare to an average firm's short-term debt borrowing. We can look at the absolute magnitude which is 0.17% (0.190*0.874) more short-term

Table 6:
RESPONSES OF BORROWING TO MONETARY POLICY

Δb_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.482**	0.479*	0.484**	0.482*	—
	(0.240)	(0.243)	(0.240)	(0.242)	—
$\Delta_t^m \times lev_{j,t-1}$		1.468		1.489	1.374
		(1.274)		(1.301)	(1.330)
$\Delta_t^m \times mat_{j,t-1}$			-0.200	-0.305	-0.103
			(1.170)	(1.210)	(1.215)
N	104737	104737	104737	104737	104737
adj. R^2	0.063	0.063	0.063	0.063	0.065
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	—
Time FE	No	No	No	No	Yes

Notes: This table reports the results from estimating $\Delta b_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where Δb_{jt} is the firm-level borrowing rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, X_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1} and maturity m_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. Finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

debt for a firm with one standard deviation more leverage (0.190), and 0.51% (0.187*2.701) more short-term debt for a firm with one standard deviation longer maturity (0.187). These firms issue short-term debt given a monetary expansion which offsets their lack of long-term borrowing. All these results further indicate that higher default risk from having more long-term debt hinders firm responses to monetary expansions.

2.4 Summary

We show significant heterogeneities in firm-level responses to monetary policy with heterogeneous leverage and debt maturity. Firms with low leverage and/or less long-term debt invest more following an expansionary monetary policy shock. These heterogeneous responses are consistent with credit ratings which reflects default risks. Firms with low leverage issue more short-term debt, and firms with more long-term debt issue less long-term debt. All these findings indicate that firms' financial positions in leverage and maturity play essential roles in shaping

Table 7:
Borrowing Responses to Monetary Policy
Long-term Debt and Short-term Debt

	(A). Long-term Debt Δb^L_{jt}			**(B). Short-term Debt Δb^S_{jt}**		
	(1)	(2)	(3)	(1)	(2)	(3)
Δ^m_t	0.389*	0.411*	—	0.093	0.071	—
	(0.220)	(0.222)	—	(0.076)	(0.081)	—
$\Delta^m_t \times lev_{j,t-1}$		0.614	0.521		0.874**	0.853**
		(1.318)	(1.336)		(0.357)	(0.350)
$\Delta^m_t \times mat_{j,t-1}$		-3.005***	-2.837**		2.701***	2.734***
		(1.103)	(1.114)		(0.638)	(0.642)
N	104737	104737	104737	104737	104737	104737
adj. R^2	0.057	0.057	0.058	0.101	0.102	0.103
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	—	Yes	Yes	—
Time FE	No	No	Yes	No	No	Yes

Notes: This table reports the results from estimating $\Delta b_{jt} = \boldsymbol{\alpha}\Delta^m_t + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta^m_t + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon^{st}_{jt}$, where Δb_{jt} is either the firm-level long-term debt or short-term debt borrowing rate, Δb^L_{jt} and Δb^S_{jt}, respectively. Δ^m_t is the monetary policy shock occurring between time $t-1$ and time t, X_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1} and maturity m_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. Finally, γ_t are time fixed effects to absorb all aggregate shocks. The error term ϵ^{st}_{jt} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

firm-level responses to monetary policy shocks. More specifically, besides the role of having a higher level of debt, the higher default risk embedded in having more long-term debt also hinders firm investment responses to monetary expansions.

3 Model

Motivated by our empirical findings, we build a heterogeneous firm model to explain the mechanism. The model economy consists of heterogeneous firms making investment and financing decisions and a monetary authority controlling the real interest rate. Firms are subject to their own idiosyncratic productivity shocks and aggregate interest rate shocks from the monetary authority. Firms can borrow by issuing both short-term and long-term debt. Each firm j ($j \in [0, 1]$)

decides investment, debt issuance, dividend, and whether to default on its debt in each period. Given the complex financial heterogeneity in the model, we assume that the monetary policy directly affects the real interest rate.[7]

3.1 Firms

Each firm j produces using capital k with a decreasing returns to scale production function:

$$y_{jt} = z_{jt} k_{jt}^{\alpha}, \qquad \alpha \in (0,1) \tag{3}$$

where z_{jt} is the idiosyncratic productivity shock for the firm j, which follows a Markov process. We omit subscript j from now on to clarify notations. The capital stock k follows the law of motion $k_{t+1} = (1-\delta)k_t + i_t$, where δ is the depreciation rate of capital and i_t is investment by the firm at time t. The adjustment of capital induces a quadratic capital adjustment cost $\frac{\theta_k}{2}(\frac{k_{t+1}}{k_t} - 1)^2 k_t$.

Firms can issue both defaultable short-term debt and long-term debt to finance operations. Let b_{St} denote the stock of outstanding short-term debt and b_{Lt} denote the stock of outstanding long-term debt at the beginning of period t. Short-term debt is a one-period contract. For long-term debt, we assume that in every period a fraction λ of the long-term principal is paid back, while the remaining $(1-\lambda)$ remains outstanding. This formulation is commonly used not only in corporate debt literature as in Hackbarth et al. (2006) but also in sovereign default literature such as Hatchondo and Martinez (2009). The level of long-term debt evolves according to:

$$b_{L,t+1} = (1-\lambda)\, b_{L,t} + n_{L,t}, \tag{4}$$

where $n_{L,t}$ is the newly issued long-term debt in time t. We allow the firms to repurchase outstanding long-term debt, so $n_{L,t}$ can be negative. There are issuance costs for debt. These issuance costs can be interpreted as flotation fees for new debt issues and bank fees. We allow for different issuance costs for short-term debt and long-term debt. Denote x' as the next period variable for variable x. The debt issuance cost is $\theta_{bS} b_S'^2 + \theta_{bL}\left(b_L' - (1-\lambda)b_L\right)^2$, where the parameter θ_{bS} captures issuance costs for short-term debt and the parameter θ_{bL} captures issuance costs for long-term debt.

[7] We capture the monetary policy transmission to the business sector in a reduced-form way. In the most recent heterogeneous firm New Keynesian general equilibrium models such as Ottonello and Winberry (2020), Jeenas (2018), and Fang (2020), monetary policy enters the firms' decision mainly through the real interest rate channel.

The dividend of the firm is given by:

$$D = (1-\tau)\underbrace{[zk^{\alpha}-\delta k]}_{\text{Taxable Income}} - \underbrace{(b_S+\lambda b_L)}_{\text{Principal Repayment}} - \underbrace{(k'-k)}_{\text{Gross Investment}} - \underbrace{\frac{\theta_k}{2}(\frac{k'}{k}-1)^2 k}_{\text{Capital Adjustment Cost}}$$
$$+ \underbrace{q_S(z,k',r,b_S',b_L')\,b_S' + q_L(z,k',r,b_S',b_L')\,\left(b_L'-(1-\lambda)b_L\right)}_{\text{Revenue from Debt Issuance}} - \underbrace{\left[\theta_{bS}b_S'^2 + \theta_{bL}\left(b_L'-(1-\lambda)b_L\right)^2\right]}_{\text{Debt Issuance Cost}}, \quad (5)$$

where τ is the corporate tax rate and δ is the deprecation rate. λ is the fraction of long-term debt that must be repaid. $q_S(z,k',r,b_S',b_L')$ and $q_L(z,k',r,b_S',b_L')$ are endogenous, state-dependent bond prices for short-term debt and long-term debt, respectively. We restrict dividends to be non-negative. This assumption implies that, if there is no feasible combination of (k',b_S',b_L') that allows for $D \geq 0$, the firm will default.

