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Debt maturity heterogeneity and investment responses to monetary policy[☆]

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ABSTRACT

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

1. Introduction

Investment is a key channel of monetary transmission, one which is often influenced by financial constraints faced by firms. While the severity of these financial constraints are partially reflected by firm size, age, leverage, liquidity, and other firm characteristics, one often ignored but relevant dimension is the maturity structure of a firm's debt. The maturity structure differs across firms and across time as shown in Fig. 1. Whether debt is due immediately or in several years could make quite a difference in the severity of a firm's financial constraints. Therefore, a crucial question is: Does this debt maturity heterogeneity matter for the investment channel of monetary policy?

There are two reasons why the answer to this question is important. First, in the cross-section dimension, the answer may be of independent interest to policymakers who are concerned about the distributional effects of monetary policy across firms. Second, in the time-series dimension, the answer could be helpful to understand the effectiveness of monetary policy when the debt maturity

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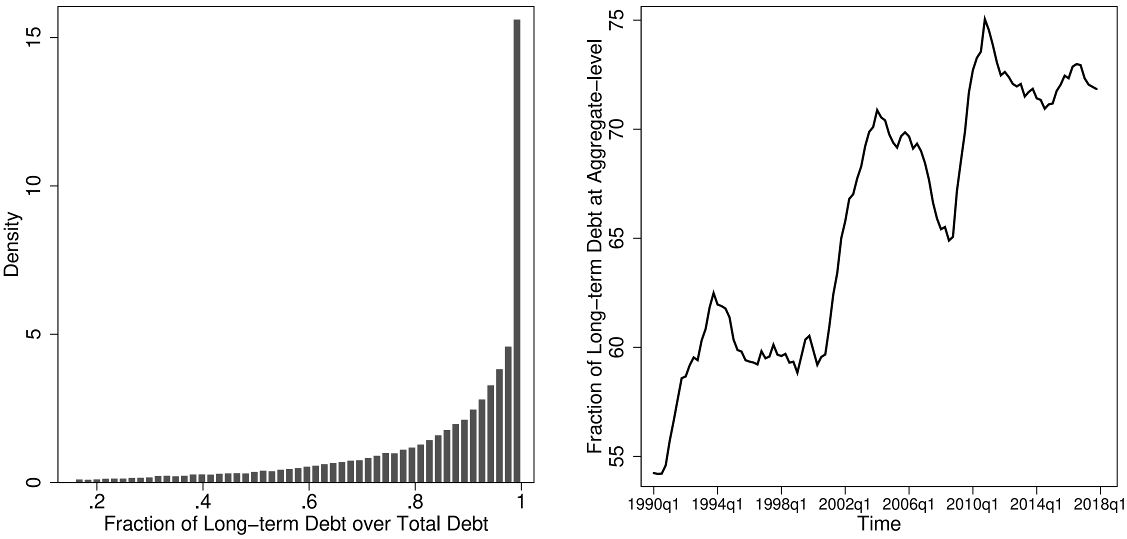


(a) Cross-section (b) Time-series

Fig. 1. Debt maturity in the cross-section and time-series.
Notes: Long-term debt is defined as debt with an outstanding maturity of more than 1 year. This figure shows that the maturity structures differ across firms and across time. Panel (a) is calculated from the non-financial Compustat Sample used in this paper. Panel (b) is the share of long-term debt in credit market liabilities of the non-agricultural non-financial corporate business sector from Fabiani et al. (2020). We are very grateful to Andrea Fabiani for providing us the time-series data. For the details of the construction, please refer to the data section in Fabiani et al. (2020).

structure changes over time, especially, as shown in Fig. 1, since average debt maturity changes over the business cycle and there is also a general trend of lengthening debt maturity.

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

Our empirical work combines monetary policy shocks, measured using high-frequency changes in Federal Funds Futures rates, with firm-level variables from Compustat Quarterly. We focus on how the semi-elasticity of investment with respect to monetary policy shocks depends on firms' debt maturities. Our estimates show that firms holding more long-term debt are significantly less responsive to monetary policy shocks on the impact of the shock as well as in the following dynamic responses using the (Jordà, 2005)-style local projections. These heterogeneous responses are significant after controlling the interactions of monetary shocks with the well-studied firm characteristics such as leverage, distance-to-default, size, age, and liquidity, which emphasizes the role played by a relevant additional dimension of heterogeneity: debt maturity. We also show that these long maturity firms also have lower credit ratings on their long-term bonds and take on less long-term debt in response to monetary expansions. These results show that the potentially higher default risk associated with holding more long-term debt lessens firm investment responses to monetary policy expansions.

We then develop a model with firms borrowing using both short-term and long-term debt to interpret these facts. The model features heterogeneous firms who face idiosyncratic productivity shocks. They 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 defaulted firms to creditors. Thus, the fundamental frictions are similar to Cooley and Quadrini (2001), Hennessy and Whited (2005), or (Gomes and Schmid, 2010).

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

The mechanism in our model is as follows. An expansionary monetary policy shock works through two channels. First, it increases the stochastic discount factor of firms since firms are owned by households. This increases the marginal benefit of investment, so all firms would prefer to invest more. Second, it lowers the external borrowing costs to finance investment. However, the effect from the second channel depends on firm debt maturity: firms with more long-term debt have weaker responses. Consider two firms with the same level of leverage, but one firm has more long-term debt. Since the long-term debt will not be paid off in the next period, the firm with more long-term debt will have higher debt and a higher default probability for the next period. With higher future default risk, the firms with more long-term debt respond less when there is an expansionary monetary policy shock, as the lenders are also aware of the higher future default risk.

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

We highlight the role of debt maturity theoretically in several aspects. First, we compare firm future default probabilities across different debt maturities, conditional on the same level of leverage. We show that firms whose long-term debt accounts for a larger share of their debt have higher future default risk, even when they have the same level of leverage. Second, we compare our model to a reference model with only short-term debt. The benchmark model with long-term debt generates a higher level of future borrowing given productivity or total indebtedness. Third, we analyze the role of debt maturity in affecting firm investment responses to monetary policy shocks. With a larger share of long-term debt, the increase in investment is smaller facing a monetary policy easing.

Finally, we estimate our empirical specification on panel data simulated from our model and find that the model can replicate our empirical findings. In particular, the model shows that the firms with more long-term debt are less responsive to expansionary monetary policy shocks. Also, the dynamics of the heterogeneous investment responses are persistent in the model, consistent with the data. Quantitatively, the dynamics of the responses stay within the data's 90% confidence interval. Together with the empirical findings, the theoretical model and its quantitative results emphasize the key role of debt maturity heterogeneity in the transmission of monetary policy shocks to firm investment.

Related Literature: This paper contributes to several strands of literature. First, this paper is related to the large literature of studies on financial frictions and their implications for the aggregate economy. Some influential examples include but are not limited to Gomes and Schmid (2010), Cooley and Quadrini (2001), Gilchrist and Zakrajšek (2012), Gilchrist et al. (2014), Khan and Thomas (2013), Khan et al. (2014), Crouzet (2018), and Arellano et al. (2019). We contribute by making maturity choice an integral part of the firm's capital structure decision, and emphasizing the relevance of debt maturity positions for shock-responsiveness.

Second, we contribute to the rapidly expanding literature that studies how the effect of monetary policy varies across firms by showing that firms with more long-term debt are less responsive to expansionary monetary policy. Other recent work argues that the firm-level response also depends on leverage/distance-to-default (Ottonello and Winberry, 2020; Lakdawala and Moreland, 2021; Anderson and Cesa-Bianchi, 2020; Auer et al., 2019), liquidity (Jeenas, 2018), age (Cloyne et al., 2018), and many other firm characteristics.[3] Our findings are consistent with these previous findings and provide further evidence on another key dimension of firm financing—debt maturity.

Among all these studies, the mostly closely related paper to ours is Ottonello and Winberry (2020) which studies the debt-investment relationship in the content of monetary policy. They study U.S. public firms' investment responses to monetary policy shocks conditional on leverage and distance to default measures as proxies for default risk. They show that firms with higher default risk are less responsive to monetary policy shocks both in the data and in a heterogeneous firm New Keynesian model with defaultable one-period bonds. Our results emphasize the role of the additional default risk embedded in having more long-term debt conditional on these existing proxies of leverage and distance to default. We extend the (Ottonello and Winberry, 2020) model to include endogenous debt maturity choices and show that debt maturity also matters for the investment responses to monetary policy.

Third, this paper is related to the dynamic capital structure and investment in corporate finance literature. Since the seminal contribution of Myers (1977), the corporate finance literature has provided different explanations on how debt might encourage or discourage investment. A large literature (Myers and Majluf, 1984; Titman and Wessels, 1988; Harris and Raviv, 1991; Smith Jr. and Watts, 1992; Denis and Sibilkov, 2010) has studied the determinants of capital structure choice and investment. We are most related to papers that emphasize the role of debt maturity (Barclay and Smith Jr., 1995; Almeida et al., 2012; Diamond and He, 2014; Jungherr and Schott, 2020). In a recent paper, 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

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

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

[3] Others include credit risk (Palazzo and Yamarthy, 2020), bond versus bank lending (Darmouni et al., 2020), asset pledgeability (Silva, 2019), and creditor rights (Vats, 2020).

this maturity trade-off into a context with monetary policy shocks. We show that the debt overhang from holding more long-term debt weakens firm investment responses to monetary expansions.

Finally, this paper is related to the large empirical literature studying the effects of monetary policy shocks using high-frequency identified (HFI) exogenous proxies for monetary policy. Pioneered by Cook and Hahn (1989), the high-frequency event-study approach has been widely adopted in macroeconomics and finance (Kuttner, 2001; Gürkaynak et al., 2005; Rigobon and Sack, 2004; Gertler and Karadi, 2015; Gorodnichenko and Weber, 2016). Wong (2016) aggregates the event-studies to quarterly measures which yields a feasible proxy for monetary shocks in studying the shock-responsiveness of households and firms behaviors.[4] This paper applies the HFI method to another dimension of firm heterogeneity, debt maturity, and verifies the results of several recent studies which also rely on the HFI method of monetary policy shocks.

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

2. Empirical evidence

This section provides empirical evidence on how firms change their investment when facing an expansionary monetary policy shock, and how the magnitude varies across the firms depending on their debt maturity positions. Section 2.1 describes the data. Section 2.2 shows that firms holding more long-term debt invest less in response to an expansionary monetary policy shock and the responses are persistent. Sections 2.3 and 2.4 provide further complementary evidence using credit ratings data and heterogeneous borrowing behaviors across firms.

