Lumpy Debt, Monetary Policy, and Investment [*]

Minjie Deng [†]

Simon Fraser University

Min Fang [‡]

University of Rochester

December 22, 2020

click here for most recent version

Abstract

We study how financial heterogeneity determines firm-level investment responses to monetary policy shocks. In Compustat, a significant number of firms hold almost zero debt, and among the firms who hold debt, both the amount and the maturity of debt vary greatly. We refer to these financial heterogeneity characteristics as *lumpy debt*. We first document that *lumpy debt* significantly affects the responses of firm investment to monetary policy shocks: firms who hold debt, hold more debt, and hold more long-term debt, are less responsive to monetary policy shocks. We then develop a heterogeneous firm model with investment, long-term and short-term debt, and default risk to interpret these facts. In the model, firms with higher leverage or more long-term debt are less responsive to monetary policy shocks because their marginal cost of external finance is high. The effect of monetary policy on aggregate investment, therefore, depends on the distribution of firm financial positions.

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

[*]We are extremely grateful to Yan Bai and Narayana Kocherlakota for their invaluable feedback and continued support. We thank George Alessandria, Mark Bils, Yongsung Chang, John Duggan, Zibin Huang, Dan Lu, Shafaat Khan, Armen Khederlarian, Pablo Ottonello, Yena Park, Sergio Montero, and other audiences at the University of Rochester, and the Wallis Institute of Political Economics for helpful discussions and comments. All errors are ours. First Version: September 10, 2018.

[†]Contact: minjie.deng16@gmail.com; 8888 University Dr, Burnaby, BC V5A 1S6, Canada

[‡]Contact: ethan.fangmin@gmail.com; 238 Harkness Hall, Rochester, NY 14620

1. Introduction

Firms have different financial positions which drive their investment decisions. This financial heterogeneity exhibits several characteristics which we refer to as *lumpy debt*: First, a significant amount of firms hold almost zero debt; Second, conditional on debt holding, firms hold significantly different levels of debt; Third, conditional on debt holding, firms hold significantly different maturity profiles of debt. Given this rich financial heterogeneity across firms, a crucial question is: Does *lumpy debt* affect the transmission of monetary policy to corporate investment?

We answer this question both empirically and theoretically. We emphasize how these *lumpy debt* characteristics play essential roles in shaping firm investment responses to monetary policy shocks. Our main empirical finding is that firms without debt, with debt but low leverage, and with debt but less long-term debt, invest more following an expansionary monetary policy shock. To speak to this evidence, we build a model that allows for firms with rich financial structures: firms can issue both short-term and long-term debt with fixed issurance costs to finance investment. In the model, firms with high leverage or long debt maturity are less responsive 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. The model shows that the aggregate effect of monetary policy depends on the initial distribution of firm financial positions.

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 shocks depends on firm financial positions: debt issuance, leverage, and maturity, conditioning on both firm fixed effects and sector-by-quarter fixed effects. Our estimates show that firms holding no debt (almost-zero-leverage, henceforth AZL), firms holding less debt (low-leverage), and firms holding more short-term debt are significantly more responsive to monetary policy shocks. We also show that these results are robust to alternative monetary policy shock measures, alternative financial positions measures, and alternative sample periods. We also externally validate our results using credit rating data.

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 that impede efficient investment are similar to Cooley and Quadrini (2001), Hennessy and Whited (2005) and Gomes and Schmid (2010). The innovation of our model is that we allow firms to issue both short-term debt and long-term debt. Short-term debt is less risky for the creditor and thus cheaper for the firm, but must be paid fully in the next period. Only a proportion of long-term debt needs to be paid off 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, equilibrium long-term debt prices typically feature a discount relative to short-term debt.[1] We calibrate the model to match the key features of firms' investment, borrowing, and other characteristics in the U.S. firm-level micro data.

In our model, 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 firms' 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's an expansionary monetary policy shock. 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 rapid 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 starts 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 Winberry (2018)), leverage (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

[1]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.

(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 emphasizing 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 lower 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 lowers the firm investment responses to monetary expansions.

Finally, this paper is related to the literature studies 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-section and dynamic properties of firm-level and aggregate investment. More recently, Khan, Senga and Thomas (2014) studies the effects of credit shocks in an economy where firms have persistent differences in TFP, capital and debt or financial assets. Gilchrist, Sim and Zakrajšek (2014) and Arellano, Bai and Kehoe (2019) study how financial frictions interacting with uncertainty shocks generate substantial output loss. Gomes, Jermann and Schmid (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 choices 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 is organized as follows. Section 2 provides empirical evidence showing that the responses to monetary policy shocks vary across firms, and the magnitude of the responses depend 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 lumpy debt 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 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 low-leverage firms and firms holding more short-term debt invest more when there is an expansionary monetary policy. Section 2.3 provides further complementary evidence on heterogeneous borrowing behaviors across the firms. Section 2.4 presents robustness checks.

2.1 Data Description

Firm-Level Panel Data: We obtain firm-level data from the 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; rich and detailed financial information, giving us the opportunity to extensively control for firm characteristics.[2]

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*) [3]; 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 (*dlcq+dlttq*). Following classic corporate finance literature, we also construct an AZL (almost-zero-leverage) dummy because almost-zero-

[2]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 variations within and between firms to offer weight to the empirical analysis of these firms.

[3]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 as 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.

leverage firms behave very differently from other firms, as documented in Strebulaev and Yang (2013). Almost-zero-leverage firms are those firms whose leverage is less than 5%. The data selection criteria approach follows Almeida et al. (2012). We disregard observations from 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 assets 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 variables construction and sample selection are in the Empirical Appendix A. We present the summary statistics for the sample in Table 1.

The non-AZL firms and AZL firms are significantly different in their corporate policies towards debt. For non-AZL firms, firm-quarter observations are required to at least have "some" debt which is debt over total assets larger than 5%. This givens us roughly 141,000 observations. For AZL firms, we group the firm-quarter observations who have almost no debt at all, which is roughly 61,000 observations. The essential reason to separate these two samples is addressed in the corporate finance literature, which is summarized as the zero-leverage firm puzzle in Strebulaev and Yang (2013). This puzzle shows that almost-zero-leverage firms have a very weak propensity to take on external debt though they have access to debt and would benefit from borrowing theoretically. These firms are similarly profitable and productive, but not significantly different in age or industry. To capture the significant differences between these two groups, we show statistics for two groups and distinguish the two groups by using a dummy variable for AZL firms in the regressions.

Table 2 shows other statistics, including size (total assets), sales-assets ratio, cash-assets ratio, profitability, and earnings volatility. Profitability is the operating income over total assets, and earnings volatility is defined as the five-quarter average net income over total assets. We find that almost-zero-leverage firms are one-fifth the size of firms who at least have some debt. Meanwhile, AZL firms are less profitable, face slightly larger earnings volatility, and hold 4 times larger share of liquidity assets than other firms. However, they show no difference in their sales-assets-ratio. As documented in Strebulaev and Yang (2013), these firms may have very different corporate financial policies. Therefore, they may respond to monetary policy shocks quite differently as well.

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

Table 1: Key Statistics for Firm-level Variables

Statistics	Investment	Leverage	Maturity>1	Borrowing	Borrowing^L	Borrowing^S
i(AZL)=0: non-AZL Firms						
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
i(AZL)=1: AZL Firms						
Observation	61,850	61,850	31,103	25,087	25,087	25,087
Mean	0.107	0.009	0.472	0.694	0.220	.473
Median	0.042	0.319	0.917	-.001	-0.016	0.000
Std	0.097	0.014	0.349	20.765	9.259	17.953
Max	0.620	0.050	1.000	1974	1236	1975
75%	0.146	0.014	0.770	0	0	0.007
25%	0.038	0	0.093	-0.243	-0.091	-0.143
Min	-0.074	0	0	-1	-1	-1

Notes: Summary statistics of firm-level variables. The data is from the 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.

Hahn (1989). This high-frequency identification imposes fewer assumptions to identify shocks than the VAR approach in Christiano, Eichenbaum and Evans (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 the changes in the traded rate of Federal Funds futures in a narrow time window around the 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, Sack and Swanson (2005), Gorodnichenko and Weber (2016) and Wong

Table 2: Other Statistics

	non-AZL Firms		AZL Firms	
Variables	Mean	St.D	Mean	St.D
Size (Total Asset millions$)	2542	10007	496	4692
Sales-Asset-Ratio	0.297	0.222	0.280	0.244
Profitability	0.026	0.046	0.009	0.075
Earning Volatility	0.036	1.007	0.051	0.086
Cash-Asset-ratio(Liquidity)	0.088	0.137	0.364	0.245

(2016), we construct our monetary policy shocks x_t^m as:

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

where t is the time of a monetary announcement, 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.[4]

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 3. $\Delta^{m,30}$ denotes the high frequency shock measure using a 30 minutes window (10 minutes before the announcement and 20 minutes after the announcement), $\Delta^{m,60}$ denotes the high frequency shock measure using a 60 minutes win-

[4]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 release 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.

dow (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.

Table 3: 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

2.2 Heterogeneous Investment Responses to Monetary Policy Shocks

We first empirically test how the investment decisions of both types of firms respond to monetary policy shocks given their debt structure, including whether they are AZL firms or not, and conditional on being non-AZL firms, their leverage and debt maturity.