3.2 Recursive Formulation

The timing of the model is as follows. At the beginning of period t, the firm draws the realization of their productivity shock z_t. Given the amount of outstanding long-term debt b_{Lt}, the firm chooses next period's investment i_t, and whether to default on its debt. If the firm does not default on its debt, it decides the amount of short-term debt $b_{S,t+1}$ and long-term debt $b_{L,t+1}$ for next period.

The state variables for a firm are given by (z,k,r,b_S,b_L), where idiosyncratic productivity z and aggregate interest rate level r are exogenous states and b_S, b_L, k are endogenous states. The value of the firm in default is 0, while the value of the firm continuing operations is given by $v^c(z,k,r,b_S,b_L)$. The value of firm is then given by

$$v(z,k,r,b_S,b_L) = \max\left\{v^c(z,k,r,b_S,b_L),\ 0\right\}. \quad (6)$$

Let $d(z,k,r,b_S,b_L)=1$ denote default. The repayment value v^c is given by maximizing the present value of dividends by choosing capital k', short-term debt b_S', long-term debt b_L' and dividends D:

$$v^c(z,k,r,b_S,b_L) = \max_{k',b_S',b_L',D}\left\{D-\psi+(1-\pi_d)\,\mathbb{E}\Lambda v(z',k',r',b_S',b_L')\right\}, \quad (7)$$

where ψ is a fixed cost for operating, including all costs that arise independently of production, for example maintenance costs and administrative costs. π_d is an exogenous firm exit rate. The stochastic discount factor is $\Lambda = \beta(1 + r^*)/(1 + r)$, where r^* is the steady state interest rate.[8] If the firm does not default, the payment to the short-term debt creditors is 1, and the payment to the long-term debt creditors is λ. The outstanding fraction $(1 - \lambda)$ of long-term debt is valued by creditors at the end-of-period bond price q_L'. Thus the value of owning one unit of a long-term bond that is not in default is $\lambda + (1 - \lambda)q_L'$.

When the firm does not default, optimal new debt takes the form of two decision rules mapping today's state into tomorrow's debt levels:

$$b_S' = H_{b_S}(z, k, r, b_S, b_L),$$

$$b_L' = H_{b_L}(z, k, r, b_S, b_L).$$

If the firm defaults, it exits the market and will be replaced by a new firm with no debt and the lowest possible level of capital, which will have its productivity drawn from the long run distribution of the Markov process. The recovery value to the debt holder is given by:

$$R(z, k, r, b_S, b_L) = \max\{\chi[(1 - \tau)(zk^\alpha - \delta k) + k - \frac{\theta_k}{2}k],\ 0\} \tag{8}$$

where $0 < \chi < 1$ reflects that default is costly. $1 - \chi$ represents litigation fees, valuations costs and other direct monetary costs of default. When the firm defaults on its short-term debt, it triggers a default on its long-term debt as well. Upon default, the creditors holding short-term debt and long-term debt have equal claims for each dollar of debt against the recovery value of the firm.

Given this characterization of the debt and default decisions, we can now define equilibrium bond prices. The lenders are competitive and risk neutral. They face a risk-free interest rate r and are willing to purchase firm bonds as long as they break even in expected value. The lenders are aware that firms may default on their bonds. Thus, the break-even condition implies the price functions for short-term and long-term bonds:

$$q_S(z, k', r, b_S', b_L') = \frac{1 - \pi_d}{1 + r}\left[\mathbb{E}(1 - d(z', k', r', b_S', b_L')) + \mathbb{E}d(z', k', r', b_S', b_L')\frac{R(z', k', r', b_S', b_L')}{b_S' + b_L'}\right], \tag{9}$$

[8] When there are no monetary policy shocks, $\Lambda = \beta$.

$$q_L(z, k', r, b'_S, b'_L) = \frac{1-\pi_d}{1+r}\Big[\mathbb{E}(1 - d(z', k', r', b'_S, b'_L))(\lambda + (1-\lambda)q'_L) + \mathbb{E}d(z', k', r', b'_S, b'_L)\frac{R(z', k', r', b'_S, b'_L)}{b'_S + b'_L}\Big], \quad (10)$$

where $q'_L = q_L(z', k'', r', H_{b_S}(z', k', r', b'_S, b'_L), H_{b_L}(z', k', r', b'_S, b'_L))$. The debt prices reflect the future default probabilities and the value of the firm in default. The debt price functions show a crucial difference between short-term debt and long-term debt: short-term debt prices only reflect next period's default probability, while the long-term debt price captures the entire future path of default probabilities through its dependence on q'_L. Compared with short-term debt, long-term debt reduces rollover costs but increases the overall default risk.

3.3 Monetary Policy

We model monetary policy in a reduced-form setting, as we focus on the heterogeneous firms' debt and investment decisions. We assume the monetary authority directly manipulates the exogenous path of the real interest rate. This shortcut is rationalized by previous works in heterogeneous firm New Keynesian Models (i.e., Jeenas (2018), Ottonello and Winberry (2020), and Fang (2020)) which show that monetary policy affects firm investment primarily through the real interest rate channel. In our model, the changes in the real interest rate enter into two parts of a firm's decision process: the stochastic discount factor, and the risk-free interest rate in the bond price functions.

3.4 Equilibrium

Now we define the recursive equilibrium. For firm j, the equilibrium consists of a set of policy functions for (i) capital $k'(z, k, r, b_S, b_L)$; (ii) short-term debt $b'_S(z, k, r, b_S, b_L)$; (iii) long-term debt $b'_L(z, k, r, b_S, b_L)$; and a set of value functions of $v^c(z, k, r, b_S, b_L)$, $v(z, k, r, b_S, b_L)$, as well as bond price functions $q_S(z, k', r, b'_S, b'_L)$ and $q_L(z, k', r, b'_S, b'_L)$ such that:

1. The firm's choices for capital $k'(z, k, r, b_S, b_L)$, short-term debt $b'_S(z, k, r, b_S, b_L)$, long-term debt $b'_L(z, k, r, b_S, b_L)$, default set $d(z, k, r, b_S, b_L)$, and its value functions $v^c(z, k, r, b_S, b_L)$ and $v(z, k, r, b_S, b_L)$ solve its optimization problem (7).

2. The firm bond price schedules (9) and (10) reflect each firm's default probabilities and satisfy the lenders' break-even conditions.

3. Consistency. Future firm decision rules $H_k = k''(z', k', r', b'_S, b'_L)$, $H_{b_S} = b''_S(z', k', r', b'_S, b'_L)$, $H_{b_L} = b''_L(z', k', r', b'_S, b'_L)$, and $H_d = d'(z', k', r', b'_S, b'_L)$ are consistent with the firm choices.

3.5 Transformed Problem

Instead of keeping track of short-term debt b_S and long-term debt b_L separately, we recast the model in terms of total debt b and the share of long-term debt f, where $f = b_L/(b_S + b_L)$, to facilitate the computation. The transformation is equivalent to the original problem since $b_S = b \times (1 - f)$ and $b_L = b \times f$. Using total debt b, and the share of long-term debt f, we rewrite the key equations in the model. The state variables for a firm are now given by (z, k, r, b, f), where idiosyncratic productivity z and the aggregate interest rate level r are exogenous states, while capital k, total debt b, and the share of long-term debt f are endogenous states. The dividend of a firm is given by:

$$\begin{aligned} D = (1-\tau)\underbrace{[zk^{\alpha} - \delta k]}_{\text{Taxable Income}} - \underbrace{(b(1-f) + \lambda bf)}_{\text{Principal Repayment}} - \underbrace{(k'-k)}_{\text{Gross Investment}} - \underbrace{\frac{\theta_k}{2}(\frac{k'}{k} - 1)^2 k}_{\text{Capital Adjustment Cost}} \\ + \underbrace{q_S(z, k', r, b', f')b'(1-f') + q_L(z, k', r, b', f')(b'f' - (1-\lambda)bf)}_{\text{Revenue from Debt Issuance}} \\ - \underbrace{[\theta_{bS}(b'(1-f'))^2 + \theta_{bL}(b'f' - (1-\lambda)bf)^2]}_{\text{Debt Issuance Cost}}, \end{aligned} \tag{11}$$