2.1. Data description

Firm-Level Panel Data: We obtain firm-level panel data from Compustat Quarterly, which contains quarterly balance-sheet information on publicly listed U.S. firms. The quarterly database has several advantages: quarterly frequency, which is the highest frequency we could obtain at the firm level; a sufficiently long data history, covering the whole period for which we have a monetary policy shock measure; and rich and detailed financial information, giving us the opportunity to extensively control for firm characteristics.[5]

The key variables are investment, borrowing, and debt maturity, which are constructed following standard methods. Investment i_{jt} is defined as the ratio (×100%) of quarterly capital expenditures (*capxy*) to the lag of quarterly property, plant and equipment (*ppentq*) as in Almeida et al. (2012), Chaney et al. (2012), and Cloyne et al. (2018)[6]; 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 (*Δdlttq*) and changes in short-term debt (*Δdlcq*) over total debt (*dlcq+dlttq*) respectively (both ×100%). Finally, debt maturity m_{jt} is constructed as the ratio of debt maturing in more than 1 year (*dlttq*) over total debt (*dlcq+dlttq*).

We also construct key control variables, especially leverage and distance-to-default as in Ottonello and Winberry (2020) to show that the maturity channel captures more than do current measures of default risk.[7] 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 distance-to-default is constructed as in Gilchrist and Zakrajšek (2012) and Blanco and Navarro (2016). Other controls include age as in Cloyne et al. (2018), size (represented by total assets), cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. The data selection criteria approach follows (Almeida et al., 2012). We disregard observations from the financial sector (SICs 6000–6999), NGO and governmental enterprises (SICs 8000s & 9000s), and utilities (SICs 4900–4999). We drop firm-quarter observations with missing or negative sales, with more than 100% sales or asset growth in a quarter, with cash

4 The advantage of the HFI method is that by examining a narrow window around the announcement, this ensures that the identified monetary policy shock is relatively clearer than other measures. However, the HFI method relies heavily on the variations of the Federal Fund Rate Futures (therefore, the sample period is limited, and there is very limited variations in the zero lower bound era) as well as suffering from central bank information effects as shown in Nakamura and Steinsson (2018). In a recent paper, Jarociński and Karadi (2020) proposes a measure removing the central bank information effects. Our results are robust when adopting the (Jarociński and Karadi, 2020)-measure.

5 However, it has two shortcomings: first, it only includes public firms, which excludes private and smaller firms; second, detailed debt maturity data is only available in the Fundamentals Annual. Despite these flaws, it covers a large fraction of U.S. output as a rough measure. The nominal gross margin (sales minus cost of goods sold) of all non-financial U.S. Compustat firms in 2006 is roughly 3.4 trillion USD (calculated by authors) while the nominal gross value added of non-financial corporate business in 2006 is 7 trillion USD (Fred data series: A455RC1Q027SBEA). The Compustat sample also offers substantial variation within and between firms.

6 The measure is consistent with the perpetual inventory method in Ottonello and Winberry (2020) which uses $\Delta log k_{jt+1}$ as the investment expenditure rate at period t, where k_{jt+1} is the book value of the tangible capital stock of firm j at the end of period t. 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.

7 The Black–Scholes–Merton distance-to-default measure is constructed with the assumption of constant maturity of debt. The additional default risk embedded in having more long-term debt conditional on the same leverage is potentially not captured in the measure.

Table 1
Key statistics for firm-level variables.

Statistics	Inv.(%)	Mat.	Lev.	dd	Δb(%)	Δb^L(%)	Δb^S(%)
Observation	141,306	141,306	141,265	113,843	125,380	125,380	125,380
Mean	5.8	0.842	0.35	4.81	0.039	3.0	0.9
Median	4.2	0.917	0.32	4.13	−.001	−1.6	0.0
Std	5.4	0.187	0.19	3.95	0.307	28.2	13.4
Max	40.7	1.000	0.95	40.23	12.902	1167.7	562.9
75%	7.4	0.985	0.46	6.93	0.052	2.9	1.4
25%	2.3	0.764	0.21	1.96	−0.044	−3.5	−0.8
Min	−5.2	0.159	0.06	−4.36	−0.928	−92.1	−83.0

Notes: The data is from Compustat Quarterly. Investment is defined as the ratio of quarterly capital expenditures (For the first fiscal quarter, we use *capxy* directly. For the second to the last fiscal quarter, we use changes in *capxy* since *capxy* is the year-to-date capital expenditures.) to the lag of quarterly property, plant and equipment (*ppentq*). Maturity > 1 (Mat.) is defined as the ratio of long-term debt to total debt. Leverage (Lev.) is defined as the debt-to-assets ratio and distance-to-default (dd) is measured as in Gilchrist and Zakrajšek (2012). Variables Investment (Inv.), Borrowing (Δb), Borrowing in Long-term Debt (Δb^L), and Borrowing in Short-term Debt (Δb^S) are all measured in percentage points.

Table 2
Statistics of monetary policy shocks.

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

Note: $\Delta_e^{m,30}$ denotes the high frequency shock measure using a 30 min window (10 min before the announcement and 20 min after the announcement), $\Delta_e^{m,60}$ denotes the high frequency shock measure using a 60 min window (15 min before the announcement and 45 min after the announcement), $\Delta_t^{m,tight}$ denotes $\Delta_e^{m,30}$ aggregated to a quarterly series, and $\Delta_t^{m,wide}$ denotes $\Delta_e^{m,60}$ similarly aggregated. Among the 175 announcements, there are 23 unscheduled meeting announcements other than the 8 regularly scheduled meetings per year. Excluding these unscheduled meeting announcements does not make a qualitative difference to the results.

holdings larger than assets, with capital expenditures or property, plant and equipment larger than total assets, and with potentially mis-measured debt structures. Details of variable construction and sample selection are in the Online Appendix A.1 and A.2. We present the summary statistics of key variables in Table 1 as well as for control variables in the Online Appendix A.3.

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

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

$$\Delta_e^m = \tau(e) \times (ffr_{e+\Delta_+} - ffr_{e-\Delta_-}) \quad (1)$$

where e is the time of a monetary announcement event and ffr_t is the implied Federal Funds rate from a current-month Federal Funds futures contract at time e. 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. $\tau(e) = \frac{\tau^n(e)}{\tau^n(e)-\tau^d(e)}$ 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. $\tau^d(e)$ denotes the day of the meeting in the month and $\tau^n(e)$ 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.[8] Therefore, our empirical analysis is only applicable to conventional monetary policy regimes.

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

To match our quarterly firm-level data in Compustat, we sum up the identified shocks Δ_e^m within the same quarter to generate a quarterly measure of the shock series Δ_t^m (t denotes the quarter) from the first quarter in 1990 to the last quarter in 2008. The statistics are summarized in Table 2 and a time series plot is provided in the Online Appendix A.3. The differences between the tight and wide 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. We also consider other forms of high-frequency-identified monetary policy shocks including a smoothed measure as in Ottonello and Winberry (2020) and a measure removing central bank information effects as in Jarociński and Karadi (2020). We provide a summary of both in the Online Appendix A.3.

2.2. Heterogeneous investment responses to monetary policy

We first empirically test how the investment decisions of firms respond to monetary policy shocks given their within-firm variation in financial positions including the maturity structures of their debt and other indicators of default risk including leverage and distance-to-default.

Baseline Specification. Our baseline empirical specification is:

$$i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \boldsymbol{\beta}' \left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right)\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt} \tag{2}$$

where i_{jt} is the firm-level investment rate which builds into capital at quarter t+1 where $i_{jt} = 1$ stands for a 1% corporate investment rate therefore $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}'$ could be directly interpreted as $\boldsymbol{\alpha}$% and $\boldsymbol{\beta}'$% changes in the firm's investment rate. Δ_t^m is the monetary policy shock occurring at quarter t, X_{jt-1} is a vector capturing firm j's financial positions at quarter $t-1$, including lagged maturity m_{jt-1}, leverage l_{jt-1}, and distance-to-default dd_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including X_{jt-1}, total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j and γ_{qs} are firm fixed effects and sector-seasonality fixed effects where $q = \{1, 2, 3, 4\}$ stands for calendar quarter (seasonality) in a year. Finally, γ_t are time fixed effects to absorb all aggregate shocks. Since controlling for γ_t completely absorbs the variations in $\boldsymbol{\alpha}\Delta_t^m$, in order to compare the heterogeneous effects in $\boldsymbol{\beta}'$ to the average effect $\boldsymbol{\alpha}$,[9] we shut down the time fixed effects in some regressions. The error term ϵ_{jt} is two-way clustered at both the firm level and quarterly time level.

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

Our main coefficient of interest is $\boldsymbol{\beta}'$, which measures how the semi-elasticity of investment i_{jt} with respect to monetary shocks Δ_t^m depends on the within-firm variation in the financial positions $\left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right)$, in particular for this paper, $\left(maturity_{jt-1} - \mathbb{E}_j[maturity_{jt}]\right)$. Using the interaction of within-firm variation in financial positions with the monetary shock $\left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right)\Delta_t^m$ ensures that our results are not driven by permanent heterogeneity in responsiveness across firms. This choice is consistent with our economic model in the theoretical part, in which firms are assumed to be ex-ante homogeneous.[10]

Baseline Results. Table 3 shows the results. In Columns (1), (2), and (5), we do not control for the time fixed effect, so we can compare the heterogeneous effect relative to the average effect. First, Column (1) shows the average response. A conventional unit easing of the monetary policy shock increases the average corporate investment rate by 0.185%. Column (2) shows that the heterogeneous responses depending on a firm's debt maturity, and Column (5) shows that these heterogeneous responses depending on firm's debt maturity are not reflected in firm's leverage (level of debt) and/or distance-to-default. The coefficients of the interaction terms between monetary shocks and maturity are significantly negative, showing that the firms with more long-term debt are less responsive to the expansionary monetary policy shocks.

In Columns (3), (4), and (6), we replace the aggregate controls with time fixed effects to validate the heterogeneous effects of a monetary shock. In these empirical specifications, the average effect is not available anymore. After controlling for debt level heterogeneity reflected in leverage or distance-to-default as in Ottonello and Winberry (2020), the coefficients of $\Delta_t^m \times \left(mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}]\right)$ are still significant and the magnitudes do not change much. It shows that the heterogeneous responses due

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

[10] However, this is not necessary the case in the data. For instance, firms in industries with longer sales turnover may be permanently borrowing more long-term debt and potentially facing higher default risk. Our results may be partly determined by such permanent differences in responsiveness if we interact the level of financial position with the monetary shock.