Our baseline empirical specification is:

$$\begin{aligned} i_{jt} = (\boldsymbol{\alpha}\Delta_t^m + \beta_0' x_{jt-1} + \boldsymbol{\beta'} x_{jt-1}\Delta_t^m) \times i(AZL_{jt}) \\ + \Gamma' Z_{jt-1} + \Psi' Agg_{t-1} + \gamma_j + \gamma_q + \gamma_s + \epsilon_{jt}^s \end{aligned} \tag{2}$$

where i_{jt} is the investment rate by firm j at time t, Δ_t^m is the sign-flipped monetary policy shock occurs between time $t-1$ and time t, which is standardized via dividing by 25bps. Here we use the 30 minutes window measure for monetary policy shocks.[5] x_{jt-1} is a vector capturing firm j's

[5]The results are robust to using alternative monetary policy shocks. We provide the results using alternative measures in the Appendix A.5.

corporate debt structure at time $t-1$, including leverage l_{jt-1} and maturity m_{jt-1}. $i(AZL_{jt})$ is an indicator representing whether a firm is an AZL firm or not; Z_{jt-1} is a vector of firm controls, Agg_{t-1} is a vector of aggregate controls; γ_j, γ_t, and γ_s are the firm fixed effect, quarter fixed effect, and 2-digit sector fixed effect, respectively. The residual ϵ^s_{jt} is clustered at the 2-digit sector level.

The coefficients of interest are $\boldsymbol{\alpha}$ and $\boldsymbol{\beta'}$. $\boldsymbol{\alpha}$ shows the average effect of monetary policy shock on firm investment, and $\boldsymbol{\beta'}$ measures how semi-elasticity of investment with respect to monetary policy shock Δ^m_t depends on firm's debt structure $\{l_{jt-1}, m_{jt-1}\}$. To isolate the effect of debt structure, we control for various factors that may also affect firm investment. First, the firm fixed effect captures permanent differences in endogenous responses across firms, while quarter and sector fixed effects capture differences in how broad sectors are exposed to aggregate conditions, and seasonal effect within a year. Second, the firm-level controls Z_{jt-1} include total assets, cash holdings, total revenue, sales, sales growth, profitability, earnings volatility, and net equity issuance. Finally, the aggregate controls Agg_{t-1}, including market volatility measure VIX, GDP growth, unemployment, and inflation, capturing any other potential effects from the aggregate economic conditions. [6]

Table 4 shows the results. First, Column (1) shows that the AZL firms are more than twice as responsive compared to non-AZL firms. A tightening of monetary policy shock (25bps cut in federal fund rate) reduces corporate investment rate of AZL firms and non-AZL firms by 0.63% and 0.25%, respectively. 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. The three-way interaction term coefficients for the non-AZL firms are significantly negative, showing that the firms with higher leverage and longer debt maturity are less responsive to the expansionary monetary policy shocks.[7] For a non-AZL firm with one standard deviation higher in leverage $(sd_{lev} = 0.190)$ or maturity $(sd_{mat} = 0.187)$, this effect is reduced by 0.084% (0.44×0.19) or 0.047% (0.25×0.187), respectively. These results indicate that the investment responses of firms to monetary policy shocks differs significantly depending on their corporate debt structure.

[6]We use aggregate controls instead of time fixed effect because otherwise the time fixed effect will absorb all the variations of monetary policy shocks, which means we are not able to observe the average effect through $\boldsymbol{\alpha}$. With all these aggregate controls, we could control for the potential aggregate effects coming through the demand channel.

[7]The heterogeneous responses depending on leverage or maturity within the group of almost-zero-leverage firms are not meaningful, so here we focus on the three-way interaction coefficients for the non-AZL firms.

Table 4: **Heterogeneous Investment Responses: All Firms**

i_{jt}	(1)	(2)	(3)	(4)
$\Delta_t^m \times$ AZL	0.630***	0.643***	0.667***	0.700***
	(0.081)	(0.077)	(0.110)	(0.104)
$\Delta_t^m \times$ non-AZL	0.255***	0.255***	0.264***	0.264***
	(0.046)	(0.046)	(0.047)	(0.046)
$\Delta_t^m \times lev_{j,t-1} \times$ AZL		-2.887		-3.820**
		(2.227)		(1.838)
$\Delta_t^m \times lev_{j,t-1} \times$ non-AZL		-0.457**		-0.440**
		(0.179)		(0.175)
$\Delta_t^m \times mat_{j,t-1} \times$ AZL			-5.066	-6.731
			(4.380)	(4.295)
$\Delta_t^m \times mat_{j,t-1} \times$ non-AZL			-0.280*	-0.250*
			(0.151)	(0.147)
N	151253	151253	151253	151253
adj. R^2	0.031	0.031	0.032	0.032
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Notes: All regressions include firm fixed effect, quarter fixed effect, two-digit SIC sector fixed effect and we cluster the standard errors by two-digit SIC sectors. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

2.3 Heterogeneous Borrowing Responses to Monetary Policy Shocks

Since the financial heterogeneity across leverage and maturity among AZL firms is not meaningful by definition, we separately examine the debt behavior of AZL and non-AZL firms. Although many previous papers exclude AZL firms in their analysis, we still prefer to include them here because these firms are a substantial fraction of all firms. [8] We will first present the responses of AZL firms and then for non-AZL firms.

2.3.1 Responses of AZL Firms

The investment responses of AZL firms to monetary policy shocks are much stronger compared to non-AZL firms. How do they finance their investment? The empirical specification is a reduced version of equation (2):

$$dep_{jt} = \boldsymbol{\alpha}\Delta_t^m + \boldsymbol{\beta'}x_{jt-1} + \Gamma' Z_{jt-1} + \Psi' Agg_{t-1} + \gamma_j + \gamma_q + \gamma_s + \epsilon_{jt}^s \tag{3}$$

where the sample only includes the AZL firms. The dependent variables dep_{jt} are investment i_{jt}, debt borrowing Δb_{jt}, long-term debt borrowing Δb_{jt}^L , and short-term debt borrowing Δb_{jt}^S, respectively. 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 firm controls, Agg_{t-1} is a vector of aggregate controls, and γ_j, γ_t, and γ_s are firm fixed effect, quarter fixed effect, and 2-digit sector fixed effect, respectively. The residual ϵ_{jt}^s is clustered at the 2-digit sector level.

The results are in Table 5. Column (1) shows the response of investment, where the coefficient implies that a 25 bps interest rate cut would generate 0.57% growth in investment rate, similar to the coefficient of the pooled regression, which is 0.63%. From Column (2) to (4), we find that AZL firms reduce borrowing to interest rate cuts. A 25 bps interest rate cut leads them to get rid of almost all their debt (mainly short-term debt), which is quite surprising since they generally hold very little debt from the start. For those firms, it is highly likely that they are not financially constrained. Thus, their investment responses are not affected through the credit channel of monetary policy, but other

[8] As Strebulaev and Yang (2013) addressed, these firms account for 35% of all public firms in 2007 just before the crisis. They also invest more, pay more tax, and pay more dividends. In our sample, AZL firms account for roughly 30% (61,850/203,156) of the sample. Moreover, roughly 50% (30,747/61,850) of them have zero leverage. Most AZL firms do not even have a credit rating. Only 1,218 observations out of 61,850 observations of AZL firms have credit rating data. Hence, we are not able to create a robust matching between credit rating and financial positions.

Table 5: **Responses of AZL firms**

dep_{jt}	i_{jt}	Δb_{jt}	Δb^L_{jt}	Δb^S_{jt}
Δ^m_t	0.569***	-81.386**	-7.576	-73.811**
	(0.073)	(30.630)	(8.489)	(29.048)
N	43838	20644	20644	20644
adj. R^2	0.035	0.115	0.001	0.162
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Notes: All regressions include firm fixed effect, quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01

aggregate channels, for instance, the demand channel.

2.3.2 Responses of non-AZL Firms

We then test how non-AZL firms respond to monetary policy shocks given their corporate debt structure, which includes both leverage and debt maturity. We look at three different dimensions of firm choices: how much to invest, how much to borrow, and what fraction is for long-term debt. The empirical specification is similar to equation (3), except that here it has interaction terms to explore the heterogeneous effects:

$$\begin{aligned} dep_{jt} = \boldsymbol{\alpha}\Delta^m_t + \beta_0' x_{jt-1} + \boldsymbol{\beta'} x_{jt-1}\Delta^m_t \\ + \Gamma' Z_{jt-1} + \Psi' Agg_{t-1} + \gamma_j + \gamma_q + \gamma_s + \epsilon^s_{jt} \end{aligned} \tag{4}$$

where dep_{jt} is either investment i_{jt}, debt borrowing Δb_{jt}, long-term debt borrowing Δb^L_{jt}, or short-term debt borrowing Δb^S_{jt}. 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 firm controls, Agg_{t-1} is a vector of aggregate controls, and γ_j, γ_t, and γ_s are firm fixed effect, quarter fixed effect, and 2-digit sector fixed effect, respectively. The residual ϵ^s_{jt} is clustered at the 2-digit sector level.

Investment: In Table 6, we examine the firms' investment by reporting the results from estimating the regression equation (4) with dep_{jt} given as investment i_{jt}. The results are similar to in previous section using the pooled sample. Among the non-AZL firms, firms with higher leverage and longer debt maturities are less responsive to monetary policy shocks. The results are in line with the results in the previous section though the magnitudes are slightly different.

Table 6: **Heterogeneous Investment Responses**

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.185***	0.186***	0.187***	0.188***
	(0.036)	(0.037)	(0.037)	(0.038)
Δ_t^m x $lev_{j,t-1}$		-0.315*		-0.296*
		(0.168)		(0.166)
Δ_t^m x $mat_{j,t-1}$			-0.302**	-0.281*
			(0.147)	(0.143)
N	105110	105110	105110	105110
R^2	0.040	0.040	0.040	0.041
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Notes: All regressions include firm fixed effect, quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. Standard errors in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Borrowing: In Table 7, we report the results from estimating the regression equation (4) with dep_{jt} given as 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 debt maturity. Column (1) shows that a 25 bps monetary policy expansion increases firms' borrowing by 0.48%. Column (2) to (4) show that there is no significant evidence showing that firms' different leverage or debt maturity affect their borrowing when there is a monetary policy shock.