The value of the firm when continuing operation is:

$$v^c(z, k, r, b, f) = \max_{k', b', f', D} \left\{ D - \psi + (1-\varepsilon)\mathbb{E}\Lambda v(z', k', r', b', f') \right\} \tag{12}$$

The price functions for short-term and long-term bond are:

$$q_S(z, k', r, b', f') = \frac{1-\pi_d}{1+r}\left[\mathbb{E}(1 - d(z', k', r', b', f')) + \mathbb{E}d(z', k', r', b', f')\frac{R(z', k', r', b', f')}{b'}\right], \tag{13}$$

and

$$\begin{aligned} q_L(z, k', r, b', f') = \frac{1-\pi_d}{1+r}\Big[\mathbb{E}(1 - d(z', k', r', b', f'))(\lambda + (1-\lambda)q_L') \\ + \mathbb{E}d(z', k', r', b', f')\frac{R(z', k', r', b', f')}{b'}\Big], \end{aligned} \tag{14}$$

where $R(z, k, r, b, f) = \max\{\chi[(1-\tau)(zk^{\alpha} - \delta k) + k - \frac{\theta_k}{2}k], 0\}$ is the recovery value to the debt holder when the firm defaults.

4 Quantitative Analysis

We parametrize the model using U.S. firm-level data. The model generates predictions consistent with the key empirical evidence given in Section 2.

4.1 Parameterization and moments

The model is calibrated at a quarterly frequency. The productivity shock z follows an AR(1) process:

$$\log(z_t) = \rho_z \log(z_{t-1}) + \eta_z \varepsilon_{z,t}$$

where ε_z has a standard normal distribution. We also assume that the interest rate takes the form of an AR(1) process, which is a simple way to create inertia in response to a monetary shock:

$$\log(r_t) = \rho_r \log(r_{t-1}) + \eta_r \varepsilon_{r,t}$$

There are two groups of parameters. The first group of parameters are assigned and those in the second group are chosen jointly to match data moments. The parameters in the first group are listed in Table 8. The discount factor β is 0.96. Following Gomes and Schmid (2010) and Arellano et al. (2012), we set the decreasing returns to scale parameter α to 0.65. The capital depreciation rate is set to 2.5% per quarter. We set the long-term debt repayment rate to 0.05 to match the average maturity of long-term debt of 5 years. The corporate income tax rate is set to be 0.2. We set the debt recovery rate to be 0.8, which is in line with Arellano et al. (2012). We set the productivity parameters and exogenous firm exit rate following Ottonello and Winberry (2020). The interest rate shock process parameters are in line with the literature. We scale the interest rate process so that the average interest rate is 1%.

The second group of parameters listed in Table 9 are chosen to match moments reported in Table 10. We target an average annualized investment rate of 23.2%, and we target a mean annual default rate of 3.0% as estimated in a survey of businesses by Dun and Bradstreet (www.dnb.com). We target a mean leverage ratio of 35.2%, which was the average level for the firm sample in Section 2. This is consistent with the average leverage ratio of 34.4% from the microdata underlying the Quarterly Financial Reports, as reported in Crouzet and Mehrotra (2017). We target a mean long-term debt share of 84.2% as calculated in Section 2. The model generates similar statistics to the ones in the data.

Table 8: Fixed Parameters

Parameter	Description	Value
β	Discount factor	0.96
α	Capital share	0.65
δ	Capital depreciation rate	0.025
λ	Long-term debt repayment rate	0.05
τ	Corporate income tax rate	0.2
χ	Recovery rate	0.8
π_d	Exogenous exit rate	0.01
ρ_z	Productivity persistence	0.9
η_z	Productivity volatility	0.03
ρ_r	Interest rate persistence	0.5
η_r	Interest rate volatility	0.08

Notes: This table reports the values for the assigned parameters in the model.

Table 9: Fitted Parameters

Parameter	Description	Value
θ_k	Capital adjustment cost	0.5
θ_{bS}	Short-term debt issuance cost	0.12
θ_{bL}	Long-term debt issuance cost	1.17
ψ	Fixed cost of operation	1.605

Notes: This table reports the values for the estimated parameters in the model to match the moments in Table 10.

Table 10: Model Fit

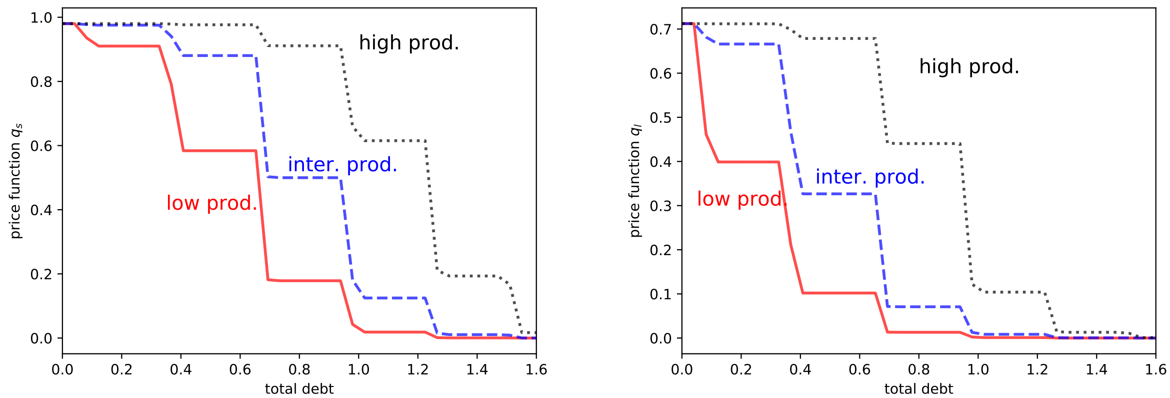
Average annualized moments	Data	Model
Investment rate (%)	23.2	20.5
Default rate (%)	3.0	3.3
Leverage (%)	35.2	36.9
Long-term debt share (%)	84.2	85.3

Notes: This table reports the moments that we target to estimate the parameters listed in Table 9. The moments are average annualized moments. The target moments for the investment rate, leverage and long-term debt share are calculated from the sample in our empirical section. The mean annual default rate of 3.0% is taken from the survey by Dun and Bradstreet (www.dnb.com).

4.2 Prices for Short-term and Long-term Bonds

Using the estimated model, we show the price functions in the model for short-term and long-term bonds with respect to different productivity levels and different capital stock levels. Figure 2 plots the price function q_s in Panel (a) and the price function q_l in Panel (b) as a function of total debt. With more debt, both prices decrease because of higher default risk. Note that a lower q_s

Figure 2:
Bond Prices as Functions of Total Debt for Different Productivity Levels

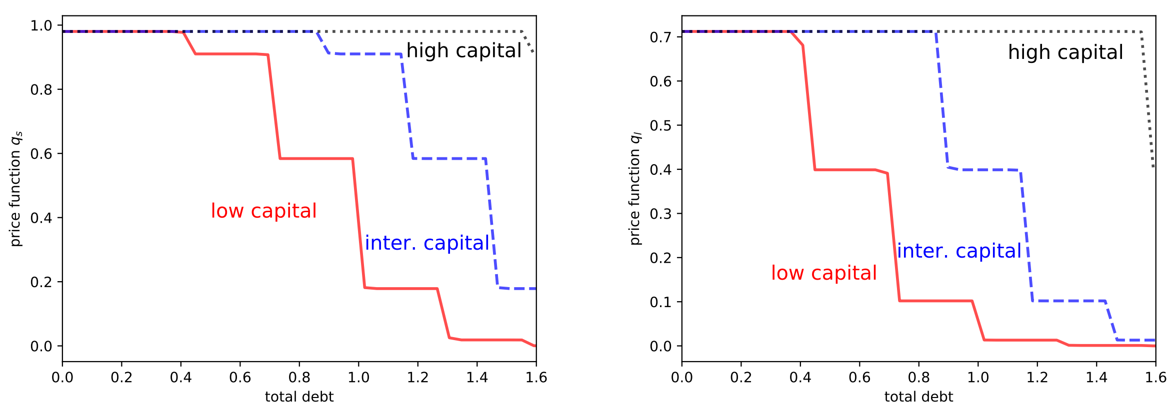


(a) Price function q_s

(b) Price function q_l

Notes: This figure plots short-term and long-term bond prices as functions of total debt for different productivity levels. The x-axis is the total debt. The y-axis is short-term bond price in Panel (a) and long-term bond price in Panel (b). The solid red line, dashed blue line and dotted black line draws for low productivity, intermediate productivity, and high productivity, respectively.