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

Table 3
Heterogeneous responses of investment to monetary policy.

i_{jt}	(1)	(2)	(3)	(4)	(5)	(6)
Δ_t^m	0.185**	0.186**	–	–	0.207**	–
	(0.075)	(0.075)	(.)	(.)	(0.085)	(.)
$\Delta_t^m \times (mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}])$		−0.555***	−0.663***	−0.748***	−0.615***	−0.750***
		(0.181)	(0.184)	(0.201)	(0.213)	(0.202)
$\Delta_t^m \times (lev_{j,t-1} - \mathbb{E}_j[lev_{j,t}])$			−0.319*		0.357	0.495
			(0.187)		(0.373)	(0.365)
$\Delta_t^m \times (dd_{j,t-1} - \mathbb{E}_j[dd_{j,t}])$				0.082***	0.059**	0.090***
				(0.028)	(0.029)	(0.031)
N	104737	104737	104737	88648	88648	88648
adj. R^2	0.365	0.365	0.373	0.368	0.360	0.368
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Seasonality FE	Yes	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	–	–	Yes	–
Time FE	No	No	Yes	Yes	No	Yes
Time-Firm Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results from estimating $i_{jt} = \alpha\Delta_t^m + \beta' (X_{jt-1} - \mathbb{E}_j[X_{jt}])\,\Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}$ where i_{jt} is the firm-level investment rate which builds into capital at quarter $t+1$, Δ_t^m is the monetary policy shock occurring at quarter t, X_{jt-1} is a vector capturing firm j's financial position at quarter $t-1$, including lagged maturity m_{jt-1}, leverage l_{jt-1}, and distance-to-default dd_{jt-1}. Z_{jt-1} is a vector of lagged firm-level controls, including X_{jt-1}, total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j and γ_{qs} are firm fixed effects and quarter-sector seasonality fixed effects, respectively. Finally, γ_t are time fixed effects to absorb all aggregate shocks. Since controlling for γ_t completely absorbs the variations in $\alpha\Delta_t^m$, in order to compare the heterogeneous effects in β' to the average effect α,[11] we shut down the time fixed effects in some regressions. The error term ϵ_{jt} is two-way clustered at both the firm level and quarterly time level. The sign "—" means estimations not available.
*Significance level: $p < 0.1$.
**Significance level: $p < 0.05$.
***Significance level: $p < 0.01$.

to debt maturity are not well explained by leverage or distance-to-default. Also, the magnitude of the debt maturity channel is comparable to the existing channels. In terms of magnitudes, Column (3) provides a comparison between the maturity channel and the leverage channel. In our sample, one standard deviation of maturity is $sd_{mat} = 0.187$, one standard deviation of leverage is $sd_{lev} = 0.19$, and one standard deviation of distance-to-default is $sd_{dd} = 3.95$. According to the corresponding coefficients of −0.663 and −0.319, the heterogeneous responses due to debt maturity are comparable (twice) to the magnitude explained by debt leverage. Column (4) provides a comparison between the maturity channel and the distance-to-default channel. According to the corresponding coefficients of −0.748 and 0.082, the heterogeneous responses due to debt maturity is comparable (43%) to the magnitude explained by distance-to-default.

Finally, we focus on Column (6) for quantitative interpretations.[12] For firms with debt maturity one standard deviation longer than average ($sd_{mat} = 0.187$), this effect is reduced by 0.14% (0.75×0.187). Compared to the average effect of 0.207%, a standard deviation longer in debt maturity generates 68% ($0.14\%/0.207\%$) less of an investment response. More importantly, controlling for the interaction of monetary shocks with distance-to-default does not affect the signs or significance of the coefficient of interaction of monetary shocks with maturity. Our explanation for this follow from the Black–Scholes–Merton distance-to-default measure being constructed with the assumption of constant maturity of debt. The additional default risk embedded in having more long-term debt conditional on the same leverage is not captured in the measure. These results indicate that the investment responses of firms to monetary policy shocks differ significantly depending on their debt maturity structure.

Dynamics Specification. In order to estimate the dynamics of the differential responses, we employed the (Jordà, 2005)-style *local projection* version of our baseline specification (2):

$$\sum_{\tau=t+0}^{\tau=t+h} i_{j\tau} = \beta_h' (X_{jt-1} - \mathbb{E}_j[X_{jt}])\,\Delta_t^m + \Gamma_h' Z_{jt-1} + \gamma_{jh} + \gamma_{qsh} + \gamma_{th} + \epsilon_{jth} \tag{3}$$

where $h \geq 0$ denotes h quarters ahead for both variables and coefficients. The dependent variable, accumulation of past investment into capital stock, is approximated through the following transformation: $\sum_{\tau=t+0}^{\tau=t+h} i_{j\tau} = logk_{jt+h} - logk_{jt}$. The coefficient β_h' measures how the cumulative response of investment in quarter $t+h$ to a monetary policy shock in quarter t depends on the firm's demeaned financial position X_{jt-1} in quarter $t-1$. The coefficient α_h measures the average cumulative response of investment in quarter $t+h$ to the same monetary policy shock.

[12] Column (6) shows that distance-to-default captures the default risk embedded in leverage as in Ottonello and Winberry (2020). In both their findings and this paper, when controlling for $\Delta_t^m \times (dd_{j,t-1} - \mathbb{E}_j[dd_{j,t}])$, the coefficient of $\Delta_t^m \times (lev_{j,t-1} - \mathbb{E}_j[lev_{j,t}])$ is not significant anymore.

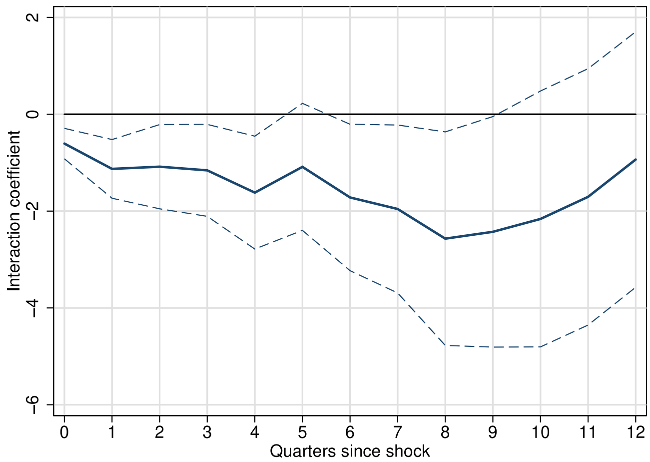
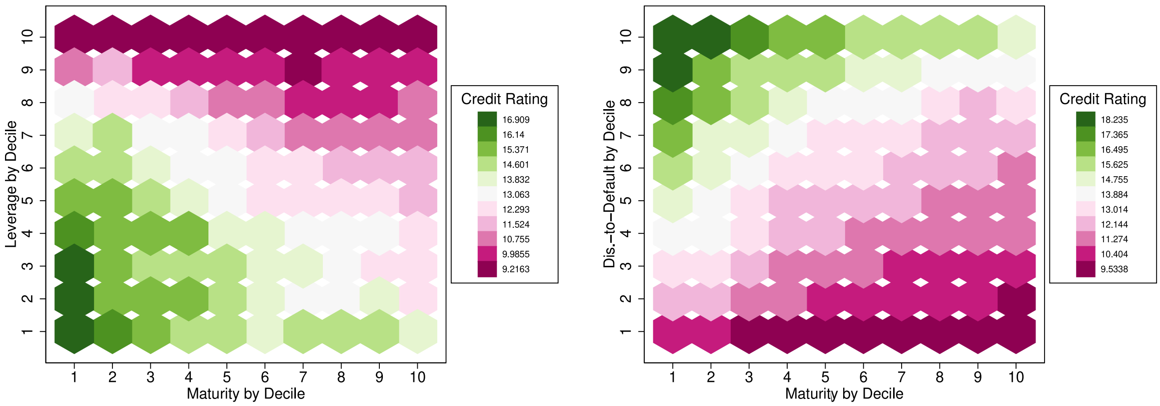


Fig. 2. Dynamics of heterogeneous responses to monetary policy.
Notes: Dynamics of the interaction coefficient between debt maturity positions and the monetary shock over time. The figure reports the coefficient β_h over quarters h from $\sum_{\tau=t+0}^{\tau=t+h} i_{j\tau} = \beta_h' \left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right) \Delta_t^m + \Gamma_h' Z_{jt-1} + \Psi_h' Agg_{t-1} + \gamma_{jh} + \gamma_{qsh} + \epsilon_{jth}$,where all variables are defined in the notes for Table 3. Dashed lines indicate the 90% confidence interval.



(a) Maturity and Leverage (b) Maturity and Distance-to-Default

Fig. 3. Credit rating distributions over maturity and leverage/distance-to-default.
Notes: This figure shows the heatmaps of credit rating over the two-dimension distribution of maturity and leverage or distance-to-default. Maturity, leverage, and distance-to-default are equally divided into ten deciles, therefore, 10*10 = 100 groups. We then calculate the average credit rating of each group: green bins represent higher credit ratings and purple bins represent lower credit ratings. This figure shows that default risk embedded in having more long-term debt is not fully captured in either leverage or distance-to-default.

Eq. (3) is very close to Eq. (2), except that on the left-hand side is the cumulative responses in investment ($\sum_{\tau=t+0}^{\tau=t+h} i_{j\tau}$). The coefficients of interest are $\boldsymbol{\beta}_h$ for the within-firm debt maturity variation interacting with monetary policy shocks across periods $h \in [0, 1, \ldots, H]$, which indicate the heterogeneous effect for h quarters in the future for a monetary policy shock at quarter t, given all the independent variables in the previous quarter $t-1$.

Dynamics Results. Fig. 2 shows the dynamics of $\boldsymbol{\beta}_h$ for the interaction term of monetary policy and firms' debt maturities $\Delta_t^m \times \left(mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}]\right)$. The peak of the differences by maturity occurs after eight quarters and the differences disappear after twelve quarters. Focusing on the point estimations, the differences are quite persistent. However, these persistent differences are less precisely estimated with larger standard errors, so for the rest of the paper, we mainly focus on the effect of the shock on impact at quarter zero.

Robustness Checks and Additional Empirical Results. Online Appendix B provides two sets of robustness checks and additional empirical results. The first set contains a number of robustness checks of our main results regarding monetary policy shocks. Online Appendix B.1 provides robustness checks with respect to alternative monetary policy shocks including the identified 60-minute window shocks, identified smoothed aggregation as in Ottonello and Winberry (2020), as well as identified monetary policy shocks controlling for the central bank information channel of monetary policy as in Jarociński and Karadi (2020).