Long vs. 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 borrow-

Table 7: **Non-Heterogeneous Borrowing Responses**

Δb_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.482**	0.479*	0.484**	0.482*
	(0.240)	(0.242)	(0.240)	(0.242)
Δ_t^m x $lev_{j,t-1}$		1.468		1.489
		(1.274)		(1.301)
Δ_t^m x $mat_{j,t-1}$			-0.200	-0.305
			(1.170)	(1.210)
N	105110	105110	105110	105110
R^2	0.047	0.047	0.047	0.047
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Notes: All regressions include firm fixed effect, quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01

ing Δb_{jt}^S. Interestingly, we find heterogeneous responses for firms when we look at the long-term debt and short-term debt separately. In Table 8, we report the results from estimating equation (4) with dep_{jt} given as both long-term debt Δb_{jt}^L and long-term debt Δb_{jt}^S in Panel (A) and Panel (B), respectively. We show that an average firm would borrow roughly 0.40% more long-term debt given a 25 bps monetary expansion. To an average non-AZL firm, monetary expansion significantly increases firms' long-term debt, but not short-term debt.

We then compare the heterogeneous effects across the firms. Panel (A) shows that firms with longer maturity 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 borrow 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 debt for a firm

Table 8: **Heterogeneous Long-/Short-Term Borrowing Responses**

	(A). Long-term Debt Δb^L_{jt}				(B). Short-term Debt Δb^S_{jt}			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Δ^m_t	0.389*	0.389*	0.411*	0.411*	0.093	0.091	0.072	0.071
	(0.220)	(0.222)	(0.220)	(0.222)	(0.076)	(0.076)	(0.080)	(0.081)
Δ^m_t x $lev_{j,t-1}$		0.411		0.614		1.057***		0.874**
		(1.297)		(1.318)		(0.342)		(0.357)
Δ^m_t x $mat_{j,t-1}$			-2.962***	-3.005***			2.762***	2.701***
			(1.078)	(1.103)			(0.633)	(0.638)
N	105110	105110	105110	105110	105110	105110	105110	105110
R^2	0.043	0.043	0.043	0.043	0.096	0.096	0.097	0.097
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: All regressions include firm fixed effect, quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01

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 borrow short-term debt given a monetary expansion which offsets their lack of long-term borrowing.

2.4 Robustness Checks and Remarks

Robustness Checks: In Empirical Appendix A, we provide some additional results and several robustness checks. For additional results, we show the dynamics of the investment responses using the Local Projection of Jordà (2005) and we proxy the financial heterogeneity using S&P credit ratings. For robustness checks based on the monetary shock measure, we check three different alternatives: an alternative measure using the 60-minute window shocks, using only post-1994 data because monetary policy announcements are more transparent after 1993, and an alternative measure by smoothed aggregation as in Ottonello and Winberry (2018), using 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 other dimensions, in particular their size, sales, and sales growth. These additional results and robustness checks uniformly suggest that the results in the main text are robust.

Remarks: We show significant heterogeneities in firm-level responses to monetary policy across their financial positions. On investment, firms without debt, with debt but low leverage, and with debt but less long-term debt, invest more following an expansionary monetary policy shock. On borrowing, firms with debt but low leverage borrow more short-term debt, and firms with debt but more long-term debt borrow less long-term debt. These findings indicate that firm financial positions, including debt issurance, leverage, and maturity, play essential roles in shaping firm-level responses to monetary policy shocks.

3. Model

Motivated by the empirical findings, we build a heterogeneous firm model to explain the mechanisms. The model economy consists of heterogeneous firms making financing and investment decisions and a monetary authority controlling the real interest rate. Firms are subject to idiosyncratic productivity shocks and aggregate interest rate shocks from the monetary authority. Each firm j ($j = 1, 2, ..., N$) decides how much to invest, how much short-term and long-term debt to borrow, how large a dividend to pay, and whether to default. Given the complex financial heterogeneity in the model, we assume that the monetary policy directly affects the real interest rate.[9]

3.1 Setup

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

$$y_{jt} = z_{jt} k_{jt}^{\alpha}, \qquad \alpha \in (0, 1) \tag{5}$$

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

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 the 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 short-term debt b_S and long-term debt b_L. Short-term debt is a one-period contract. Let b_{St} denote the level of the short-term debt and b_{Lt} denote the stock of outstanding defaultable long-term debt at the beginning of period t. 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 in corporate debt literature as in Hackbarth, Miao and Morellec (2006). The level of long-term debt evolves according to:

$$b_{L,t+1} = (1-\lambda)b_{L,t} + n_{L,t} \tag{6}$$

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 bond 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 costs is $\theta_{bs}b_S'^2 + \theta_{bl}(b_L' - (1-\lambda)b_L)^2$. At the end of period $t-1$, the firm has an amount b_{Lt} of outstanding long-term debt. Given b_{Lt}, the firm chooses next period's investment i_t, and how many short-term bonds $b_{S,t+1}$ and long-term bonds $b_{L,t+1}$ to hold. At the beginning of period t, the firm draws the realization of z_t. Then firm decides whether to default. If the firm defaults on its debt, the shareholders can walk away because of limited liability. The value of the firm in default to shareholders is 0. There is also a proportional corporate income tax τ. The taxable income is calculated as income minus depreciation. This implies that there is a tax benefit for investment and debt issuance. The dividend of the firm is given by:

$$\begin{aligned} D = (1-\tau)\underbrace{[zk^\alpha - \delta k]}_{\text{Taxable Income}} - \underbrace{(b_S + \lambda b_L)}_{\text{Principal Repayment}} - \underbrace{(k' - k)}_{\text{Gross Investment}} - \underbrace{\frac{\theta_k}{2}(\frac{k'}{k} - 1)^2 k}_{\text{Capital Adjustment Cost}} \\ + \underbrace{q_S(z, k', r, b_S', b_L')b_S' + q_L(z, k', r, b_S', b_L')(b_L' - (1-\lambda)b_L)}_{\text{Revenue from Debt Issuance}} \\ - \underbrace{[\theta_{bS}b_S'^2 + \theta_{bL}(b_L' - (1-\lambda)b_L)^2]}_{\text{Debt Issuance Cost}} \end{aligned} \tag{7}$$

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 Firms' Recursive Problem

The state variables for a firm are given by (z, k, r, b_S, b_L), where idiosyncratic productivity z_t and aggregate interest rate level r_t are exogenous states and b_{St}, b_{Lt}, k_t are endogenous states. The value of the firm in default is 0, while the value of the firm continuing operations is given by $v^c(z, k, r, b_S, b_L)$. Since shareholders can simply walk away if the value of owning the firm becomes negative, the value of the firm to shareholders is bounded below by 0. The value of firm is then given by

$$v(z, k, r, b_S, b_L) = max\left\{v^c(z, k, r, b_S, b_L), 0\right\} \tag{8}$$

The non-defaulting value 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:

$$v^c(z, k, r, b_S, b_L) = \max_{k', b'_S, b'_L, D} \left\{ D - \psi + (1-\epsilon) E_t \Lambda_{t,t+1} \iint v(z', k', r', b'_S, b'_L) f(z', z) dz' f(r', r) dr' \right\} \tag{9}$$

where ψ is the fixed cost for operating, and ϵ is the exogenous death rate. The stochastic discount factor is $\Lambda_{t,t+1} = \beta \frac{1+r^*}{1+r_t}$ ($\Lambda_{t,t+1} = \beta$ when there are no monetary policy shocks). 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 $\lambda + (1-\lambda) q'_L$.

Suppose that the value function is strictly increasing in idiosyncratic productivity z, the default threshold is unique. If $z \leq z^*$, the firm will default, otherwise the firm will continue. The default threshold z^* for a firm is given by

$$z^*(k, r, b_S, b_L) = \{z : v^c(z, k, r, b_S, b_L) = 0\} \tag{10}$$

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:

$$b'_S = \tilde{b}_S(z, k, r, b_S, b_L)$$

$$b'_L = \tilde{b}_L(z, k, r, b_S, b_L)$$

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

$$R(z, k, r, b_S, b_L) = max(\chi[(1-\tau)(zk^\alpha - \delta k) + k - \frac{\theta_k}{2}k], 0) \tag{11}$$

where χ reflects that default is costly. $1-\chi$ of the recovery value is wasted if default occurs. This fraction represents litigation fees, valuations costs and other direct monetary costs of default. When the firm default 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 risk neutral and are willing to lend to the firms as long as they break even in expected values. The price of a new debt issue is the discounted sum of the value of the promised future payments, adjusted by the cumulative probability of repayment. We can write the long-term bond price recursively by assuming that the lender forecasts future debt levels using the firm's decision rules. The price functions for short-term and long-term bonds are expressed as follows:

$$\begin{aligned} q_S(z, k', r, b'_S, b'_L) = \frac{1-\epsilon}{1+r}[\iint_{z^*}^{\infty} f(z', z)dz' f(r', r)dr' \\ + \iint_{-\infty}^{z^*} \frac{R(z', k', r', b'_S, b'_L)}{b'_S + b'_L} f(z', z)dz' f(r', r)dr'] \end{aligned} \tag{12}$$

$$q_L(z,k',r,b'_S,b'_L) = \frac{1-\epsilon}{1+r}[\iint_{z^*}^{\infty}(\lambda+(1-\lambda)q'_L)f(z',z)dz'f(r',r)dr'+ \iint_{-\infty}^{z^*}\frac{R(z',k',r',b'_S,b'_L)}{b'_S+b'_L}f(z',z)dz'f(r',r)dr'] \quad (13)$$

where $q'_L = q_L(z',k'',r',\tilde{b}_S(z',k',r',b'_S,b'_L),\tilde{b}_L(z',k',r',b'_S,b'_L))$. 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 the 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 the rollover cost, but increases the overall default risk.