Figure 3:
Bond Prices as Functions of Total Debt for Different Capital Levels



(a) Price function q_s

(b) Price function q_l

Notes: This figure plots short-term and long-term bond prices as functions of total debt for different productivity levels. The x-axis is total debt. The y-axis is the short-term bond price in Panel (a) and long-term bond price in Panel (b). The solid red line, dashed blue line, and dotted black lines indicate prices for low productivity, intermediate productivity, and high productivity firms, respectively.

or q_l indicate that the firm obtains less debt for the same repayment, thus facing more expensive debt financing. We plot firms with high productivity in dotted black lines, firms with intermediate productivity in dashed blue lines, and firms with low productivity in solid red lines. There are two observations. First, debt financing is more expensive when productivity is low. This is because lower productivity is associated with lower debt repayment capacity, which increases default risk. Second, for the same productivity level, the long-term debt price q_l is lower than the short-term price q_s due to higher default risk.

Figure 3 plots the bond prices as functions of total debt with respect to different capital stock levels. The solid red line, dashed blue line, and dotted black line draw the prices for firms with low capital, intermediate capital, and high capital, respectively. There are two observations as well. First, firms with low capital stock have less capacity to produce and repay their debt, thus suffering from higher default risk and more expensive debt financing. Second, for the same capital stock level, the long-term debt price q_l is lower than the short-term price q_s due to higher default risk.

4.3 Decision Rules

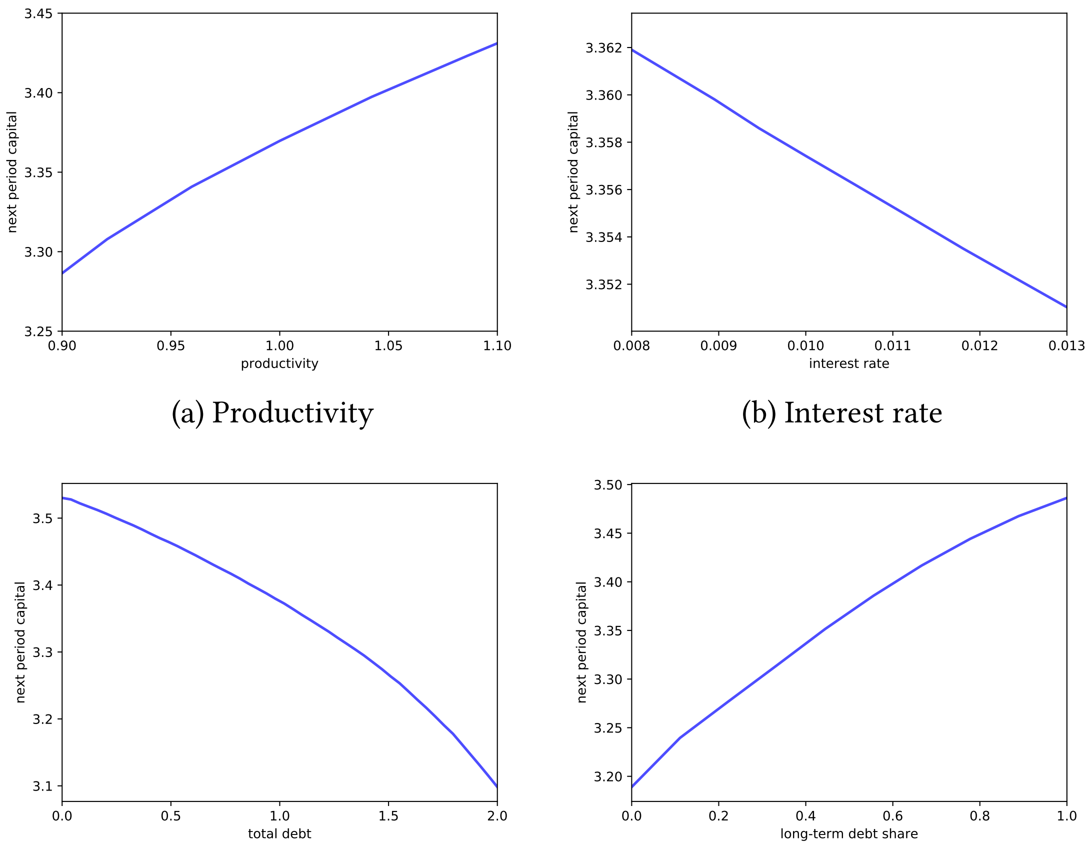
Taking the bond prices as given, firms make choices that satisfy their optimization problem. In this subsection, we study firm investment and financing behavior, and how behavior changes with firm characteristics and monetary policy. In particular, we show that firms with longer debt maturity are less responsive to an expansionary monetary policy shock.

Figure 4 plots the average decision rules for next period capital (k') as a function of productivity, interest rate, total debt, and long-term debt share. Panel (a) plots next period capital as a function of productivity. With higher productivity, the marginal benefit of producing is higher, leading to a higher optimal investment decision. Panel (b) plots next period capital as a function of the interest rate. A higher interest rate increases the financing cost of debt, thus hindering the investment of firms.

Next period capital as a function of total debt, shown in Panel (c), is declining in total debt. This means that high levels of debt depress investment. Panel (d) shows that when firms can repay only a fraction of their debt, they tend to have more next period capital.[9] This is because long-term debt involves lower rollover costs each period, thus allowing firms to put more resources into capital investment. Note that this is when the interest rate does not change. As we will show later, when there is an interest rate shock, a larger share of long-term debt serves as an obstacle

[9] We focus on the changes of investment depending on firms' debt maturity when there is a monetary policy shock. Nevertheless, the level effects of total debt and maturity shown in Panel (c) and (d) on firms' optimal capital choices are consistent with our empirical evidence. The results are available upon request.

Figure 4:
Decision Rules for Next Period Capital as a Function of
Productivity, Interest Rate, Debt, and Maturity



(a) Productivity

(b) Interest rate

(c) Total debt

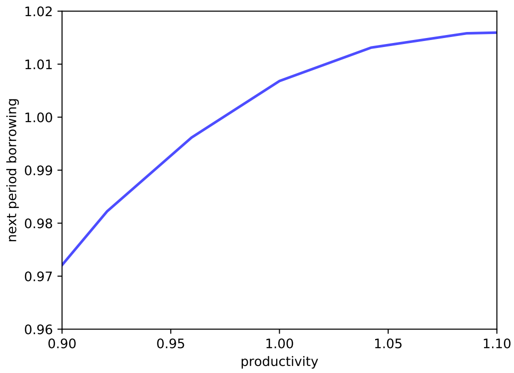
(d) Maturity

Notes: This figure plots the decision rules for next period capital as a function of productivity, interest rate, total debt, and debt maturity. The lines are the average decision rules along specific dimensions. For example, the line in Panel (a) plots the average next period capital along the dimensions except productivity. Next period capital increases with productivity (Panel (a)), decreases with the interest rate (Panel (b)), decreases with total debt (Panel (c)), and increases with the share of long-term debt (Panel (d)). The relationship with productivity is the standard prediction from models with firm investment. The relationships in Panel (b) - (d) are consistent with our empirical findings.