Table 4
Heterogeneous responses of investment to monetary policy by long-term bond credit ratings.

i_{jt}	(1)	(2)	(3)	(4)	(5)	(6)
Δ_t^m	0.180***	0.126*	–	–	0.139*	–
	(0.062)	(0.065)	(.)	(.)	(0.070)	(.)
Δ_t^m x $\{Rating_{j,t-1} \geq A\}$		0.254***	0.227***	0.249**	0.287***	0.248***
		(0.083)	(0.080)	(0.095)	(0.087)	(0.093)
$\Delta_t^m \times (mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}])$		−0.215	−0.438	−0.275	−0.046	−0.277
		(0.265)	(0.326)	(0.279)	(0.274)	(0.279)
$\Delta_t^m \times (lev_{j,t-1} - \mathbb{E}_j[lev_{j,t}])$			−0.603**		−0.268	−0.145
			(0.269)		(0.518)	(0.486)
$\Delta_t^m \times (dd_{j,t-1} - \mathbb{E}_j[dd_{j,t}])$				0.033*	0.009	0.031
				(0.020)	(0.019)	(0.019)
N	38997	38997	38997	32584	32584	32584
adj. R^2	0.468	0.468	0.476	0.472	0.463	0.472
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Seasonality FE	Yes	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	–	–	Yes	–
Time FE	No	No	Yes	Yes	No	Yes
Time-Firm Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results from estimating $i_{jt} = \boldsymbol{\alpha}\Delta_t^m + \boldsymbol{\beta}'\left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right)\Delta_t^m + \boldsymbol{\beta}'\mathbf{1}_{CR_{jt-1}>A}\Delta_t^m + +\gamma_z' Z_{jt-1} + \gamma_a' Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}$ where i_{jt} is the firm-level investment rate which builds into capital at quarter $t+1$, Δ_t^m is the monetary policy shock occurring at quarter t, X_{jt-1} is a vector capturing firm j's financial positions at quarter $t-1$, including lagged maturity m_{jt-1}, leverage l_{jt-1}, and distance-to-default dd_{jt-1}. $\mathbf{1}_{CR_{jt-1}>A}$ is an indicator of credit rating better than or equal to A (number grade: 17). Z_{jt-1} is a vector of lagged firm-level controls, including X_{jt-1}, total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j and γ_{qs} are firm fixed effects and quarter-sector seasonality fixed effects, respectively. And finally, γ_t are time fixed effects to absorb all aggregate shocks. Since controlling for γ_t completely absorbs the variations in $\boldsymbol{\alpha}\Delta_t^m$, in order to compare the heterogeneous effects in $\boldsymbol{\beta}'$ to the average effect $\boldsymbol{\alpha}$,[13] we shut down the time fixed effects in some regressions. The error term ϵ_{jt} is two-way clustered at both the firm level and quarterly time level. The sign "—" means estimations not available.

*Significance level: $p < 0.1$.

**Significance level: $p < 0.05$.

***Significance level: $p < 0.01$.

The second set contains a number of robustness checks relating our main results to various strands of the existing literature on other characteristics of firm-level heterogeneity. Online Appendix B.2 provides robustness checks on firm-level characteristics, including interactions of the monetary shock with un-meaned financial positions, interactions of the monetary shock with the permanent component of financial positions, and controlling for interactions of the monetary shock with other firm-level covariates in the literature. Online Appendix B.2 provides robustness checks using a dynamic panel regression controlling for up to the last four quarters of firm-level investment.

We relate our findings to empirical studies documenting heterogeneous responses across firms with different distance-to-default/leverage, liquidity, and age. First, as we already shown in Table 3, firms with higher leverage or shorter distance-to-default are less responsive to monetary shocks, consistent with recent work by Ottonello and Winberry (2020). Second, firms with fewer liquid assets reduce investment relative to others in response to monetary shocks, consistent with (Jeenas, 2018). Finally, younger firms are more responsive to monetary shocks, consistent with (Cloyne et al., 2018). The coefficient of interaction of monetary shocks with debt maturity is still significant after controlling for interactions of monetary shocks with all other firm-level covariates. These additional results and robustness checks suggest that the results of the baseline estimation in Table 3 are robust.

2.3. Evidence from S&P credit ratings

We argue that the heterogeneous responses by maturity are at least partially driven by firm heterogeneity in default risk embedded in their long-term debt, which is not captured by well-studied indicators of default risk (leverage or distance-to-default) . To provide evidence on how default risk embedded in firms' long-term debt affects the effect of monetary policy, we employ the credit ratings of corporate bonds from Standard & Poor, which are only available for long-term bonds. The data is from 1990 to 2008, with monthly credit ratings for most U.S. listed firms. Corporate bonds are graded into 22 groups from AAA+ (the highest, 22) to SD (selective default, the lowest, 1). We merge this with our Compustat sample, resulting in 49,066 firm-quarter observations.

First, we show that firm heterogeneity maturity is linked to credit ratings. Fig. 3 plots the heatmaps of credit rating over the two-dimension distribution of maturity and leverage or distance-to-default. Maturity, leverage, and distance-to-default are equally

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

Table 5
Borrowing responses to monetary policy long-term debt vs short-term debt.

	(A). Long-term Debt Δb^L_{jt}			(B). Short-term Debt Δb^S_{jt}		
	(1)	(2)	(3)	(1)	(2)	(3)
Δ^m_t	0.389*	0.395*	–	0.093	0.089	–
	(0.223)	(0.224)	(.)	(0.111)	(0.112)	(.)
$\Delta^m_t \times (mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}])$		−4.137**	−4.321**		2.802	3.147
		(2.059)	(2.114)		(1.714)	(2.035)
$\Delta^m_t \times (lev_{j,t-1} - \mathbb{E}_j[lev_{j,t}])$			7.432**			2.894**
			(3.002)			(1.221)
$\Delta^m_t \times (dd_{j,t-1} - \mathbb{E}_j[dd_{j,t}])$			0.357***			0.005
			(0.133)			(0.039)
N	104737	104737	88648	104737	104737	88648
adj. R^2	0.057	0.057	0.058	0.101	0.101	0.102
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Sector-Seasonality FE	Yes	Yes	Yes	Yes	Yes	Yes
Aggregate Controls	Yes	Yes	–	–	Yes	–
time FE	No	No	Yes	Yes	No	Yes
Time-Firm Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results from estimating $\Delta b_{jt} = \boldsymbol{\alpha}\Delta^m_t + \boldsymbol{\beta}'\left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right)\Delta^m_t + +\gamma'_z Z_{jt-1} + \gamma'_a Agg_{t-1} + \gamma_j + \gamma_{qs} + \gamma_t + \epsilon_{jt}$ where $\Delta b_{jt} = \{\Delta b^L_{jt}, \Delta b^S_{jt}\}$ is the firm-level long-term (short-term) debt borrowing rate which builds into long-term (short-term) debt at quarter $t+1$, Δ^m_t is the monetary policy shock occurring at quarter t, X_{jt-1} is a vector capturing firm j's financial positions at quarter $t-1$, including lagged maturity m_{jt-1}, leverage l_{jt-1}, and distance-to-default dd_{jt-1}. $\mathbf{1}_{CR_{jt-1}>A}$ is an indicator of credit rating larger than or equal to A (number grade: 17). Z_{jt-1} is a vector of lagged firm-level controls, including X_{jt-1}, total assets, cash holdings, revenue, sales, sales growth, profits, earnings volatility, and net equity issuance. Agg_{t-1} is a vector of aggregate controls, including the VIX index, GDP growth, unemployment rate, and inflation. γ_j and γ_{qs} are firm fixed effects and quarter-sector seasonality fixed effects, respectively. Finally, γ_t are time fixed effects to absorb all aggregate shocks. Since controlling for γ_t completely absorbs the variations in $\boldsymbol{\alpha}\Delta^m_t$, in order to compare the heterogeneous effects in $\boldsymbol{\beta}'$ to the average effect $\boldsymbol{\alpha}$,[14]we shut down the time fixed effects in some regressions. The error term ϵ_{jt} is two-way clustered at both the firm level and quarterly time level. The sign "—" means estimations not available.
*Significance level: $p < 0.1$.
**Significance level: $p < 0.05$.
***Significance level: $p < 0.01$.

divided into ten deciles, therefore, 10*10=100 groups. We then calculate the average credit rating of each group: green bins represent higher credit ratings and purple bins represent lower credit ratings. This figure shows that default risk embedded in having more long-term debt is not fully captured in either leverage or distance-to-default. Conditional on the level of leverage/distance-to-default, having more long-term debt lowers a firm's credit rating. Online Appendix C.1 provides additional empirical results on the relationships between credit rating and maturity, leverage, and distance-to-default.

Second, we show that firms with high credit ratings in their long-term debt invest more in response to monetary policy shocks. We extend the regression in the baseline specification (2) by adding the interaction of long-term bond credit ratings with monetary shocks. Since the sample is smaller and there is not too much variation across time, we use an indicator if a firm's long-term bonds are rated above A: $CR_{j,t-1} \geq A$ as in Ottonello and Winberry (2020). This indicator reflects whether a firm's long-term bonds are riskier, which is highly correlated with both the level of leverage and more importantly maturity. Table 4 reports the results. Since the credit ratings reflect the higher default risk embedded within the maturity, leverage, and distance-to-default measures of a firm, the explanatory power of all three measures are reduced. These results indicate that the higher default risk stemming from having more long-term debt is hindering firm responses to monetary expansions.

2.4. Heterogeneous borrowing responses to monetary policy

We then test how firm borrowing behavior responds to monetary policy shocks given their debt maturities. The empirical specification is the same as the baseline specification Eq. (2), except we replace the dependent variables with Δb_{jt} (changes in debt).

To further explore the potential heterogeneous responses in terms of borrowing, we decompose debt borrowing Δb_{jt} into long-term debt borrowing Δb^L_{jt}, and short-term debt borrowing Δb^S_{jt}. Interestingly, we find heterogeneous responses for firms when we look at long-term debt and short-term debt separately. In Table 5, we report the results from estimating Eq. (2) with the dependent variable being either long-term debt Δb^L_{jt} or short-term debt Δb^S_{jt} in Panel (A) and Panel (B), respectively. We show that an average

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

firm borrows roughly 0.40% more long-term debt following a monetary expansion. However, they do not increase short-term debt borrowing. This finding is consistent with recent work by Fabiani et al. (2020) who shows that a loosening of the policy rate lengthens corporate debt maturity. Online Appendix C.2 provides additional empirical results on firms' borrowing responses.

We then compare the heterogeneous effects across the firms. Panel (A) shows that firms with longer maturity profiles are statistically significantly less responsive in taking on long-term debt. A one standard deviation increase in maturity (0.187) lowers long-term debt borrowing by 0.81% (0.187×−4.321). Combined with the coefficient of Δ_t^m, a firm with almost exclusively long-term debt would not take on any new long-term debt. Panel (B) shows that firms do not adjust their short-term debt given a monetary expansion. These results further indicate that higher default risk from having more long-term debt hinders firm investment responses to monetary expansions partially through more costly external financing in long-term debt.

2.5. Remarks on empirical evidence

We show significant heterogeneities in firm-level responses to monetary policy with heterogeneous debt maturity. Firms with more long-term debt invest less following an expansionary monetary shock. These heterogeneous responses are not explained by leverage or existing distance-to-default measures and are consistent with credit ratings of long-term bonds which reflect default risks. Further, firms with more long-term debt issue less long-term debt following an expansionary monetary policy shock. All these findings indicate that firms' financial positions in terms of maturity play an essential role in shaping firm-level responses to monetary policy shocks. More specifically, besides the role of having a higher level of debt, the higher default risk embedded in having more long-term debt also hinders firm investment responses to monetary expansions.