3.3 Monetary Policy

We model the 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 (2018), and Fang (2020)) and show that monetary policy affecting firms' investment primarily through the real interest rate channel. In our model, the changes in the real interest rate enters 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:

- Taking as given bond prices, firm's capital and debt choices satisfy its optimization problem.
- Taking as given bond prices, firm's default decision satisfy its optimization problem.
- The bond prices reflect the firm default risk and satisfy the lenders' break-even condition.

4. Quantitative Analysis

We now take the model to the data by parametrizing the model with the U.S. firm-level data. The key moments are the mean and volatility of investment rate, average default rate, leverage, as well as debt maturity profiles at the firm level. Using the estimated model, we present the decision rules of the firms and show that the model is consistent with the key features of the micro data as presented in Section 2 for non-AZL firms.

4.1 Parameterization

The model is at quarterly frequency. We assume 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 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 is taken directly from the literature, and the second group is chosen to match data moments. We set the capital share to 0.34 and the capital depreciation rate to 0.025. 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.[10] We set the productivity parameters following Ottonello and Winberry (2018). The interest rate shock process parameters are in line with the literature. We scale interest rate process so that the average interest rate is 1%. All fixed parameters are listed in Table 9.

The second group of parameters listed in Table 10 are chosen to match moments reported in Table 11. Although we chose all parameters jointly to match the moments, we can provide a heuristic description of how the moments inform specific parameters. The discount factor β matters mostly for the average investment, and the capital adjustment cost θ_k mostly affects the investment volatil-

[10] Recovery rates vary in literature. In most sovereign default literature, there is no recovery rate or the recovery value is quite low, while in literature with firm default, the recovery rate is sometimes high, for example, 0.91 in Ottonello and Winberry (2018), but sometimes assumed to be zero, as in Crouzet (2016). We performed sensitivity checks with different values for the recovery rate and found that it is not central to the results.

Table 9: Fixed Parameters

Parameter	Description	Value
α	Capital share	0.34
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
ϵ	Exogenous death rate	0.005
ρ_z	Productivity persistence	0.86
η_z	Productivity volatility	0.03
ρ_r	Interest rate persistence	0.5
η_r	Interest rate volatility	0.08

Table 10: Fitted Parameters

Parameter	Description	Value
β	Discount factor	0.92
θ_k	Capital adjustment cost	1.0
θ_{bS}	Short-term debt issuance cost	0.1
θ_{bL}	Long-term debt issuance cost	3.8
ψ	Fixed cost of operation	0.81

ity. The issuance costs for short-term debt θ_{bS} and for long-term debt θ_{bL} affect primarily leverage and maturity. The debt issuance costs also shape investment incentives and the resulting dynamics. The average default rate is mostly a function of the fixed operating cost ψ. We target a mean quarterly default rate of 0.75% quarterly as estimated in a survey of businesses by Dun and Bradstreet (www.dnb.com). We target a mean leverage ratio of 30.6%, 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 72.9% as calculated in Section 2. The moments for the investment

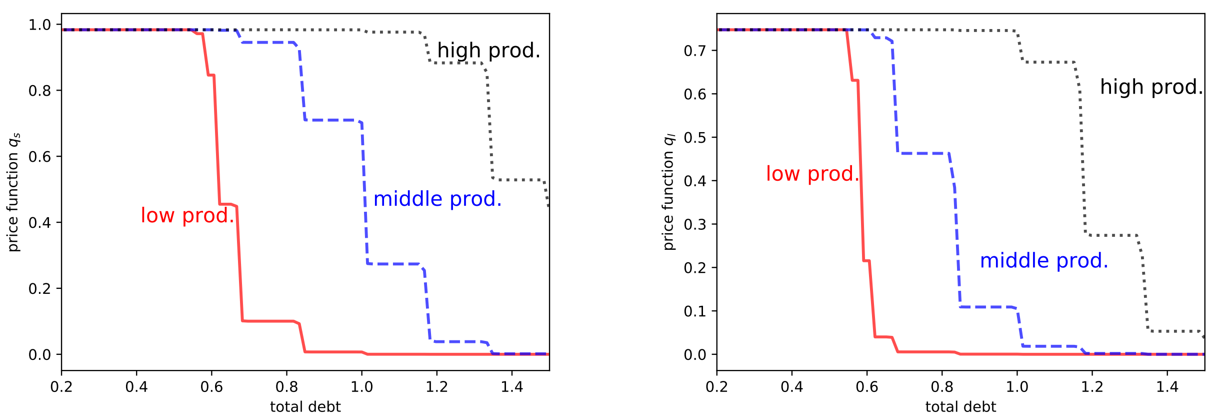
Table 11: Model Fit

Annualized Moments	Data	Model
Avg. investment rate (%)	10.4	11.8
Std. investment rate (%)	16.0	17.3
Avg. default rate (%)	3.0	3.2
Avg. leverage (%)	30.6	36.1
Avg. long-term debt share (%)	72.9	74.7

rate are taken from Zwick and Mahon (2017), computed using the annual IRS corporate income tax returns. The model generates similar statistics to the ones in the data.

4.2 Bond Prices

Figure 1: Bond Prices as a Function of Total Debt

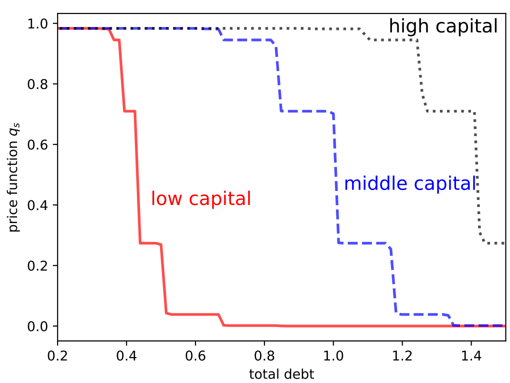


(a) Price function q_s (b) Price function q_l

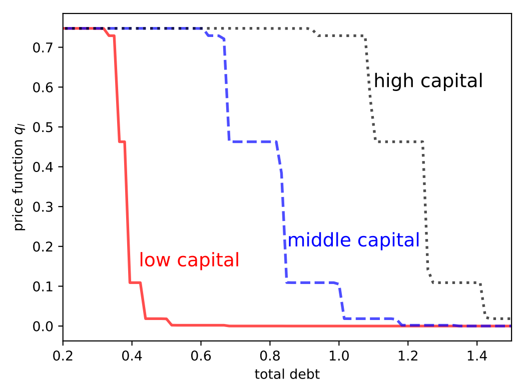
Notes: This figure plots short-term and long-term bond prices. The x-axis is the total debt, and the y-axis is short-term bond price in Panel (a) and long-term bond price in Panel (b). The solid red line, dashed blue line and dotted black line draws for low productivity, intermediate productivity, and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

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 1 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 or q_l indicate that the firm obtains less debt with the same repayment, thus facing more expensive debt financing. We plot for 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 same productivity level, long-term debt price q_l is lower than short-term price q_s due to higher default risk.

Figure 2: Bond Prices as a Function of Total Debt for Different Capital Levels



(a) Price function q_s



(b) Price function q_l

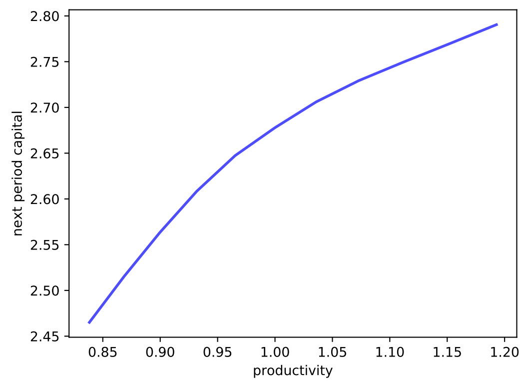
Notes: This figure plots short-term and long-term bond prices. The x-axis is the total debt, and the y-axis is short-term bond price in Panel (a) and long-term bond price in Panel (b). The solid red line, dashed blue line and dotted black line draws for low productivity, intermediate productivity, and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

Figure 2 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, the firms with low capital stock have lower capacity to produce and repay their debt, thus suffering from higher default risk and more expensive debt financing. Second, for same capital stock level, long-term debt price q_l is lower than short-term price q_s due to higher default risk.

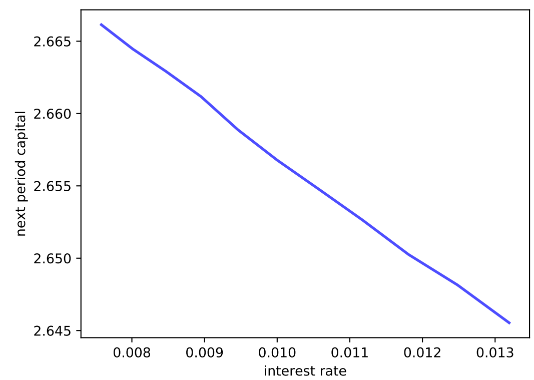
4.3 Decision Rules

Taking the bond prices as given, firms make choices that satisfy their optimization problem. In this subsection, we show how firms making their investment and financing decisions with respect to their idiosyncratic states and the aggregate level of interest rate.