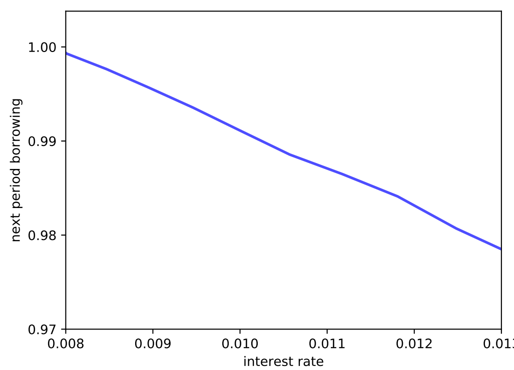
for firms to change their investment.

Figure 5 plots the average decision rules for the next period total debt (b') as a function of productivity, interest rate, total debt, and long-term debt share. Panel (a) plots next period debt as a function of productivity. With higher productivity, firms have a lower default risk, a lower cost of financing, and thus borrow more. Panel (b) plots next period debt as a function of the interest

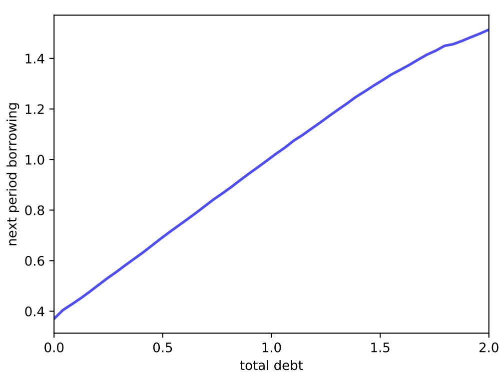
Figure 5:
Decision Rules for Next Period Borrowing as a Function of Productivity, Interest Rate, Debt, and Maturity



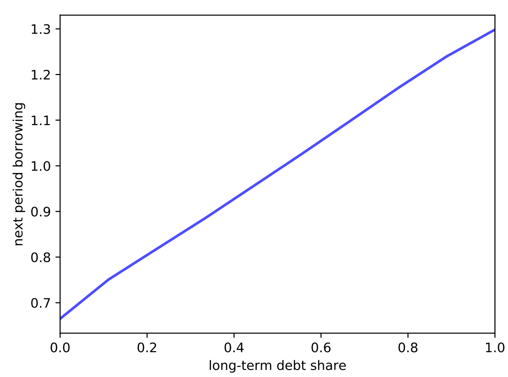
(a) Productivity



(b) Interest rate



(c) Total debt



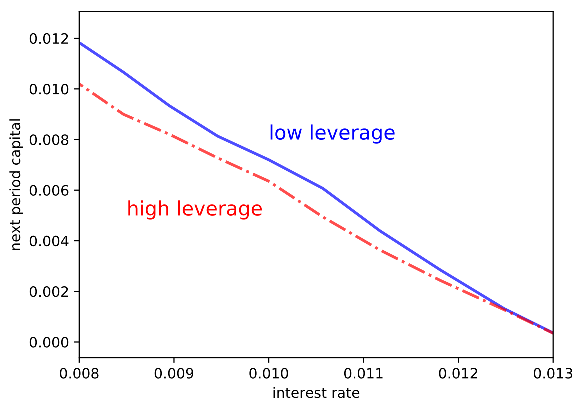
(d) Maturity

Notes: This figure plots the decision rules for next period borrowing as a function of productivity, interest rate, total debt, and debt maturity. The lines are the average decision rules along specific dimension. For example, the line in Panel (a) plots the average next period debt along the dimensions except productivity. The next period debt increases with productivity (Panel (a)), decreases with interest rate (Panel (b)), increases with total debt (Panel (c)), and increases with the share of long-term debt (Panel (d)).

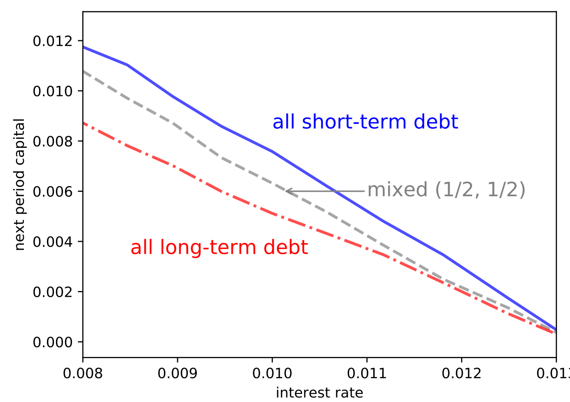
rate. A higher interest rate increases the financing cost of debt, thus reducing the incentive to borrow. Panel (c) plots next period debt as a function of current debt. Panel (d) plots next period debt as a function of long-term debt share. When firms hold a larger share of long-term debt, absent default, they will mechanically have more debt next period as most is not repaid.

As we showed in the empirical section, we focus on the responses of firm investment when there is a monetary policy shock. In particular, we find that firms with higher leverage or a larger share of long-term debt respond less to expansionary monetary policy. The model generates consistent results. To see this, we compare the decision rules for next period capital as a function of the real interest rate for firms with debt heterogeneity in Figure 6. Panel (a) plots for firms with different degrees of leverage, where the solid blue line indicates a low leverage firm (b=0.2) and the dash-dotted red line indicates a high leverage firm (b=2.0). Panel (b) plots for firms with different maturity, where the solid blue line indicates a firm with only short-term debt (f=0) and the dash-dotted red line indicates a firm with only long-term debt (f=1). We also plot a case where half the debt is short-term and the other half is long-term debt (f=1/2), using the dashed gray line. We normalize each series by its value when the interest rate is at the grid maximum. When the interest rate decreases, firms increase investment. With higher leverage and/or a larger share of long-term debt, the increase in investment is smaller, indicating that firms respond less when there is a positive monetary policy shock (decrease in interest rate).

Figure 6:
THE ROLE OF DEBT HETEROGENEITY



(a) Leverage



(b) Maturity

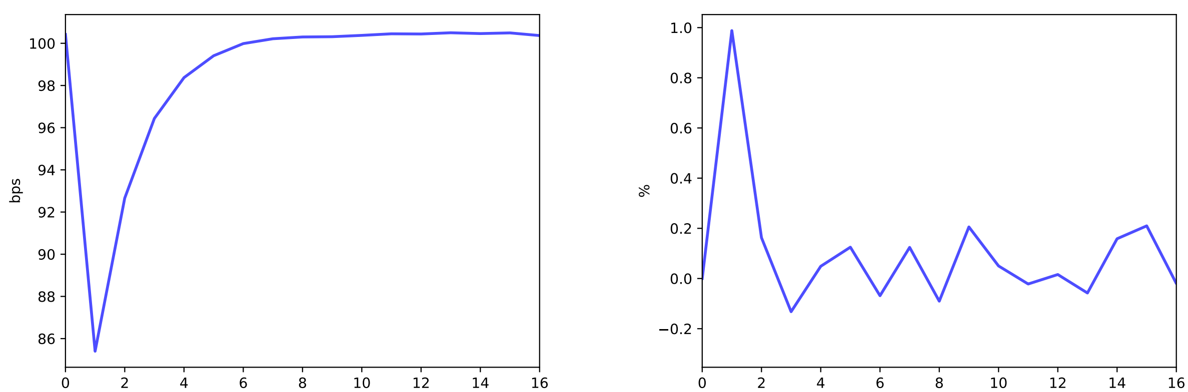
Notes: This figure plots the decision rules for next period capital with respect to the interest rate for different leverage and maturity levels. We normalize each series by its value when the interest rate is at the grid maximum. In Panel (a), the solid blue line plots for firms with low leverage (b=0.2) and the dash-dotted red line plots for firms with high leverage (b=2.0). In Panel (b), the solid blue line plots for firms with only short-term debt (f=0), the dash-dotted red line plots for firms with only long-term debt (f=1), and the dashed gray line is firms with half short-term debt and half long-term debt (f=1/2).