3. Model

Motivated by our empirical findings, we build a heterogeneous firm model to explain the mechanism. The model economy consists of heterogeneous firms making investment and financing decisions and a monetary authority controlling the real interest rate. Firms are subject to their own idiosyncratic productivity shocks and aggregate interest rate shocks from the monetary authority. Firms can borrow by issuing both short-term and long-term debt. Each firm j ($j \in [0,1]$) decides investment, debt issuance, dividend, and whether to default on its debt in each period. Given the complex financial heterogeneity in the model, we assume that monetary policy directly affects the real interest rate.[15]

3.1. Firms

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

$$y_{jt} = z_{jt} k_{jt}^{\alpha}, \qquad \alpha \in (0,1) \tag{4}$$

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

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

$$b_{L,t+1} = (1-\lambda)\, b_{L,t} + n_{L,t}, \tag{5}$$

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

The dividend of the firm is given by:

$$\begin{aligned} D = (1-\tau)\ & \underbrace{[zk^{\alpha} - \delta k]}_{\text{Taxable Income}} - \underbrace{(b_S + \lambda b_L)}_{\text{Principal Repayment}} - \underbrace{(k'-k)}_{\text{Gross Investment}} - \underbrace{\frac{\theta_k}{2}(\frac{k'}{k} - 1)^2 k}_{\text{Capital Adjustment Cost}} \\ & + \underbrace{q_S(z,k',r,b_S',b_L')\, b_S' + q_L(z,k',r,b_S',b_L')\, \left(b_L' - (1-\lambda)b_L\right)}_{\text{Revenue from Debt Issuance}} - \underbrace{\left[\theta_{bS} b_S'^2 + \theta_{bL}\left(b_L' - (1-\lambda)b_L\right)^2\right]}_{\text{Debt Issuance Cost}}, \end{aligned} \tag{6}$$

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

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

3.2. Recursive formulation

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

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

$$v(z,k,r,b_S,b_L) = \max\left\{v^c(z,k,r,b_S,b_L),\ 0\right\}. \tag{7}$$

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

$$v^c(z,k,r,b_S,b_L) = \max_{k',b'_S,b'_L,D}\left\{D - \psi + (1-\pi_d)\,\mathbb{E}\Lambda v(z',k',r',b'_S,b'_L)\right\}, \tag{8}$$

where ψ is a fixed cost for operating, including all costs that arise independently of production, for example maintenance costs and administrative costs. π_d is an exogenous firm exit rate. The stochastic discount factor is $\Lambda = \beta(1+r^*)/(1+r)$, where r^* is the steady state interest rate.[16] If the firm does not default, the payment to the short-term debt creditors is 1, and the payment to the long-term debt creditors is λ. The outstanding fraction $(1-\lambda)$ of long-term debt is valued by creditors at the end-of-period bond price q'_L. Thus the value of owning one unit of a long-term bond that is not in default is $\lambda + (1-\lambda)q'_L$.

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

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

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

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

$$R(z,k,r,b_S,b_L) = \max\{\chi[(1-\tau)(zk^\alpha - \delta k) + k - \frac{\theta_k}{2}k],\ 0\} \tag{9}$$

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

Given this characterization of the debt and default decisions, we can now define equilibrium bond prices. The foreign lenders are competitive and risk neutral.[17] They face a risk-free interest rate r and are willing to purchase firm bonds as long as they break even in expected value. The lenders are aware that firms may default on their bonds. Thus, the break-even condition implies the price functions for short-term and long-term bonds:

$$q_S(z,k',r,b'_S,b'_L) = \frac{1-\pi_d}{1+r}\left[\mathbb{E}(1-d(z',k',r',b'_S,b'_L)) + \mathbb{E}d(z',k',r',b'_S,b'_L)\frac{R(z',k',r',b'_S,b'_L)}{b'_S+b'_L}\right], \tag{10}$$

$$\begin{aligned} q_L(z,k',r,b'_S,b'_L) = \frac{1-\pi_d}{1+r}\Big[&\mathbb{E}(1-d(z',k',r',b'_S,b'_L))(\lambda+(1-\lambda)q'_L) \\ &+ \mathbb{E}d(z',k',r',b'_S,b'_L)\frac{R(z',k',r',b'_S,b'_L)}{b'_S+b'_L}\Big], \end{aligned} \tag{11}$$

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

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

[17] Since foreign lenders are not directly affected by the domestic monetary policy, our framework provides a clear mechanism to show the (heterogeneous) impact of monetary policy on firm-level investment. The assumption of risk neutrality is a simplification. As shown in Uribe and Schmitt-Grohé (2017), compared with risk neutral foreign lenders, the assumption of risk averse foreign lenders has quantitatively negligible effects on the predictions of the model.

3.3. Monetary policy

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

3.4. Equilibrium

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

1. The firm's choices for capital $k'(z,k,r,b_S,b_L)$, short-term debt $b'_S(z,k,r,b_S,b_L)$, long-term debt $b'_L(z,k,r,b_S,b_L)$, default set $d(z,k,r,b_S,b_L)$, and its value functions $v^c(z,k,r,b_S,b_L)$ and $v(z,k,r,b_S,b_L)$ solve its optimization problem (8).
2. The firm bond price schedules (10) and (11) reflect each firm's default probabilities and satisfy the lenders' break-even conditions.
3. Consistency. Future firm decision rules $H_k = k''(z',k',r',b'_S,b'_L)$, $H_{b_S} = b''_S(z',k',r',b'_S,b'_L)$, $H_{b_L} = b''_L(z',k',r',b'_S,b'_L)$, and $H_d = d'(z',k',r',b'_S,b'_L)$ are consistent with the firm choices.

3.5. Transformed problem

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

$$\begin{aligned} D = (1-\tau) & \underbrace{[zk^\alpha - \delta k]}_{\text{Taxable Income}} - \underbrace{(b(1-f)+\lambda bf)}_{\text{Principal Repayment}} - \underbrace{(k'-k)}_{\text{Gross Investment}} - \underbrace{\frac{\theta_k}{2}(\frac{k'}{k}-1)^2 k}_{\text{Capital Adjustment Cost}} \\ &+ \underbrace{q_S(z,k',r,b',f')b'(1-f') + q_L(z,k',r,b',f')(b'f'-(1-\lambda)bf)}_{\text{Revenue from Debt Issuance}} \\ &- \underbrace{[\theta_{bS}(b'(1-f'))^2 + \theta_{bL}(b'f'-(1-\lambda)bf)^2]}_{\text{Debt Issuance Cost}}, \end{aligned} \tag{12}$$

The value of the firm when continuing operation is:

$$v^c(z,k,r,b,f) = \max_{k',b',f',D} \left\{ D - \psi + (1-\pi_d)\mathbb{E}\Lambda v(z',k',r',b',f') \right\} \tag{13}$$

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

$$q_S(z,k',r,b',f') = \frac{1-\pi_d}{1+r}\left[\mathbb{E}(1-d(z',k',r',b',f')) + \mathbb{E}d(z',k',r',b',f')\frac{R(z',k',r',b',f')}{b'}\right], \tag{14}$$

and

$$\begin{aligned} q_L(z,k',r,b',f') = & \frac{1-\pi_d}{1+r}\Big[\mathbb{E}(1-d(z',k',r',b',f'))(\lambda+(1-\lambda)q'_L) \\ & + \mathbb{E}d(z',k',r',b',f')\frac{R(z',k',r',b',f')}{b'}\Big], \end{aligned} \tag{15}$$

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

4. Quantitative analysis

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

Table 6
Fixed parameters.

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

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

Table 7
Fitted parameters.

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

Notes: This table reports the values for the estimated parameters in the model to match the moments in Table 8.

Table 8
Model fit.

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

Notes: This table reports the moments that we target to estimate the parameters listed in Table 7. The moments are average annualized moments. The target moments for the investment rate, leverage and long-term debt share are calculated from the sample in our empirical section. The mean annual default rate of 3.0% is taken from the survey by Dun and Bradstreet (www.dnb.com).

4.1. Parameterization and moments

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

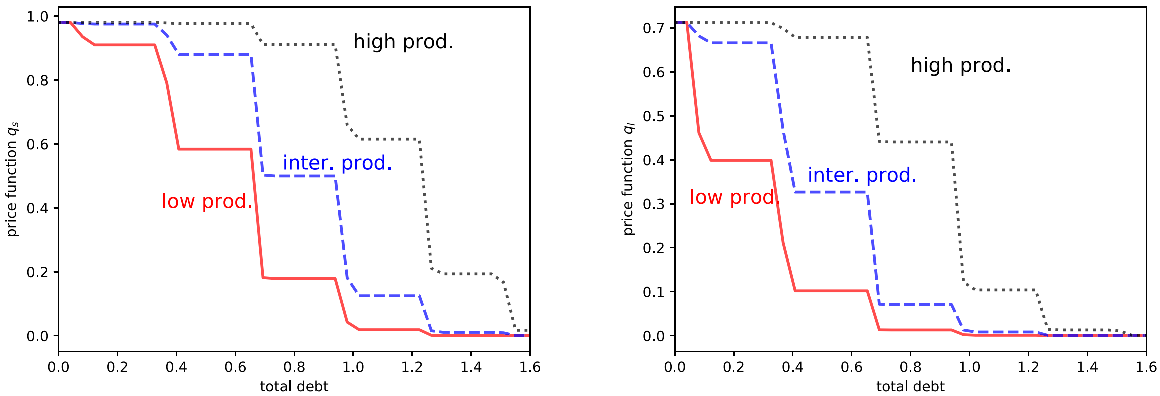
$$\log(z_t) = \rho_z \log(z_{t-1}) + \eta_z \epsilon_{z,t}$$

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

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

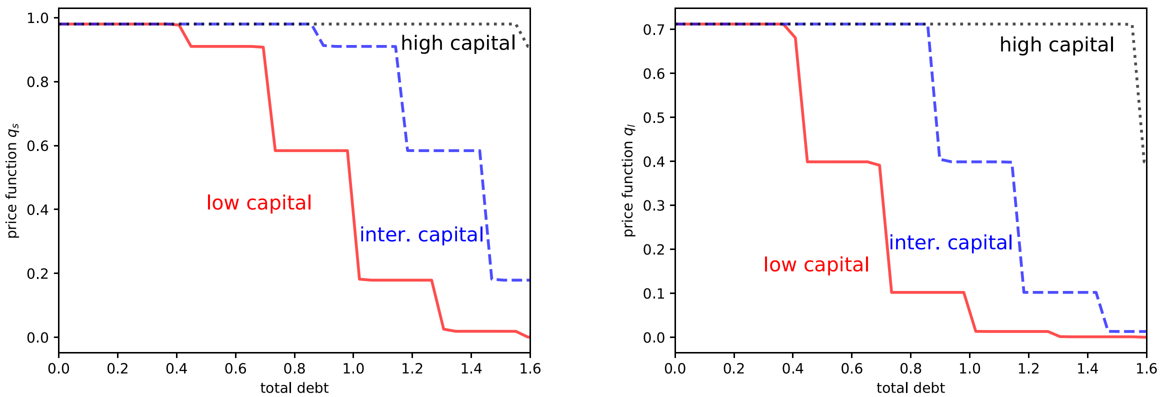
There are two groups of parameters. The first group of parameters are assigned and those in the second group are chosen jointly to match data moments. The parameters in the first group are listed in Table 6. The discount factor β is 0.96. Following Gomes and Schmid (2010) and Arellano et al. (2012), we set the decreasing returns to scale parameter α to 0.65. The capital depreciation rate is set to 2.5% per quarter. We set the long-term debt repayment rate to 0.05 to match the average maturity of long-term debt of 5 years. The corporate income tax rate is set to be 0.2. We set the debt recovery rate to be 0.8, which is in line with Arellano et al. (2012). We set the productivity parameters and exogenous firm exit rate following Ottonello and Winberry (2020). The interest rate shock process parameters are in line with the literature. We scale the interest rate process so that the average interest rate is 1%.