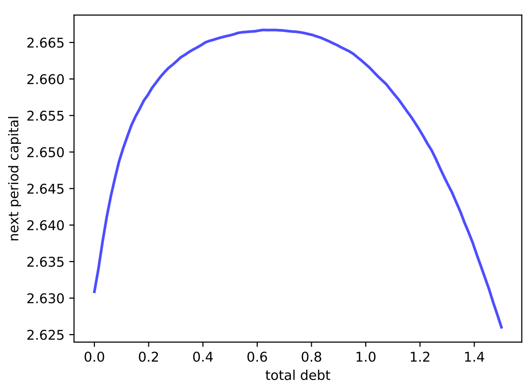
Figure 3: Decision Rules for Next Period Capital



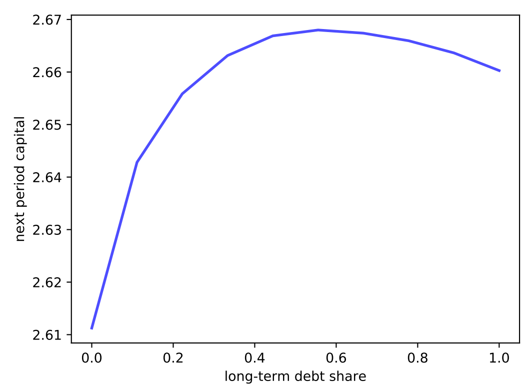
(a) Productivity



(b) Interest Rate



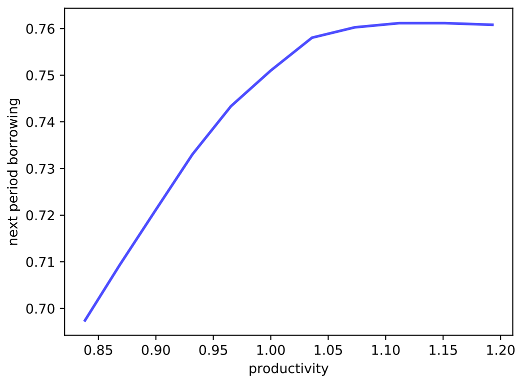
(c) Total Debt



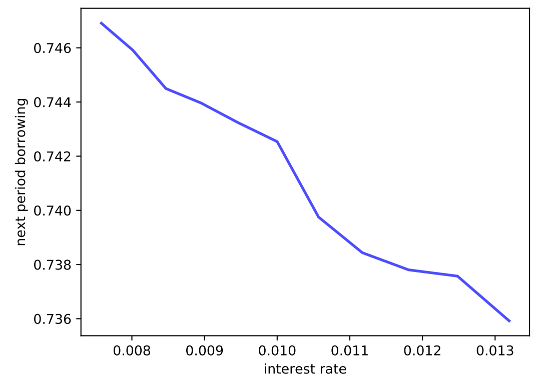
(d) Maturity

Figure 3 plots the average decision rules for next period capital as a function of productivity, the interest rate, total debt, and the 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

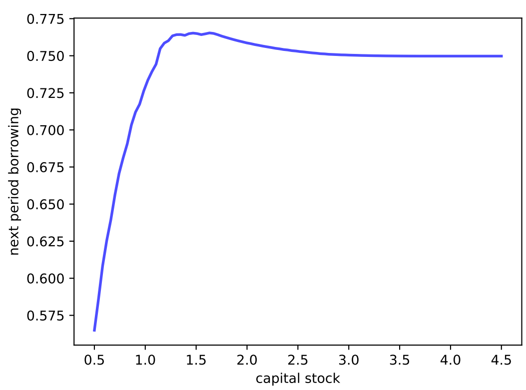
Figure 4: Decision Rules for Next Period Borrowing



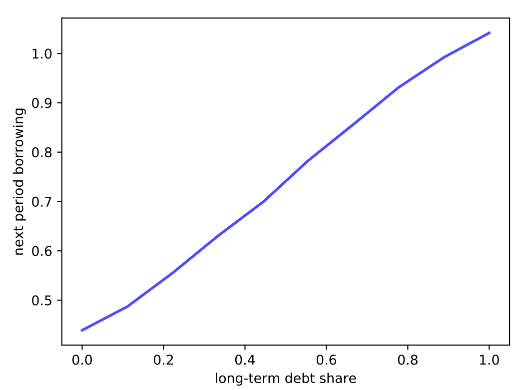
(a) Productivity



(b) Interest Rate



(c) Capital Stock



(d) Maturity

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 the firms. Next period capital as a function of total debt, shown in the Panel (c), exhibits a hump-shaped pattern. When debt rises at low levels of total debt, firms can finance more profitable investment, leading to reduced long-term risk. However, when total debt increases further, the default risk increases and the financing cost spikes, decreasing optimal next period capital. Panel (d) plots next period capital as a function of the long-term debt share. Similar to Panel (c), when firms hold little of their debt as long-term maturities, replacing short-term debt with long-term debt allows for more worthwhile long-term investment to occur. However, too much long-term debt increases the default risk, leading to decreasing investment and next period capital.

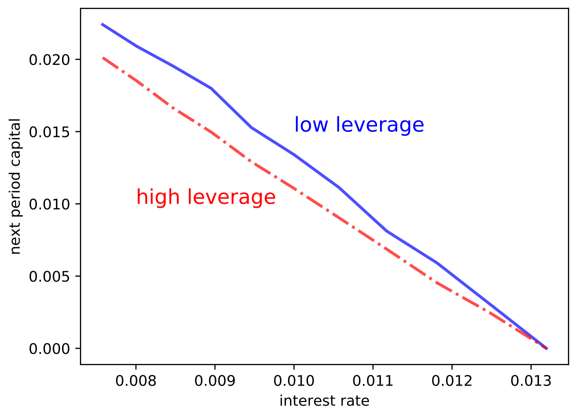
Figure 4 plots the average decision rules for the next period total debt as a function of productivity, the interest rate, current capital stock, and the long-term debt share. Panel (a) plots next period debt as a function of productivity. With higher productivity, firms have a lower default risk, a lower cost of financing, and thus borrow more. However, the debt increases more slowly with productivity when the debt amount is high as more debt increases financing costs, reducing the incentive to expand the firm with productivity. Panel (b) plots next period debt as a function of the interest rate. A higher interest rate increases the financing cost of debt, thus decreasing the borrowing of firms. Panel (c) plots next period debt as a function of the current capital stock. With more capital, the default risk is low, leading to more borrowing. Panel (d) plots next period debt as a function of the long-term debt share. When firms hold more long-term debt, absent default, they will mechanically have more debt next period as most is not repaid.

4.4 Financial Positions and Investment Sensitivity to the Interest Rate

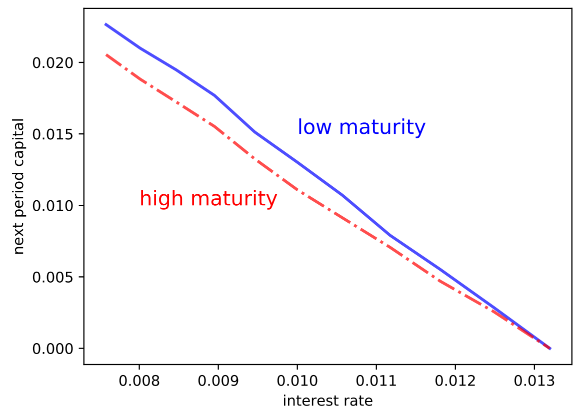
In this subsection, we show how heterogeneity in financial positions affects a firm's investment sensitivity to the interest rate. Figure 5 plots the heterogeneous responses of investment when the interest rate changes for firms in different financial positions (leverage and maturity). In both Panel (a) and Panel (b) of Figure 5, we plot for the average next period capital as a function of the interest rate, and we normalize each series by its value when the interest rate is at the grid maximum. When the interest rate decreases, firms increases investment. Panel (a) compares the decision rules with different level of indebtedness and Panel (b) compares the decision rules with different maturity structures. With high leverage or long maturity, the increase in investment is smaller.

The intuition is that higher leverage leads to higher default risk in the next period which hinders investment incentives. Further, conditional on leverage, longer maturity leads to higher default risk in the future which hinders investment as well. The leverage mechanism is the "distance to default" as in Ottonello and Winberry (2018). Because higher leverage firms are closer to the default boundary, i.e. more financially constrained, their investment decisions are less responsive to external changes in the interest rate. In this paper, we emphasize a second mechanism operating through maturity: longer maturity generates higher future default risk for long-term debt. This mechanism is not documented for monetary policy but is discussed in Diamond and He (2014). In their paper, because long-term creditors face higher future default risk, they ask for better prices on outstand-

Figure 5: Next period capital when interest rate changes



(a) Leverage



(b) Maturity

Notes: This figure plots the decision rules of next period capital with respect to interest rate for different leverage and maturity level. We normalize each series by its value when interest rate is the highest in the grid. The solid blue lines plot for the ones with low leverage (Panel (a)) or low maturity (Panel (b)). The dash-dotted red lines plot for the ones with high leverage (Panel (a)) or high maturity (Panel (b)).

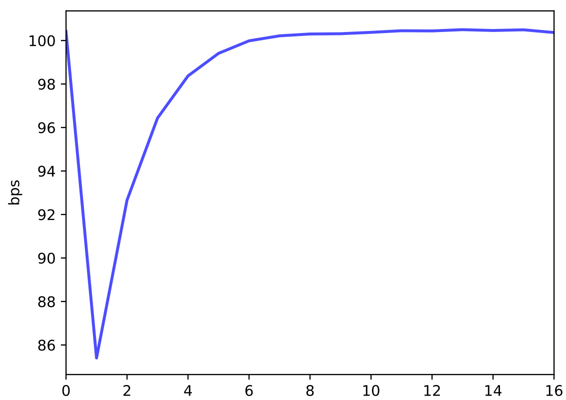
ing long-term debt in the future. Unlike short-term debt which must be paid off next period, part of the benefit of increasing investment following the interest rate cut goes to the creditors instead of equity holders. As a result, firms with more long-term debt are less responsive to monetary policy stimulus.