Unlike Ottonello and Winberry (2020) where high leverage constitutes a force for under-investment, we emphasize a new mechanism through debt maturity. The intuition is that a larger share of long-term debt leads to higher debt default risk in the future which hinders investment. As long-term creditors face higher future default risk, they ask for better prices on outstanding long-term debt in the future. When the interest rate decreases, it is beneficial for firms to invest. With more long-term debt, part of the benefit of increasing investment following the interest rate cut goes to creditors instead of equity holders. As a result, firms with a larger share of long-term debt are less responsive to monetary policy stimulus.

4.4 Aggregate Responses to Monetary Policy Shocks

Having presented some key features of bond prices, firm decision rules, and their sensitivity to interest rate changes, we now study firm behavior in aggregate by generating impulse response functions following an expansionary monetary policy shock in the model. We simulate 30,000 paths for the model over 500 periods. In period 401 (period 1 in the figures below), there is a $15bps$ cut in the real interest rate. This is taken from the classic empirical investigation in Christiano et al. (2005) and more recent HANK literature such as Ottonello and Winberry (2020), Jeenas (2018), and Fang (2020) where a conventional $25bps$ negative shock to the Taylor rule residual will generate a $12.5bps$ to $15bps$ initial drop in the real interest rate. The real interest rate then follows its conditional Markov process with $\rho_r = 0.5$. The impulse responses plot the variable averages across the 30,000 simulations.

Figure 7:
Aggregate Response to Monetary Policy Shock: Investment Rate



(a) Real interest rate

(b) Changes in investment rate

Notes: This figure plots the average impulse response function of investment rate (Panel (b)) to an expansionary monetary policy shock as shown in Panel (a).

We present the impulse responses of the average investment for an average firm in Figure 7. Panel (a) shows the resulting path for the real interest rate. The real interest rate drops for 15bps after an expansionary monetary policy shock. After the shock, the interest rate gradually goes back to the previous interest rate level following the AR(1) process. Panel (b) plots the response of the average investment rate. This expansionary monetary policy shock results in an average firm increasing their investment rate by 1.0% at the peak, which is in line with the peak impulse response of 1.2% as in Christiano et al. (2005).

4.5 Heterogeneous Responses to Monetary Policy Shock

Using the model-simulated data, we conduct regression analysis and show that the model generates similar heterogeneous responses across firms as in the data. With stochastic productivity, we simulate a panel of heterogeneous firms where each firm has its own path. We keep the data for 76 periods (quarters), which is consistent with Section 2.2. Using model-simulated data, we study firms' investment when there are monetary policy shocks and the heterogeneous responses for firms with heterogeneous financial positions. Specifically, we regress the investment rate on the real interest rate shocks and its interactions with leverage and maturity, controlling for leverage and maturity, including firm fixed effects:

$$i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_j + \epsilon_{jt}^t, \tag{15}$$

where i_{jt} is the model-generated investment rate of firm j in time t, Δ_t^m is the interest rate shock, which is given by the gap between the interest rate in time t and in time $t-1$. We normalize the interest rate shock by dividing by 15bps, and flip the sign so that a positive Δ_t^m indicates the same expansionary monetary policy as in our empirical regression equation (2). X_{jt-1} represents leverage or maturity in time $t-1$ and γ_j is firm fixed effect.

Table 11 reports the regression coefficients for the model and the data. The coefficients for the data are the ones from Table 3. The model generates coefficients qualitatively matching the data. With an expansionary monetary policy shock, an average firm increases its investment rate, due to a higher discount factor and cheaper borrowing costs to finance investment. The heterogeneous responses across firms' leverage and maturity positions are also significant. The magnitude of the regression coefficients from the model are also quantitatively similar to those in the data. Firms with lower leverage or a lower share of long-term debt have less default risk, and thus face lower marginal financing costs compared with other firms. With lower financing costs, these firms seize the opportunity provided by the monetary policy stimulus and invest more.

Table 11:
Regression Results: Model and Data

	Model			Data		
	(1)	(2)	(3)	(1)	(2)	(3)
Δ_t^m	0.339***	0.330***	0.414***	0.186***	0.187***	0.188***
	(0.103)	(0.106)	(0.117)	(0.037)	(0.037)	(0.038)
Δ_t^m x $lev_{j,t-1}$	-0.956***		-0.647*	-0.315*		-0.296*
	(0.298)		(0.374)	(0.168)		(0.166)
Δ_t^m x $mat_{j,t-1}$		-0.427***	-0.243		-0.302**	-0.281*
		(0.141)	(0.177)		(0.147)	(0.143)

Notes: This table compares the regression results from model-simulated data and Compustat data. The "Model" reports results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_j + \epsilon_{jt}^t$, where i_{jt} is the firm-level investment rate, Δ_t^m is the interest rate shock occurring between time $t-1$ and time t, X_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1} and maturity m_{jt-1}. γ_j is the firm fixed effect. Significance level: * p<0.1, ** p<0.05, *** p<0.01. The "Data" reports the coefficients of the baseline regression in Section 2.

5 Conclusion

We show that a firm's financial position, reflected by leverage and maturity structure, affects its investment response to monetary policy shocks. Empirically, firms with higher leverage and longer debt maturity respond less to expansionary monetary policy shocks. Theoretically, we build a model with firm default that is quantitatively consistent with the empirical results. Firms with higher leverage and/or longer maturity are less responsive to the positive aggregate shock because their marginal financing cost for investment is higher. Complementary to existing studies showing that *leverage* (Ottonello and Winberry, 2020; Lakdawala and Moreland, 2019; Auer et al., 2019), *age* (Cloyne et al. (2018)), *liquidity* (Jeenas (2018)), *credit risk* (Palazzo and Yamarthy (2020)), *bond v.s. bank lending* (Darmouni et al. (2020)), *asset pledgeability* (Silva (2019)), and *creditor rights* (Vats (2020)) can determine firm-level responses to monetary shocks, we provide both empirical evidence of and a theoretical mechanism for another relevant financial dimension: *debt maturity*.

We show that besides the level of debt, the most studied perspective, the split between long-term debt versus short-term debt significantly affects firm-level responses to monetary policy shocks. Since firms borrow and invest differently when there is a monetary policy shock, the effectiveness of monetary policy depends on the distribution of firms' debt maturity. The result also suggests that the effectiveness of a monetary policy may vary across countries and time when the economies have distinct firm-sector profiles. For instance, the same expansionary monetary policy shock may have a weaker impact in a country where firms mostly hold long-term debt versus a country where firms mostly hold short-term debt.

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Appendix

A Empirical Appendix

A.1 Compustat Variable Construction

We have briefly described the constructions of the key variables. In this appendix, we provide detailed information on how all variables are constructed and our justifications for our data choices. The database is Compustat's North America Fundamentals Quarterly.

Investment: Investment is defined as the ratio of quarterly capital expenditures (*capxy*) to the lag of quarterly property, plant and equipment (*ppentq*). As the capital expenditures (*capxy*) is a cumulative value within a fiscal year, we take differences between quarters except for the first fiscal quarter. The exact variable is $i_{jt} = capxy_{jt}/ppentq_{jt}$. This measure is considered more accurate because it suffers less from mismeasurement problems or firm-specific depreciation rate issues. Other measures usually use the difference between *ppentq* observations, adjust them with price index, back out the capital level, and then take the log-difference of the capital levels. This approach assumes the same depreciation rate for all firms as well as the same price index for all firms, which could be problematic. However, the capital expenditures (*capxy*) is a direct measure of how much "money" within that period a firm actually spent within a period to form property, plant and equipment (*ppentq*), hence neither inflation rate nor depreciation rates need to be considered.