The second group of parameters listed in Table 7 are chosen to match moments reported in Table 8. We target an average annualized investment rate of 23.2%, and we target a mean annual default rate of 3.0% as estimated in a survey of businesses by Dun and Bradstreet (www.dnb.com). We target a mean leverage ratio of 35.2%, which was the average level for the firm sample in Section 2. This is consistent with the average leverage ratio of 34.4% from the microdata underlying the Quarterly Financial Reports, as reported in Crouzet and Mehrotra (2020). We target a mean long-term debt share of 84.2% as calculated in Section 2. The model generates similar statistics to the ones in the data.



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

Fig. 4. Bond prices as functions of total debt for different productivity levels.
Notes: This figure plots short-term and long-term bond prices as functions of total debt for different productivity levels. The x-axis is the total debt. The y-axis is the short-term bond price in Panel (a) and the 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.



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

Fig. 5. Bond prices as functions of total debt for different capital levels.
Notes: This figure plots short-term and long-term bond prices as functions of total debt for different productivity levels. The x-axis is total debt. The y-axis is the short-term bond price in Panel (a) and long-term bond price in Panel (b). The solid red line, dashed blue line, and dotted black line indicate prices for low productivity, intermediate productivity, and high productivity firms, respectively.

4.2. Prices for short-term and long-term bonds

Using the estimated model, we show the price functions in the model for short-term and long-term bonds with respect to different productivity levels and different capital stock levels. Fig. 4 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 for the same repayment, thus facing more expensive debt financing. We plot firms with high productivity in dotted black lines, firms with intermediate productivity in dashed blue lines, and firms with low productivity in solid red lines. There are two observations. First, debt financing is more expensive when productivity is low. This is because lower productivity is associated with lower debt repayment capacity, which increases default risk. Second, for the same productivity level, the long-term debt price q_l is lower than the short-term price q_s due to higher default risk.

Fig. 5 plots the bond prices as functions of total debt with respect to different capital stock levels. The solid red line, dashed blue line, and dotted black line draw the prices for firms with low capital, intermediate capital, and high capital, respectively. There are two observations as well. First, firms with low capital stock have less capacity to produce and repay their debt, they suffer from higher default risk and more expensive debt financing. Second, for the same capital stock level, the long-term debt price q_l is lower than the short-term price q_s due to higher default risk.

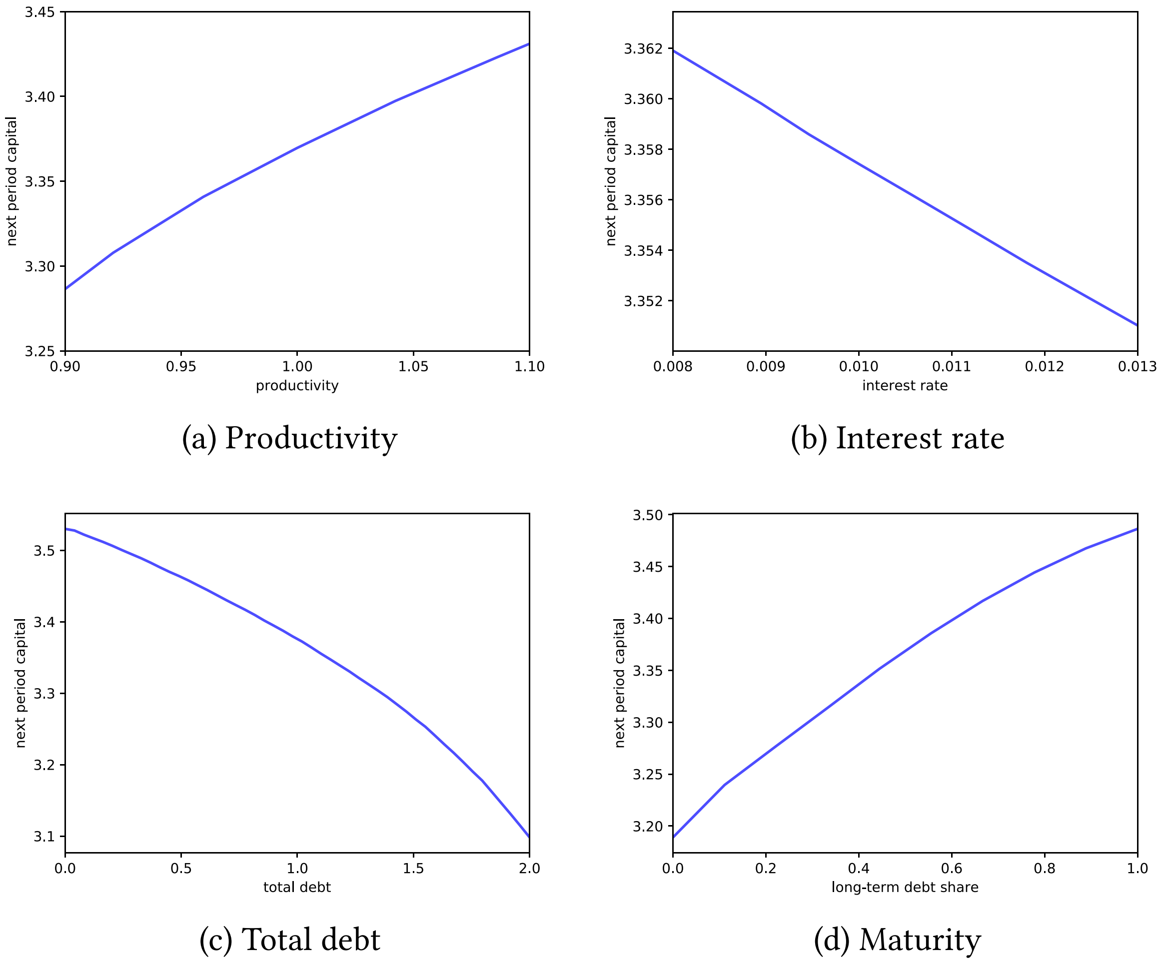


Fig. 6. Decision rules for next period capital as a function of productivity, interest rate, debt, and maturity.
Notes: This figure plots the decision rules for next period capital as a function of productivity, interest rate, total debt, and debt maturity. The lines are the average decision rules along specific dimensions. For example, the line in Panel (a) plots the average next period capital along the dimensions except productivity. Next period capital increases with productivity (Panel (a)), decreases with the interest rate (Panel (b)), decreases with total debt (Panel (c)), and increases with the share of long-term debt (Panel (d)). The relationship with productivity is the standard prediction from models with firm investment. The relationships in Panel (b)–(d) are consistent with our empirical findings.

4.3. Decision rules for investment and borrowing

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

Fig. 6 plots the average decision rules for next period capital (k') as a function of productivity, interest rate, total debt, and long-term debt share. Panel (a) plots next period capital as a function of productivity. With higher productivity, the marginal benefit of producing is higher, leading to a higher optimal investment decision. Panel (b) plots next period capital as a function of the interest rate. A higher interest rate increases the financing cost of debt, thus hindering the investment of firms.

Next period capital as a function of total debt, shown in Panel (c), is declining in total debt. This means that high levels of debt depress investment. Panel (d) shows that when firms can repay only a fraction of their debt, they tend to have more next period capital.[18] This is because long-term debt involves lower rollover costs each period, thus allowing firms to put more resources into capital investment. Note that this is when the interest rate does not change. As we will show later, when there is an interest rate shock, a larger share of long-term debt serves as an obstacle to firms changing their investment.

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

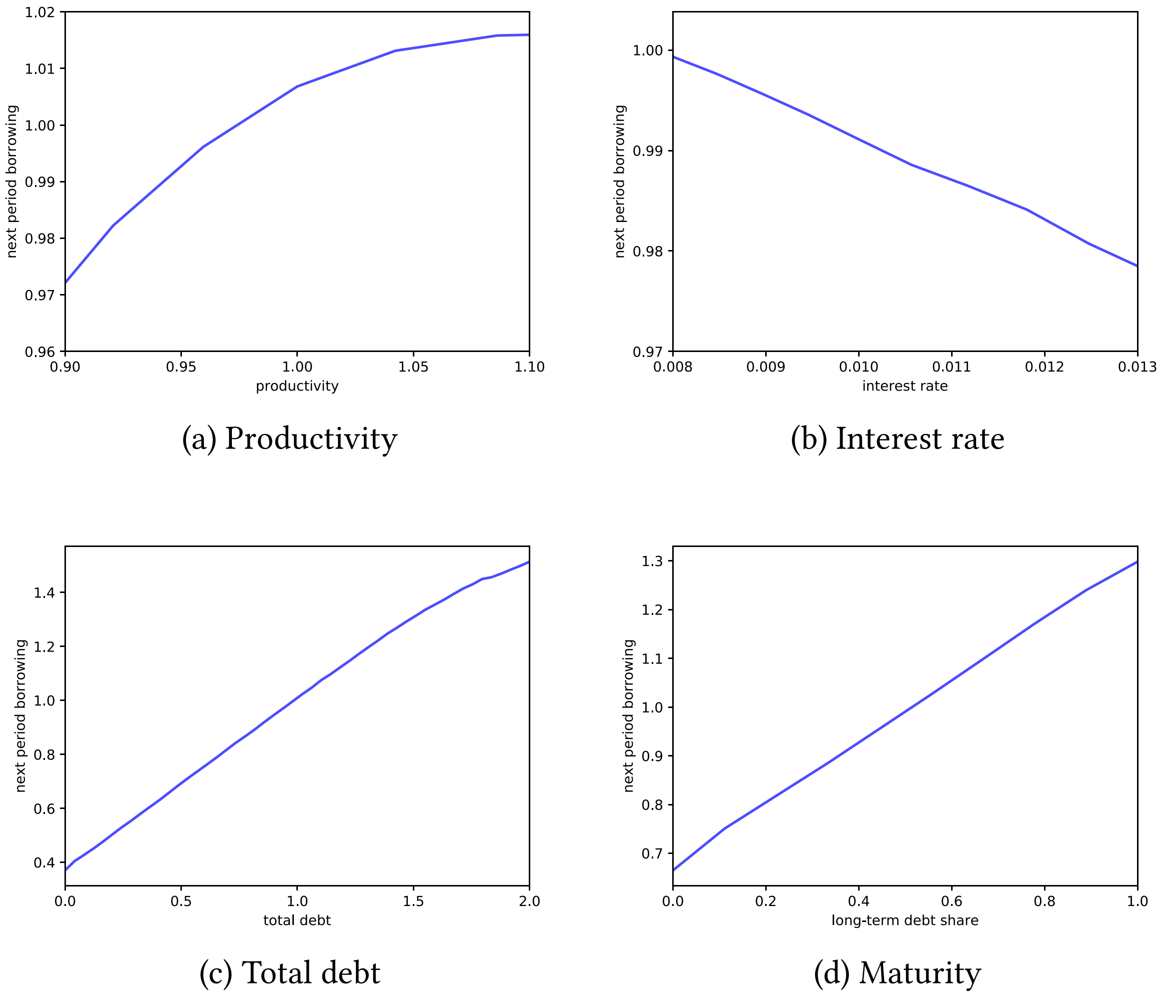


Fig. 7. Decision rules for next period borrowing as a function of productivity, interest rate, debt, and maturity.
Notes: This figure plots the decision rules for next period borrowing as a function of productivity, interest rate, total debt, and debt maturity. The lines are the average decision rules along specific dimension. For example, the line in Panel (a) plots the average next period debt along the dimensions except productivity. The next period debt increases with productivity (Panel (a)), decreases with interest rate (Panel (b)), increases with total debt (Panel (c)), and increases with the share of long-term debt (Panel (d)).