4.5 Average Responses to Monetary Policy Shocks

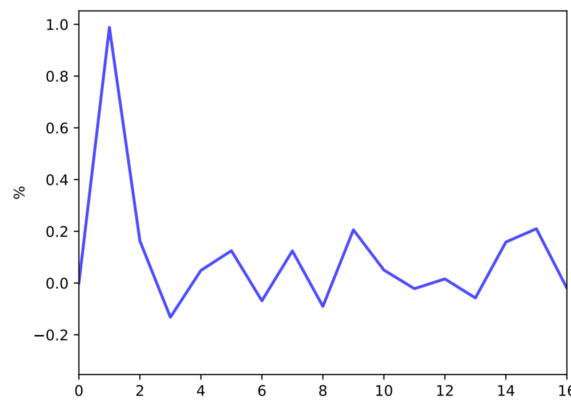
Having presented some key features of bond prices, firm decision rules, and their sensitivity to interest rate changes, we now study firm behavior in aggregate by generating impulse response functions following an expansionary monetary policy shock in the model. We simulate 30,000 paths for the model over 500 periods. In period 401 (period 1 in the figures below), there is a $15bps$ cut in 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 (2018), 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 6: Average Response to Monetary Policy Shock: Investment



(a) Real interest rate



(b) Changes in investment rate

We present the impulse responses of investment for an average firm when there is a 15bps cut in real interest rate (corresponding to the conventional 25bps cut in the federal fund rate). Panel (a) of Figure 6 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) of Figure 6 plots the response of 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).

4.6 Heterogeneous Responses to Monetary Policy Shock

Using the model-simulated data, we conduct regression analysis and show that the model generates the similar heterogeneous responses across the 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 the 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 shock, and its interactions with leverage and maturity, controlling for leverage and maturity, including firm fixed effects as in the empirical regression equation (4):

$$i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \beta_0' x_{jt-1} + \boldsymbol{\beta'} x_{jt-1}\Delta_t^m + \gamma_j + \epsilon_{jt}^s, \tag{14}$$

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 (4). x_{jt-1} represents leverage or maturity in time $t-1$ and γ_j is firm fixed effect.

Table 12: 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)

Table 12 reports the regression coefficients for the model and the data. The coefficients for the data are the ones from Table 6. The model can generate the coefficients in the same direction as in the data. With an expansionary monetary policy shock, an average firm increase its investment rate, because of higher discount factor and cheaper borrowing cost to finance its investment. The heterogeneous responses across firms' leverage and maturity positions are also significant. The magnitude of regression coefficients from the model are also in the ballpark with those in the data. The firms with lower leverage or less long-term debt have lower default risk, and could thus having lower marginal financing cost compared with other firms. With lower marginal financing cost, those firms could catch the good opportunity from the monetary policy stimulus, and invest more.

5. Conclusion

We show that a firm's financial positions affects its investment response to monetary policy shocks. Empirically, firms with more debt, higher leverage, and longer maturity response 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 distance-to-default (Ottonello and Winberry (2018)), leverage (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 another set of financial positions to include both debt issurance and debt maturity.

We show that having debt or not, having how much debt, and having how much long-term debt versus short-term debt all significantly affect the firm-level responses to monetary policy shocks. Since firms borrow and invest differently when there is a monetary policy shock, the effectiveness of a monetary policy shock depends on the distribution of the firms. 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 weaker impact in a country where firms mostly hold long-term debt versus a country where firms mostly hold short-term debt.

Our model successfully matches the heterogeneous investment responses to monetary policy shocks with respect to heterogeneous leverage and maturity. However, one limitation is that our model cannot generate the almost-zero-leverage firms who behave similarly as in the data. In the model, the firm heterogeneous financial positions are driven by idiosyncratic productivity shocks. Model firms only have zero leverage after default because of bad shocks. However, this is not the case in the data, where almost-zero-leverage firms can be very productive, pay dividends, and have high investment rates. Understanding why some firms operate with almost-zero-leverage, incorporating these reasons into the model, and quantitatively evaluating the responses of such firms would be useful future research.

References

Almeida, H, M Campello, B Laranjeira, and S Weisbenner, “Corporate debt maturity and the choice between cash and lines of credit,” *Critical Finance Review*, 2012.

Arellano, Cristina, Yan Bai, and Patrick J Kehoe, “Financial frictions and fluctuations in volatility,” *Journal of Political Economy*, 2019, *127* (5), 2049–2103.

Auer, Simone, Marco Bernardini, Martina Cecioni et al., *Corporate leverage and monetary policy effectiveness in the Euro area*, Banca d’Italia, 2019.

Barclay, Michael J and Clifford W Smith Jr, “The priority structure of corporate liabilities,” *The Journal of Finance*, 1995, *50* (3), 899–917.

Christiano, Lawrence J, Martin Eichenbaum, and Charles L Evans, “Nominal rigidities and the dynamic effects of a shock to monetary policy,” *Journal of political Economy*, 2005, *113* (1), 1–45.

Cloyne, James, Clodomiro Ferreira, Maren Froemel, and Paolo Surico, “Monetary policy, corporate finance and investment,” Technical Report, National Bureau of Economic Research 2018.

Cook, Timothy and Thomas Hahn, “The effect of changes in the federal funds rate target on market interest rates in the 1970s,” *Journal of Monetary Economics*, 1989, *24* (3), 331–351.

Cooley, Thomas F and Vincenzo Quadrini, “Financial markets and firm dynamics,” *American economic review*, 2001, *91* (5), 1286–1310.

Crouzet, Nicolas, “Default, debt maturity, and investment dynamics,” in “2016 Meeting Papers, Society for Economic Dynamics,” Vol. 533 2016.

— and Neil Mehrotra, “Small and Large Firms Over the Business Cycle,” Technical Report 2017.

Darmouni, Olivier, Oliver Giesecke, and Alexander Rodnyansky, “The Bond Lending Channel of Monetary Policy,” 2020.

Diamond, Douglas W and Zhiguo He, “A theory of debt maturity: the long and short of debt overhang,” *The Journal of Finance*, 2014, *69* (2), 719–762.

Fang, Min, “Lumpy Investment, Uncertainty, and Monetary Policy,” *Working Paper. Available at SSRN: https://ssrn.com/abstract=3543513 or http://dx.doi.org/10.2139/ssrn.3543513*, 2020.

Gertler, Mark and Simon Gilchrist, “Monetary policy, business cycles, and the behavior of small manufacturing firms,” *The Quarterly Journal of Economics*, 1994, *109* (2), 309–340.

Gilchrist, Simon, David López-Salido, and Egon Zakrajšek, “Monetary policy and real borrowing costs at the zero lower bound,” *American Economic Journal: Macroeconomics*, 2015, *7* (1), 77–109.

— , Jae W Sim, and Egon Zakrajšek, “Uncertainty, financial frictions, and investment dynamics,” Technical Report, National Bureau of Economic Research 2014.

Gomes, Joao F and Lukas Schmid, “Levered returns,” *The Journal of Finance*, 2010, *65* (2), 467–494.

Gomes, Joao, Urban Jermann, and Lukas Schmid, "Sticky leverage," *American Economic Review*, 2016, *106* (12), 3800–3828.

Gorodnichenko, Yuriy and Michael Weber, "Are sticky prices costly? Evidence from the stock market," *American Economic Review*, 2016, *106* (1), 165–99.

Gürkaynak, Refet S, Brian Sack, and Eric Swanson, "The sensitivity of long-term interest rates to economic news: Evidence and implications for macroeconomic models," *American economic review*, 2005, *95* (1), 425–436.

Hackbarth, Dirk, Jianjun Miao, and Erwan Morellec, "Capital structure, credit risk, and macroeconomic conditions," *Journal of Financial Economics*, 2006, *82* (3), 519–550.

Hennessy, Christopher A and Toni M Whited, "Debt dynamics," *The Journal of Finance*, 2005, *60* (3), 1129–1165.

Jeenas, Priit, "Firm balance sheet liquidity, monetary policy shocks, and investment dynamics," in "Technical Report," Working paper, 2018.

Jordà, Òscar, "Estimation and inference of impulse responses by local projections," *American economic review*, 2005, *95* (1), 161–182.

Kashyap, Anil K, Owen A Lamont, and Jeremy C Stein, "Credit conditions and the cyclical behavior of inventories," *The Quarterly Journal of Economics*, 1994, *109* (3), 565–592.

Khan, Aubhik, Tatsuro Senga, and Julia K Thomas, "Default risk and aggregate fluctuations in an economy with production heterogeneity," *Manuscript, Ohio State University*, 2014.

Lakdawala, Aeimit and Timothy Moreland, "Monetary Policy and Firm Heterogeneity: The Role of Leverage Since the Financial Crisis," *Available at SSRN 3405420*, 2019.

Miao, Jianjun, "Optimal capital structure and industry dynamics," *The Journal of finance*, 2005, *60* (6), 2621–2659.

Ottonello, Pablo and Thomas Winberry, "Financial Heterogeneity and the Investment Channel of Monetary Policy," Technical Report, National Bureau of Economic Research 2018.

Palazzo, Berardino and Ram Yamarthy, "Credit Risk and the Transmission of Interest Rate Shocks," 2020.

Romer, Christina D and David H Romer, "A new measure of monetary shocks: Derivation and implications," *American Economic Review*, 2004, *94* (4), 1055–1084.

Silva, Mario Rafael, "Corporate finance, monetary policy, and aggregate demand," *Journal of Economic Dynamics and Control*, 2019, *102*, 1–28.