Leverage: The definition of leverage is quite standard: as debt-to-assets ratio using debt maturing in one year plus debt maturing in longer than one year (*dlcq+dlttq*) over total asset (*atq*); This measures the debt level of a firm at each quarter.

Maturity: We define the debt maturity structure m_{jt} as the ratio of debt maturing in longer than 1 year (*dlttq*) to total debt (*dlcq+dlttq*). There exist better measures in the annual data which could give us more details, such as different maturities of less than 1 year, 2 year, ..., 5 year, and longer than 5 year. However, the frequency of the annual data is too low for this project, hence we prefer the previous measure.

Borrowing: Changes in total debt (Δ *(dlcq+dlttq)*) over total debt (*dlcq+dlttq*), which can be decomposed as long-term debt borrowing and short-term debt borrowing. Long-term debt borrowing is defined as changes in long-term debt (Δ*dlttq*) over debt (*dlcq+dlttq*). Short-term debt borrowing is defined as changes in short-term debt (Δ*dlcq*) over debt (*dlcq+dlttq*).

Control Variables: The firm-level control variables follows classic literature: a size measure (total assets atq), cash holdings $cheq$, revenue $revtq$, sales $saleq$, sales growth rate $\Delta saleq$ divided by $saleq$, profitability $oibdpq$ divided by atq, earnings volatility averaged over five quarters $\frac{1}{5} * \frac{niq}{atq}$, and net equity issurance $\Delta(lseq - ltq) - \Delta req$.

A.2 Sample Selection

Our sample selection criteria approach follows Almeida et al. (2012) as stated in the main text. We show more details here than in the paper for completeness. First, we drop observations with mismatched fiscal quarters. Some firms use a fiscal quarter which is not in line with calendar quarters, i.e., a firm may have their second fiscal quarter as (Mar, Apr, May) as opposed to the calendar quarter of (Apr, May, Jun). Matching a firm such as this one with the monetary shocks, which are set at calendar quarters, cannot be done cleanly. Second, we disregard observations from financial sector firms (SICs 6000-6999), non-profit organizations and governmental enterprises (SICs 8000s 9000s), as well as utilities (SICs 4900-4999). This is because firms in these categories behave very differently compared to other production firms.

The remaining parts are standard. We drop firms with missing or negative sales, firms with more than 100% sales or asset growth in a quarter, firms with either cash holdings, capital expenditures, or property, plant and equipment larger than total assets, and firms with potentially mis-measured debt structures (debt greater than total assets or components greater than total long-term debt). These selections are effectively trying to rule out extreme observations which could emerge when firms are entering bankruptcy. We also drop firms with very small size or a very low long-term debt ratio as in Almeida et al. (2012). Details of the sample selection process are in Table 12.

Table 12: **Sample Selection**

Compustat North America Quarterly, 1990-2008	**604,019**
Drop firms with:	
Fiscal quarter miss-match	-112,626
SIC 8000s & 9000s (NGO & Government Entrepreneurs)	-33,254
SIC 6000-6999 (Financial Firms)	-150,989
SIC 4900-4999 (Utility Firms)	-27,356
Growth of Assets > 100% in a quarter	-56,235
Missing Sales	-1,599
Sales < 0	-180
Growth of Sales > 100% in a quarter	-22,290
Cash is greater than Assets	-490
Property, Plant, and Equipment > Total Assets	-837
Total Assets (ATQ) < 10	-42,001
Missing Short-term/Long-term Debt	-9,864
Total Debt > Total Assets	-4,992
All firms	**141,306**

A.3 Robustness Check: Monetary Policy Shocks

In Table 13, we carry out a robustness check using an alternative measure of monetary policy shocks which is based on aggregating the shocks derived from observing 60 minute windows around FOMC meetings. All the point estimates are very stable in terms of significance, signs, and magnitudes comparing the the baseline estimation in Table 3.

In Table 14, we show a robustness check using an alternative measure of monetary policy shocks which is based on smoothed aggregated across quarters following Ottonello and Winberry (2020). We use a moving average of the shocks weighted by the number of days in the quarter after the shock, which allows us to weight the shocks by the time period that firms have had to react to them. Formally, the monetary policy shock in quarter q is given by:

$$x_q^m = \sum_{t \in J(q)} \omega^a(t) x_t^m + \sum_{t \in J(q-1)} \omega^b(t) x_t^m \tag{16}$$

where $\omega^a(t) = \frac{\tau_q^n(t) - \tau_q^d(t)}{\tau_q^n(t)}$, $\omega^b(t) = \frac{\tau_q^d(t)}{\tau_q^n(t)}$, $\tau_q^d(t)$ denotes the day of the monetary policy announcement in the quarter, $\tau_q^n(t)$ is the number of days in the monetary policy announcement quarter, and $J(q)$ denotes the set periods t contained in quarter q. The point estimates of average investment responses are quite stable in terms of significance, signs, and magnitudes. The only noticeable change is the slightly drop in significance of leverage interacting with monetary policy shocks.

Table 13:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY
USING SHOCKS WITH 60 MINS WINDOW

i_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.183**	0.184**	0.185**	0.186**	—
	(0.074)	(0.074)	(0.075)	(0.075)	—
$\Delta_t^m \times lev_{j,t-1}$		-0.295*		-0.277*	-0.280*
		(0.155)		(0.155)	(0.157)
$\Delta_t^m \times mat_{j,t-1}$			-0.289**	-0.270**	-0.311***
			(0.124)	(0.122)	(0.106)
N	104737	104737	104737	104737	104737
adj. R^2	0.365	0.365	0.365	0.365	0.373
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	No
Time FE	No	No	No	No	Yes

Notes: This table reports results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, x_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1}, and maturity m_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including total asset, cash holding, revenue, sales, sales growth, profit, earning volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. And finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

A.4 Robustness Check: Other Financial Positions

In Table 15, we show the investment responses considering the permanent components of firms' financial positions. The permanent components are defined as mean leverage $\bar{lev}_j = \sum_{t=1}^{T_j} lev_{j,t}/T_j$ and mean maturity $\bar{mat}_j = \sum_{t=1}^{T_j} mat_{j,t}/T_j$ over a firm's life cycle throughout the sample. First, in all regressions, the point estimates for the average effect are robustly similar. Second, we found that semi-elasticities of investment in terms of the permanent components of leverage and maturity are not significant. This suggests that the heterogeneous responses by leverage and maturity are potentially coming from the transitory components.

In Table 16, we run similar regression as in Table 15, but now with the transitory component, which is $(lev_{jt} - \bar{lev}_j)$ and $(mat_{jt} - \bar{mat}_j)$. The results are interesting. First, the point estimates for the average effect are still robust. Second, we found that semi-elasticities of investment in terms of the transitory components of leverage and maturity are significant. This suggests that

Table 14:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY
USING SMOOTHED MONETARY POLICY SHOCKS

i_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.332***	0.331***	0.333***	0.333***	—
	(0.104)	(0.104)	(0.104)	(0.104)	—
$\Delta_t^m \times lev_{j,t-1}$		-0.283*		-0.265	-0.280*
		(0.160)		(0.159)	(0.157)
$\Delta_t^m \times mat_{j,t-1}$			-0.280**	-0.261**	-0.311***
			(0.127)	(0.125)	(0.106)
N	104737	104737	104737	104737	104737
adj. R^2	0.366	0.366	0.366	0.366	0.373
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	No
Time FE	No	No	No	No	Yes

Notes: This table reports results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{jt-1} + \boldsymbol{\beta}' X_{jt-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, x_{jt-1} is a vector capturing firm j's corporate debt structure at time $t-1$, including both lagged leverage l_{jt-1}, and maturity m_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including total asset, cash holding, revenue, sales, sales growth, profit, earning volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. And finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

the heterogeneous responses by leverage and maturity are actually coming from the transitory components.