Fig. 7 plots the average decision rules for next period total debt (b') as a function of productivity, interest rate, total debt, and long-term debt share. Panel (a) plots next period debt as a function of productivity. With higher productivity, firms have a lower default risk, a lower cost of financing, and thus borrow more. Panel (b) plots next period debt as a function of the interest rate. A higher interest rate increases the financing cost of debt, thus reducing the incentive to borrow. Panel (c) plots next period debt as a function of current debt. Higher current debt increase next period borrowing. Panel (d) plots next period debt as a function of long-term debt share. When firms hold a larger share of long-term debt, absent default, they will mechanically have more debt next period as most is not repaid.

4.4. The role of debt maturity

Unlike Ottonello and Winberry (2020) where high leverage constitutes a force for under-investment, we emphasize a new mechanism through debt maturity. In this section, we highlight the role of debt maturity in three aspects. First, we compare firm future default probabilities across different debt maturities, conditional on the same level of leverage. Second, we develop a reference model with only short-term debt and compare this to our benchmark model. Third, we analyze the role of debt maturity in firm investment responses to monetary policy shocks.

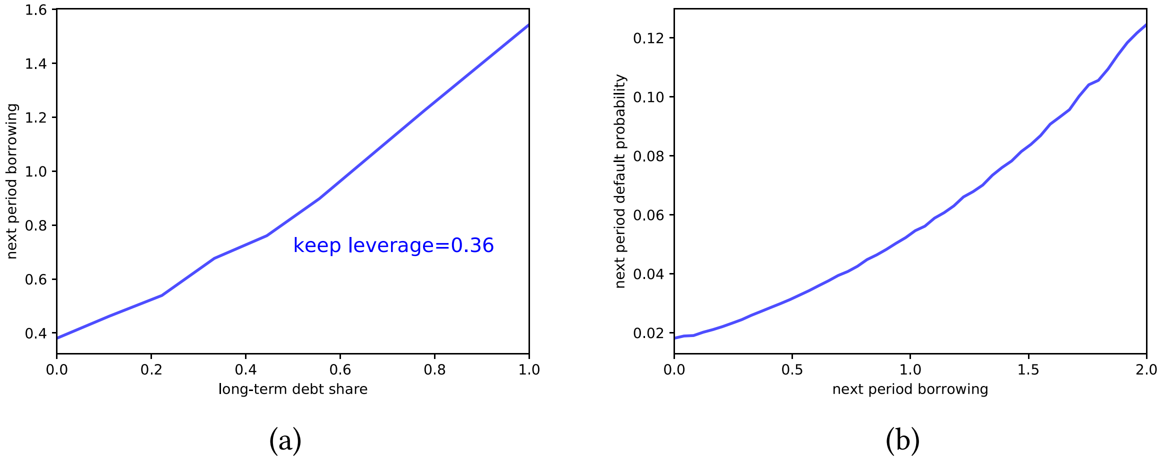


Fig. 8. Long-term debt increases future default risk.
Notes: This figure illustrates how debt maturity affects firm future default risk, given firm leverage. Panel (a) plots next period borrowing as a function of long-term debt share, keeping leverage fixed. Panel (b) shows that the next period default probability increases with more next period borrowing.

Table 9
Moments comparison.

Average annualized moments	Benchmark	Only-short-term-debt
Investment rate (%)	20.5	20.0
Default rate (%)	3.3	4.3
Leverage (%)	36.9	3.1
Long-term debt share (%)	85.3	0

Notes: This table reports the model-simulated moments for the benchmark model and only-short-term-debt model under the benchmark parameters.

4.4.1. Future default risk conditional on same leverage

In Section 3.5, we transformed the firm's problem with short-term debt b_S and long-term debt b_L into an equivalent problem in total debt b and the share of long-term debt f. This allows us to isolate the impact of debt maturity on top of leverage by comparing how future default probabilities change with debt maturity f, given the same level of leverage.

We fix leverage to 0.36, which is the average leverage for the firms in the sample. Panel (a) of Fig. 8 plots next period borrowing as a function of long-term debt share f. Firms borrow more for the next period when long-term debt accounts for a larger share of their debt, leading to a higher next period default probability (as shown in Panel (b)).

4.4.2. Comparison with only-short-term-debt model

To further highlight the role of debt maturity, we construct a reference model where the firms can only hold short-term debt. We refer to this model as the *only-short-term-debt* model. In the only-short-term-debt model, the only departure from the benchmark model is that firms can borrow by issuing only short-term debt. Table 9 reports the moments in the benchmark model and the only-short-term-debt model under the benchmark parameters. In the only-short-term-debt model, leverage falls dramatically to 3.1%, compared with 36.9% in the benchmark model. The investment rate is slightly lower and the default rate is higher than in the benchmark model. By construction, the long-term debt share in the only-short-term-debt model is zero.

Fig. 9 compares the decision rules for next period borrowing as a function of productivity and total debt for the benchmark model and the only-short-term-debt model. The red solid lines plot for the benchmark and the black dashed lines plot for the only-short-term-debt model. As in previous section, the lines are the average decision rules along specific dimension. For example, the lines in Panel (a) plot the average next period debt as a function of productivity, with other dimensions being averaged. Next period debt increases with productivity (Panel (a)) and increases with total debt (Panel (b)) in both models. The benchmark model, however, has a higher level of next period borrowing given productivity or total debt. The comparison between the two models shows that, with the presence of long-term debt, firms borrow more for the next period.

4.4.3. Heterogeneous responses due to debt maturity

As we showed in the empirical section, we focus on the responses of firm investment when there is a monetary policy shock. We find that firms with a larger share of long-term debt respond less to expansionary monetary policy. The model generates consistent results. To see this, we compare the decision rules for next period capital as a function of the real interest rate for firms with heterogeneous debt maturity f in Fig. 10. The solid blue line indicates a firm with only short-term debt (f = 0) and the dash-dotted red line indicates a firm with only long-term debt (f = 1). We also plot a case where half the debt is short-term and the other

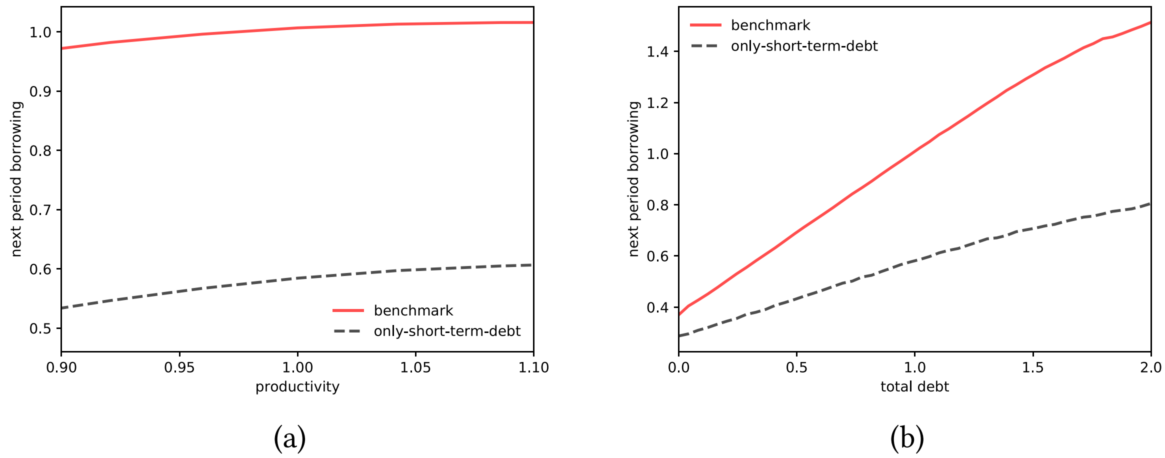


Fig. 9. Comparison: next period borrowing.
Notes: This figure plots the decision rules for next period borrowing as a function of productivity and total debt for the benchmark model and the only-short-term-debt model. The red solid lines plot for the benchmark and the black dashed lines plot for the only-short-term-debt model. The lines are the average decision rules. For example, the lines in Panel (a) plot next period debt as a function of productivity, with everything else being averaged.

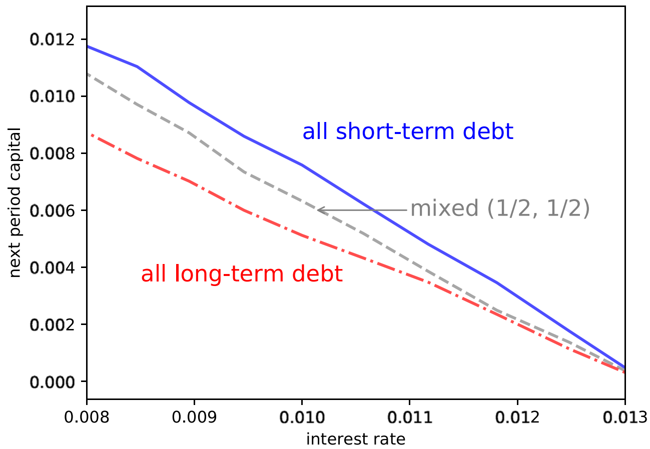


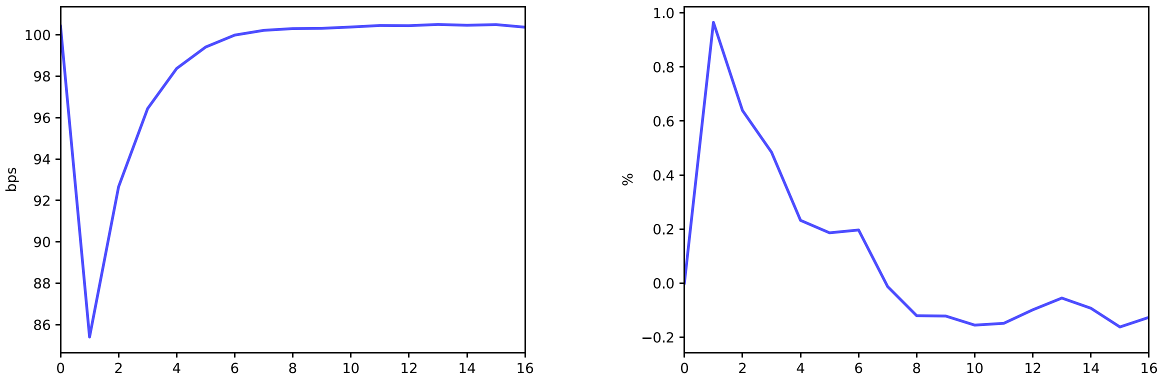
Fig. 10. Heterogeneous responses due to debt maturity.
Notes: This figure plots the decision rules for next period capital with respect to the interest rate for different debt maturity levels. We normalize each series by its own value when the interest rate is at the grid maximum. The solid blue line plots for firms with only short-term debt (f = 0), the dash-dotted red line plots for firms with only long-term debt (f = 1), and the dashed gray line is firms with half short-term debt and half long-term debt (f = 1/2).

half is long-term debt (f = 1/2), using the dashed gray line. We normalize each series by its value when the interest rate is at the grid maximum. When the interest rate decreases, firms increase investment. With a larger share of long-term debt, the increase in investment is smaller, indicating that firms respond less when there is a positive monetary policy shock (decrease in interest rate).