Strebulaev, Ilya A and Baozhong Yang, "The mystery of zero-leverage firms," *Journal of Financial Economics*, 2013, *109* (1), 1–23.

Vats, Nishant, "What Does Financial Heterogeneity Say About the Transmission of Monetary Policy?," *Available at SSRN 3559650*, 2020.

Wong, Arlene, "Population aging and the transmission of monetary policy to consumption," in "2016 Meeting Papers," Vol. 716 Society for Economic Dynamics 2016.

Zwick, Eric and James Mahon, "Tax policy and heterogeneous investment behavior," *American Economic Review*, 2017, *107* (1), 217–48.

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 13.

Table 13: **Sample Selection**

Compustat North America Quarterly, 1990-2008	**665,869**
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
AZL firms	**61,850**
non-AZL firms	**141,306**
All firms	**203156**

A.3 Additional Results: Dynamics

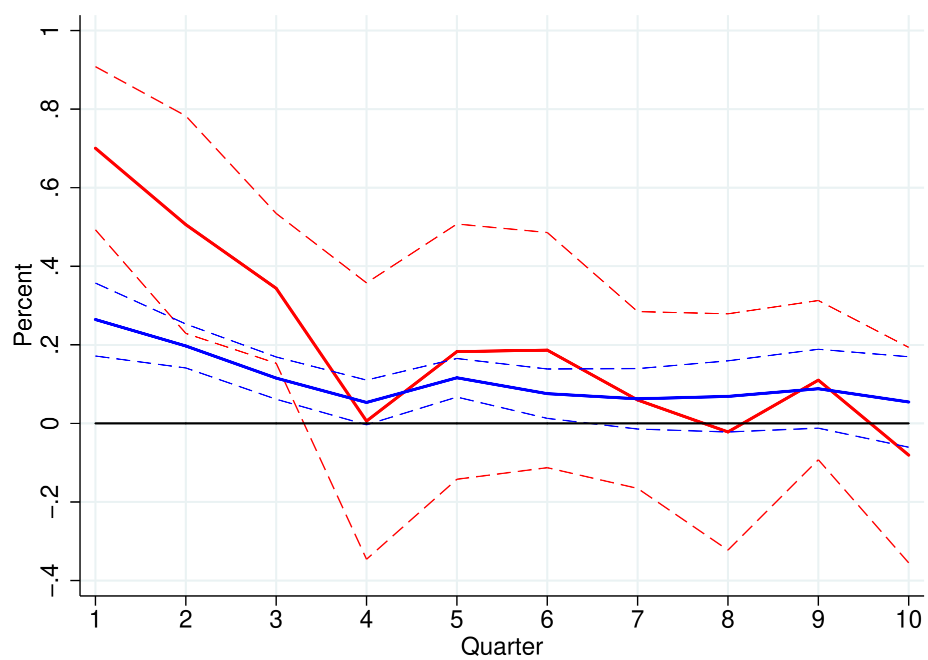
Investment is well known to be lumpy. The response of firm-level investment to monetary policy shocks may exhibit lags (as the hump-shaped aggregate responses in the VAR literature). To study the dynamics in a way that preserves comparability to the VAR literature, we employed the Local Projection method of Jordà (2005) to estimate the average and marginal effects of monetary shocks on firm investment. The local projection method does not require strong assumptions in model specification as does a VAR approach, and hence suffers less from mis-specification of the model. Further, compared to a panel VAR, a Local Projection can take advantage of the fixed effects model with various firm-level controls.

The estimation specification is:

$$i_{jt+k} = (\boldsymbol{\alpha_k}\Delta_t^m + \beta'_{0k}x_{jt-1} + \boldsymbol{\beta'_k}x_{jt-1}\Delta_t^m) \times i(AZL) \\ + \Gamma'_k Z_{jt-1} + \Psi'_k Agg_{t-1} + \gamma_{jk} + \gamma_{qk} + \gamma_{sk} + \epsilon^s_{jtk} \tag{15}$$

where k denotes k quarters ahead for both variables and coefficients. Equation (3) is very close to equation (2), except the k denoted variable i_{jt+k} and their coefficients. The coefficients of interest are $\boldsymbol{\alpha_k}$ for both groups of firms, which indicate the average effect for k quarters in the future for a monetary policy shock at time t, given all the independent variables in the previous quarter $t-1$. Figure 7 shows the dynamics of the two groups of firms in the pooled sample. The AZL firms are in red, while the non-AZL firms are in blue.

Figure 7: Dynamics of Response in Investment



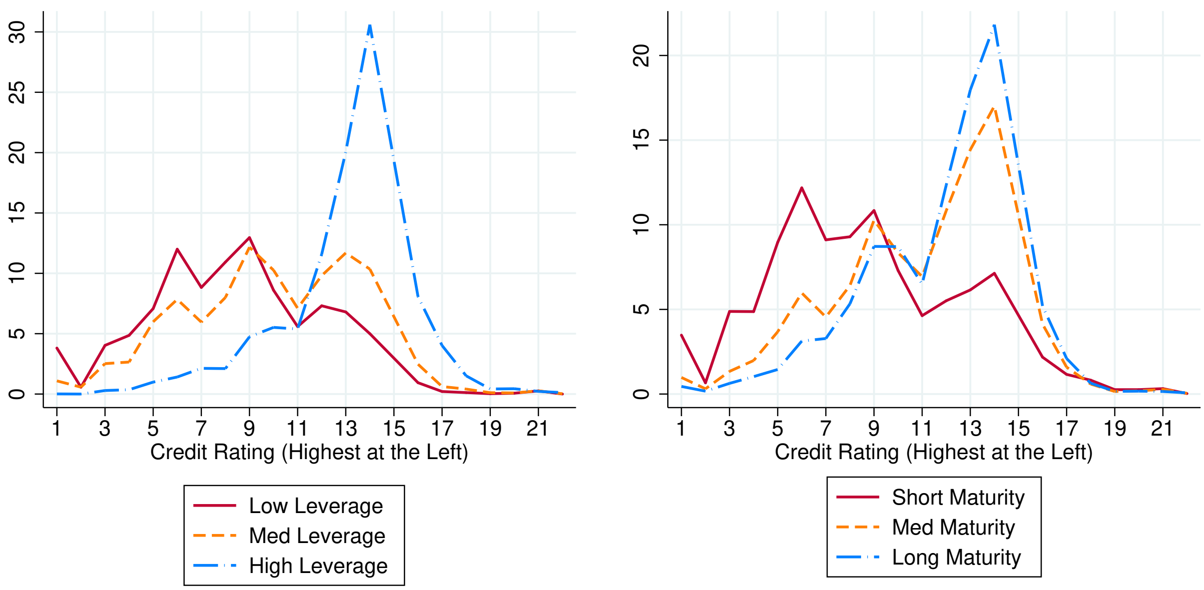
Notes: The blue line is the impulse responses of non-AZL firms and the red line is the impulse responses of AZL firms. Both dashed lines indicates the 95% confidence interval.

A.4 Additional Results: S&P Credit Rating

We argue that the heterogeneous responses by leverage and maturity from non-AZL firms[11] are at least partially driven by firm heterogeneity in default risk. To provide evidence on how default risk affects the power of monetary policy shocks, we employ the credit ratings of corporate bonds from Standard Poor. 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 (the lowest, selective default). We then merge this data set with our main sample described before; the merged sample contains 39,084 firm-quarter observations.

Figure 8: Credit Rating Distributions

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



First, we show that firm heterogeneity in leverage and maturity is linked to credit ratings. Figure 8 plots the distribution of firm credit ratings for three groups by their leverage and maturity structure. 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 BB. This pattern sticks for the three groups by maturity, among which the long maturity group also has credit ratings concentrated around BB. In contrast, the credit rat-

[11]There is almost no credit rating data for AZL firms, but we believe that AZL firms face no default risk at all.

ings of both the low leverage and low maturity groups have a peak around AA-. We also show in Table 14 that there are negative relationships between credit rating and both leverage and maturity (1 denotes the best rating and 22 denotes the worst rating) after controlling for various firm-level characteristics.

Table 14: **Debt Status on 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
Aggregate Controls	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

Second, we show that firms with high credit ratings are more responsive in investment to monetary policy shocks. We extend the regression in equation (2) by adding credit rating into the vector of firm controls, $y_{j,t-1}$. The results are plotted in Table 15. First, the average effect of monetary policy stimulus on firm investment is positive and consistent across all regressions, however, the point estimate change slightly because the sample was reduced to one third of the original sample. In row two, we show that the heterogeneous effect because of leverage is still significant and indicates a larger semi-elasticity after controlling for credit rating. In row three, the heterogeneous effect because of maturity is no longer significant after controlling for credit ratings. An alternative explanation is that since the credit ratings are only for long-term debt, which is highly co-linear with both leverage and maturity, the explanatory power of the regression was reduced. In row four of each column, we see that the marginal effect of higher credit ratings would significantly improve investment under an expansionary monetary policy shock.

Table 15: **Heterogeneous Investment Responses by Credit Ratings**

$i_{j,t}$	(1)	(2)	(3)
Δ_t^m	0.20***	0.11***	0.14***
	(-6.25)	(-2.85)	(-3.02)
Δ_t^m x $lev_{j,t-1}$	-0.63**		-0.47*
	(2.51)		(1.75)
Δ_t^m x $mat_{j,t-1}$	-0.25		-0.09
	(1.38)		(0.46)
Δ_t^m x $\{Rating_{j,t-1} \geq AA\}$		0.28***	0.21***
		(-4.67)	(-3.19)
N	39084	39084	39084
R^2	0.060	0.060	0.060
Firm Controls	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

A.5 Robustness Check: Monetary Policy Shocks

In Table 16, 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. We run the same regression as in the full paper. All the point estimates are very stable in terms of significance, signs, and magnitudes.