In Table 17, we examine the heterogeneous effects considering the interactions of monetary policy shocks with all other firm-level characteristics. We capture different aspects of size using total assets, sales, and revenue. We capture different aspects of earning status using sales growth, profitability, and earning volatility. Finally, we capture liquidity using cash and net equity issurance. We add the additional interactions sequentially and eventually including all of them in Column (4) without time fixed effects and in Column (5) with time fixed effects.

The point estimates of average effects and the heterogeneous effects over leverage and maturity still have similar magnitudes and same signs. One thing to notice is that the heterogeneous effect over maturity is always significant. However, after controlling for size and cash holdings, the significance of the leverage semi-elasticity dropped, though the signs and magnitudes still

Table 15:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY
PERMANENT COMPONENTS OF FINANCIAL POSITIONS

i_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.180**	0.179**	0.180**	0.180**	—
	(0.080)	(0.080)	(0.079)	(0.079)	—
$\Delta_t^m \times \bar{lev}_j$		-0.374*			-0.333
		(0.197)			(0.200)
$\Delta_t^m \times \bar{mat}_j$			-0.052	-0.052	-0.002
			(0.232)	(0.232)	(0.229)
N	104737	104737	104737	104737	104737
adj. R^2	0.357	0.357	0.357	0.357	0.364
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	No
Time FE	No	No	No	No	Yes

Notes: This table reports results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_j + \boldsymbol{\beta'} X_j \Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, X_j is a vector capturing firm j's corporate debt structure, including both mean leverage $\bar{lev}_j$, and mean maturity $\bar{mat}_j$. Z_{jt-1} is a vector of lagged firm-level controls, including total asset, cash holding, revenue, sales, sales growth, profit, earning volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. And finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

remain. This could be potentially the balance sheet liquidity effect addressed by Jeenas (2018).

Table 16:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY
TRANSITORY COMPONENTS OF FINANCIAL POSITIONS

i_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.185**	0.186**	0.186**	0.187**	—
	(0.073)	(0.073)	(0.074)	(0.074)	—
$\Delta_t^m \times [lev_{j,t-1} - \bar{lev}_j]$		-0.185		-0.205	-0.319*
		(0.182)		(0.195)	(0.187)
$\Delta_t^m \times [mat_{j,t-1} - \bar{mat}_j]$			-0.555***	-0.560***	-0.663***
			(0.192)	(0.198)	(0.184)
N	104737	104737	104737	104737	104737
adj. R^2	0.365	0.365	0.365	0.365	0.373
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	No
Time FE	No	No	No	No	Yes

Notes: This table reports results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' X_{j,t-1} + \boldsymbol{\beta}' X_{j,t-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t, $X_{j,t-1}$ is a vector capturing firm j's corporate debt structure, including both transitory leverage $lev_{j,t-1} - \bar{lev}_j$, and transitory maturity $mat_{j,t-1} - \bar{mat}_j$. Z_{jt-1} is a vector of lagged firm-level controls, including total asset, cash holding, revenue, sales, sales growth, profit, earning volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. And finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

Table 17:
HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY
OTHER FIRM CHARACTERISTICS

i_{jt}	(1)	(2)	(3)	(4)	(5)
Δ_t^m	0.164**	0.160**	0.127	0.126	—
	(0.077)	(0.077)	(0.099)	(0.099)	—
$\Delta_t^m \times lev_{j,t-1}$	-0.266	-0.253	-0.242	-0.248	-0.258
	(0.159)	(0.160)	(0.162)	(0.162)	(0.164)
$\Delta_t^m \times mat_{j,t-1}$	-0.269**	-0.264*	-0.281**	-0.276*	-0.326**
	(0.133)	(0.135)	(0.139)	(0.138)	(0.126)
$\Delta_t^m \times asset_{j,t-1}$	0.000**	0.000**	0.000**	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta_t^m \times cash_{j,t-1}$	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta_t^m \times revenue_{j,t-1}$		0.000*	0.000*	0.000	0.000*
		(0.000)	(0.000)	(0.000)	(0.000)
$\Delta_t^m \times sales_{j,t-1}$		0.000	0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)
$\Delta_t^m \times$ sales growth$_{j,t-1}$			0.167	0.165	0.152
			(0.194)	(0.193)	(0.182)
$\Delta_t^m \times$ profitability$_{j,t-1}$			1.054	1.077	1.140
			(1.294)	(1.291)	(1.272)
$\Delta_t^m \times$ earning vol$_{j,t-1}$				0.054**	0.053**
				(0.023)	(0.023)
$\Delta_t^m \times$ net equity issurance$_{j,t-1}$				-0.000***	-0.000***
				(0.000)	(0.000)
N	104737	104737	104737	104737	104737
adj. R^2	0.365	0.365	0.365	0.365	0.373
Firm FE	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Quarter-Sector FE	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	—
Time FE	No	No	No	No	Yes

Notes: This table reports results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \boldsymbol{\beta}' Z_{j,t-1}\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}^{st}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the monetary policy shock occurring between time $t-1$ and time t. Z_{jt-1} is a vector of lagged firm-level controls, including leverage, maturity, total asset, cash holding, revenue, sales, sales growth, profit, earning volatility, and net equity issurance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j, γ_t, and γ_s are firm fixed effects, quarter fixed effects, and sector fixed effects, respectively. And finally, γ_t are time fixed effect to absorb all aggregate shocks. The error term ϵ_{jt}^{st} is two-way clustered at both the sector level and quarterly time level. The sign "—" means estimations not available. Significance level: * p<0.1, ** p<0.05, *** p<0.01

B Theoretical Appendix

B.1 Computational Methods

This appendix describes the algorithm for computing the model. We compute the transformed model as discussed in Section 3.5. We first discretize the shock processes and state variables. We then solve the model via value function iteration. We discretize the AR(1) processes for the z and r shocks respectively using 11 equally spaced grid points with Tauchen's method. For the bonds B we use a grid with 100 equally spaced points on $B \in [0, 2]$, and 10 equally spaced points on long-term debt share $f \in [0, 1]$. For capital we use a grid with 100 equally spaced points on $k \in [0.5, 4.5]$. We have tested with different numbers of grid points and the results are robust. The firm makes borrowing (total debt, long-term debt share) and investment decisions B', f' and k' for the next period. We restrict these choice variables to be on the grid. Rather than value function iteration until convergence, and then updating the price and then repeating, we update the bond price at every value function iteration step. This approach is faster and the two different procedures deliver very similar results.

Here is a more detailed description of our algorithm:

1. Create grids for capital k, total debt B, and long-term debt share f; Create grids and discretize the Markov processes for productivity z and interest rate r.

2. Guess the value function $V_0(z, k, r, B, f)$, price function for short-term debt $q_{S0}(z, k, r, B, f)$ and the price function for long-term debt $q_{L0}(z, k, r, B, f)$.

3. Update the value of continuing operations $V_c(z, k, r, B, f)$.

4. Compare $V_c(z, k, r, B, f)$ and 0, update the default rule, price functions $q_S(z, k, r, B, f)$ and $q_L(z, k, r, B, f)$, and the value function of firm $V(z, k, r, B, f)$.

5. Check the distance $dist_v$ between the updated and prior value functions, and the distance $dist_q$ between the updated price function for long-term debt and the ones from last iteration. If either of the distances is larger than the tolerance 5e-5, then go back to 3. Otherwise, stop.