In Table 17, we show the regression using a sub-sample that excludes all pre-1994 data. As the Fed evolved over time, their post-1994 actions and policy rules likely became more transparent, possibly creating a structural break. The resulting point estimations of the average effect fall slightly but remain significant for all regressions. The exception is the significance of leverage interacting with monetary policy shocks, which is reduced, but the signs and magnitudes do not show large

Table 16: **Heterogeneous Investment using shocks with 60 mins window**

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.183***	0.184***	0.185***	0.186***
	(0.037)	(0.037)	(0.038)	(0.038)
Δ_t^m x $lev_{j,t-1}$		-0.295*		-0.277*
		(0.167)		(0.164)
Δ_t^m x $mat_{j,t-1}$			-0.289**	-0.270*
			(0.141)	(0.137)
N	105110	105110	105110	105110
R^2	0.040	0.040	0.040	0.041
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

movements for any variables.

In Table 18, 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 (2018). 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. We again run the same regression as in the main text. The point estimates of average investment responses are quite stable in terms of significance, signs, and magnitudes. The only noticeable change is the significance of leverage and maturity

Table 17: **Heterogeneous Investment with Post-1994 Period**

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.125***	0.126***	0.129***	0.130***
	(0.042)	(0.042)	(0.043)	(0.043)
Δ_t^m x $lev_{j,t-1}$		-0.182		-0.161
		(0.170)		(0.169)
Δ_t^m x $mat_{j,t-1}$			-0.303*	-0.291*
			(0.173)	(0.170)
N	105110	105110	105110	105110
R^2	0.040	0.040	0.040	0.041
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

interacting with monetary policy shocks, where both are lessened, but the signs remain positive and consistent.

A.6 Robustness Check: Financial Positions

In Table 19, we show the investment responses considering the permanent components of firms' financial positions. The permanent components are defined as mean leverage lev¯ j and mean maturity mat¯ j over a firm's life cycle throughout the sample. We run the same regression as per the main strategy in the full paper. First, in all regressions, the point estimates for the average effect are robustly similar. Second, we found that semi-elasticity of investment in terms of the permanent component of leverage is significant, while for maturity it is not. This suggests that the heterogeneous responses by leverage are coming from the prominent component, while the prominent component for maturity does not matter for the effects of monetary transmission.

In Table 20, we run similar regression as in Table 19, but now with the transitory component, which is $(lev_{jt} - l\bar{e}v_j)$ and $(mat_{jt} - m\bar{a}t_j)$. The results are interesting. First, the point estimates

Table 18: **Heterogeneous Investment with Smoothed Shocks**

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.332***	0.330***	0.332***	0.331***
	(0.045)	(0.045)	(0.045)	(0.045)
Δ_t^m x $lev_{j,t-1}$		-0.335		-0.331
		(0.238)		(0.237)
Δ_t^m x $mat_{j,t-1}$			-0.085	-0.062
			(0.158)	(0.156)
N	105110	105110	105110	105110
R^2	0.040	0.040	0.040	0.041
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

for the average effect are still robust. Second, the transitory component shows opposite patterns to Table 4. Now we observe that the transitory component of leverage has no distributional effects, while the transitory component of maturity exhibits a strong negative semi-elasticity. Combining both tables together, the distributional effects occur in terms of the permanent component of leverage and the transitory component of maturity, and these two measures show different aspects of the distributional effects of financial frictions.

In Table 21, we examine the distributional effects considering the interactions of monetary policy shocks with other firm-level characteristics capturing firm size. We captured different aspects of size using total assets, sales, and sales growth. Again, the point estimates of average effects are robust. The estimates of the semi-elasticity with respect to maturity are also robust. However, after controlling for size or sales, the significance of the leverage semi-elasticity dropped, though the signs and magnitudes still remain. Since the effective part of leverage is mainly coming from the permanent component, and size and sales are mostly permanent characteristics, the reduction in significance is natural.

Table 19: **Heterogeneous Investment with Permanent Financial Positions**

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.180***	0.179***	0.180***	0.179***
	(0.039)	(0.040)	(0.039)	(0.039)
Δ_t^m x $lev_{j,t-1}$		-0.374*		-0.375*
		(0.209)		(0.204)
Δ_t^m x $mat_{j,t-1}$			-0.052	0.012
			(0.228)	(0.219)
N	105110	105110	105110	105110
R^2	0.028	0.028	0.028	0.028
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table 20: **Heterogeneous Investment with Transitory Financial Positions**

i_{jt}	(1)	(2)	(3)	(4)
Δ_t^m	0.185***	0.186***	0.186***	0.187***
	(0.036)	(0.037)	(0.036)	(0.037)
Δ_t^m x $lev_{j,t-1}$		-0.185		-0.205
		(0.216)		(0.212)
Δ_t^m x $mat_{j,t-1}$			-0.555**	-0.560**
			(0.233)	(0.232)
N	105110	105110	105110	105110
R^2	0.040	0.040	0.040	0.040
Firm Controls	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

Table 21: **Heterogeneous Investment with Other Firm Characteristics**

i_{jt}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δ_t^m	0.27***	0.26***	0.26***	0.26***	0.26***	0.28***	-0.27***
	(-7.86)	(-6.97)	(-7.08)	(-7.09)	(-7.18)	(-7.51)	(-7.59)
Δ_t^m x $lev_{j,t-1}$	-0.23		-0.23		-0.22		-0.23
	(1.15)		(1.12)		(1.08)		(1.15)
Δ_t^m x $mat_{j,t-1}$	0.19**		0.17*		0.17**		0.19**
	(-2.13)		(-1.97)		(-2.01)		(-2.13)
Δ_t^m x $size_{j,t-1}$		0.00***	0.00***				
		(-3.83)	(-3.75)				
Δ_t^m x $sales_{j,t-1}$				0.00**	0.00**		
				(-2.36)	(-2.29)		
Δ_t^m x $sales^g_{j,t-1}$						0.00	0.00
						(-0.04)	(-0.02)
N	105110	105110	105110	105110	105110	105110	105110
R^2	0.041	0.041	0.041	0.041	0.041	0.040	0.041
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: All regressions include firm fixed effect,quarter fixed effect, two-digit SIC sector fixed effect and two-digit SIC sector clustering. t statistics in parentheses. * p<0.1, ** p<0.05, *** p<0.01

B. Theoretical Appendix

B.1 Transformation of the Model

In stead of keeping track of short-term debt b_S and long-term debt b_L, we recast the model in terms of total debt b and the share of long-term debt f, where $f = \frac{b_L}{b_S+b_L}$, 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 Section 3. The state variables for a firm is 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 any firm is given by:

$$
\begin{aligned}
D = (1-\tau)\underbrace{[zk^{\alpha}-\delta k]}_{\text{Taxable Income}} - \underbrace{(b(1-f)+\lambda bf)}_{\text{Principal Repayment}} - \underbrace{(k'-k)}_{\text{Gross Investment}} - \underbrace{\frac{\theta_k}{2}(\frac{k'}{k}-1)^2 k}_{\text{Capital Adjustment Cost}} \\
+ \underbrace{q_S(z,k',r,b',f')b'(1-f') + q_L(z,k',r,b',f')(b'f'-(1-\lambda)bf)}_{\text{Revenue from Debt Issuance}} \\
- \underbrace{[\theta_{bS}(b'(1-f'))^2 + \theta_{bL}(b'f'-(1-\lambda)bf)^2]}_{\text{Debt Issuance Cost}},
\end{aligned} \tag{17}
$$

The value of the firm when continuing operation is:

$$
v^c(z,k,r,b,f) = \max_{k',b',f',D} \left\{ D - \psi + (1-\epsilon)E_t\Lambda_{t,t+1} \iint v(z',k',r',b',f')f(z',z)dz'f(r',r)dr' \right\} \tag{18}
$$

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

$$
\begin{aligned}
q_S(z,k',r,b',f') = \frac{1-\epsilon}{1+r}[\iint_{z^*}^{\infty} f(z',z)dz'f(r',r)dr' \\
+ \iint_{-\infty}^{z^*} \frac{R(z',k',r',b',f')}{b'} f(z',z)dz'f(r',r)dr']
\end{aligned} \tag{19}
$$

$$q_L(z,k',r,b',f') = \frac{1-\epsilon}{1+r}\Big[\iint_{z^*}^{\infty}(\lambda+(1-\lambda)q_L')f(z',z)dz'f(r',r)dr' + \iint_{-\infty}^{z^*}\frac{R(z',k',r',b',f')}{b'}f(z',z)dz'f(r',r)dr'\Big] \tag{20}$$

where

$$z^*(k,r,b,f) = \{z : v^c(z,k,r,b,f) = 0\} \tag{21}$$

$$R(z,k,r,b,f) = max(\chi[(1-\tau)(zk^\alpha - \delta k) + k - \frac{\theta_k}{2}k],0) \tag{22}$$

$$b' = \tilde{b}(z,k,r,b,f) \tag{23}$$

$$f' = \tilde{f}(z,k,r,b,f) \tag{24}$$

$$q_L' = q_L(z',k'',r',\tilde{b}(z',k',r',b',f'),\tilde{f}(z',k',r',b',f')) \tag{25}$$

B.2 Computational Methods

This appendix describes the algorithm for computing the model. We compute the transformed model as discussed in Section B.1. We first discretize the shock processes and state variables. We then solve the model vis value function iteration. We discretize the AR(1) process for the z and r shock respectively using 11 equally spaced grid points with Tauchen's method. For the bond B we use a grid with 100 equally spaced points on $B \in [0, 1.5]$, 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 $k \in [0.5, 4.5]$. 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

Markov process 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.