The intuition is that a larger share of long-term debt leads to a higher future default risk which hinders investment, as shown in the firm decision rules and the comparison of data moments between the two models. When the interest rate decreases, it is beneficial for firms to invest. With more long-term debt, part of the benefit of increasing investment following the interest rate cut goes to creditors instead of equity holders. As a result, firms with a larger share of long-term debt are less responsive to monetary policy stimulus.

4.5. Aggregate responses to monetary policy shocks

Having presented some key features of bond prices, firm decision rules, and their sensitivity to interest rate changes, we now study firm behavior in aggregate by generating impulse response functions following an expansionary monetary policy shock in the model. We simulate 30,000 paths for the model over 500 periods. In period 401 (period 1 in the figures below), there is a 15 bps cut in the real interest rate. This is taken from the classic empirical investigation in Christiano et al. (2005) and more recent HANK literature such as Ottonello and Winberry (2020), Jeenas (2018), and Fang (2020) where a conventional 25 bps negative shock to



(a) Real interest rate (b) Changes in investment rate

Fig. 11. Aggregate response to monetary policy shock: investment rate.
Notes: This figure plots the average impulse response function of investment rate (Panel (b)) to an expansionary monetary policy shock as shown in Panel (a).

the Taylor rule residual generates a 12.5 bps to 15 bps 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.

We present the impulse responses of investment rate for an average firm in Fig. 11. Panel (a) shows the resulting path for the real interest rate. The real interest rate drops for 15bps after an expansionary monetary policy shock. After the shock, the interest rate gradually goes back to the previous interest rate level following the AR(1) process. Panel (b) plots the response of the average investment rate. This expansionary monetary policy shock results in an average firm increasing their investment rate by about 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 shocks

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

$$i_{jt} = \beta' \left(X_{jt-1} - \mathbb{E}_j[X_{jt}] \right) \Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_j + \gamma_t + \epsilon_{jt}, \tag{16}$$

where i_{jt} is the model-generated investment rate of firm j in quarter t and Δ_t^m is the interest rate shock, which is given by the gap between the interest rate in quarter t and in quarter $t-1$. We normalize the interest rate shock by dividing by 15 bps and flip the sign so that a positive Δ_t^m indicates the same expansionary monetary policy as in our empirical regression Eq. (2). X_{jt-1} represents firm j's leverage or debt maturity in quarter $t-1$, Z_{jt-1} is a vector of lagged firm-level controls, including leverage, debt maturity, total assets, sales, and sales growth. γ_j are firm fixed effects and γ_t are quarter fixed effects. We focus on the heterogeneous effects β'.

Table 10 reports the regression coefficients for the model and the data. The coefficients for the data are the ones from Table 3. Column (1) shows the results when we focus on the firm-level heterogeneity in debt maturity. The negative coefficient indicates that firms with more long-term debt are less responsive to expansionary monetary policy shocks, consistent with our empirical finding. Column (2) reports the results when we add both interactions with debt maturity and leverage. The coefficient of $\Delta_t^m \times \left(mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}] \right)$ is still significant and the magnitude does not change much.

Using the model-simulated data, we employ the Jordà (2005)-style local projection version of our baseline specification as in Section 2.2, and then we can compare the dynamics of the heterogeneous responses in the data and those from the model. The local projection specification we run for the model is as follows:

$$\sum_{\tau=t+0}^{\tau=t+h} i_{j\tau} = \beta_h' \left(X_{jt-1} - \mathbb{E}_j[X_{jt}] \right) \Delta_t^m + \Gamma_h' Z_{jt-1} + \gamma_{jh} + \gamma_{jth} + \epsilon_{th} \tag{17}$$

where $h \geq 0$ denotes h quarters ahead for both variables and coefficients. As in Section 2.2, the coefficient β_h' measures how the cumulative response of investment in quarter $t+h$ to a monetary policy shock in quarter t depends on the firm's demeaned financial position X_{jt-1} in quarter $t-1$. Panel (b) of Fig. 12 plots the dynamics of the heterogeneous responses due to heterogeneous debt maturity in the model. Fig. 12 shows that the dynamics of the heterogeneous responses of investment are persistent in the model, consistent with the data. Quantitatively, the dynamics of the responses stay within the data's 90% confidence interval after the shock.

Table 10
Regression results: Model and data.

	Model		Data	
	(1)	(2)	(1)	(2)
$\Delta_t^m \times (mat_{j,t-1} - \mathbb{E}_j[mat_{j,t}])$	−0.370***	−0.365**	−0.656***	−0.663***
	(0.128)	(0.163)	(0.185)	(0.184)
$\Delta_t^m \times (lev_{j,t-1} - \mathbb{E}_j[lev_{j,t}])$		−0.016		−0.319*
		(0.341)		(0.187)
Firm FE	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Notes: This table compares the regression results from model-simulated data and Compustat data. "Model" reports results from estimating $i_{jt} = \beta' \left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right) \Delta_t^m + \gamma_z' Z_{jt-1} + \gamma_j + \gamma_t + \epsilon_{jt}$, where i_{jt} is the firm-level investment rate, Δ_t^m is the interest rate shock occurring between quarter $t-1$ and quarter t, X_{jt-1} is a vector capturing firm j's corporate debt structure at quarter $t-1$, including both demeaned and lagged maturity and leverage. Z_{jt-1} is a vector of lagged firm-level controls, including leverage, debt maturity, total assets, sales, and sales growth. γ_j are firm fixed effects and γ_t are time fixed effects. "Data" reports the coefficients of the baseline regression in Table 3. "Data" Column (1) corresponds to Table 3 Column (2) but with time fixed effects. "Data" Column (2) corresponds to Table 3 Column (3).
*Significance level: $p < 0.1$.
**Significance level: $p < 0.05$.
***Significance level: $p < 0.01$.

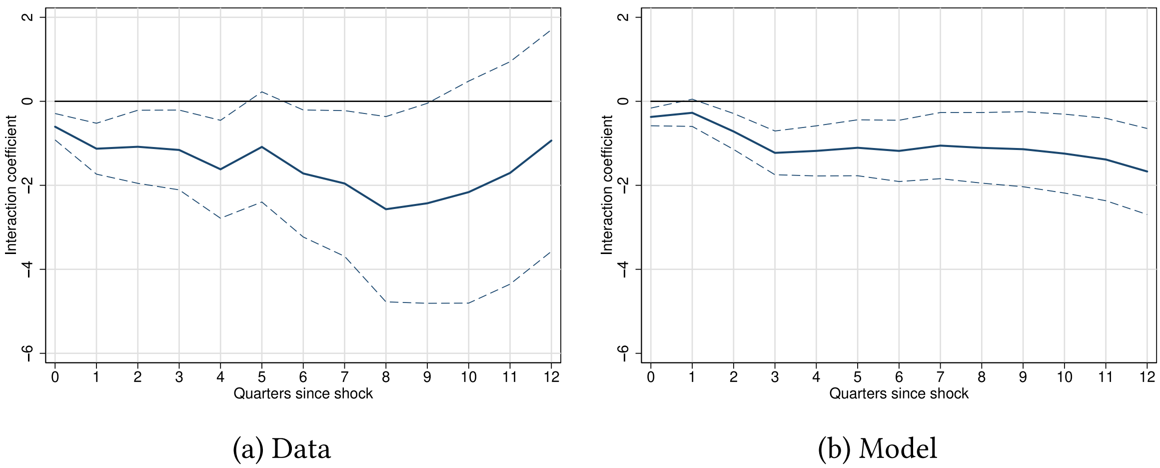


Fig. 12. Dynamics of heterogeneous responses: data vs. model.
Notes: Dynamics of the interaction coefficients between debt maturity positions and monetary shocks overtime. Panel (a) is the dynamics responses in the data as in Fig. 2. Panel (b) plots the coefficient β_h over quarters h from estimating $\sum_{\tau=t+0}^{\tau=t+h} i_{j\tau} = \beta_h' \left(X_{jt-1} - \mathbb{E}_j[X_{jt}]\right) \Delta_t^m + \Gamma_h' Z_{jt-1} + \gamma_{jh} + \gamma_{th} + \epsilon_{jth}$ using the model-simulated data. Dashed lines indicates the 90% confidence interval.

4.7. Relationship to literature on debt maturity and monetary policy

Finally, we briefly relate our work to two strands of recent literature on debt maturity and monetary policy. The first strand studies how debt maturity affects the effectiveness of monetary policy. Lakdawala and Moreland (2021) finds that firms with high leverage disproportionately rely on long-term debt and that in a post-global financial crisis sample they respond more to unconventional monetary policy. Though our results cannot be directly compared to theirs since we focus on conventional monetary policy, our model could provide a mechanism for their results. As documented in Swanson (2015), unconventional monetary policy, more specifically, large-scale asset purchases (LSAPs), have large effects on long-term bonds but essentially no effect on short-term ones. Consider the price functions (14) and (15) in our model. If LSAPs directly increase the long-term bond price q_L but not the short-term bond price q_S, firms with more long-term debt face lower costs to roll over their debt following the quantitative easing episode. Therefore, high leverage firms relying on long-term debt could potentially invest more in response to unconventional monetary expansions than other firms. In a more recent paper, Jungherr et al. (2021) also studies how endogenous debt maturity structure matters for monetary policy and lands on a similar conclusion. Different to ours, their empirical study uses merged bond-level data from Mergent Fixed Income Securities Database (FISD) and firm-level balance sheet data from Compustat. The second strand of this literature studies how monetary policy affects debt maturity. Both Fabiani et al. (2020) and Bräuning et al. (2020) show that a loosening of monetary policy lengthens corporate debt maturities, which is consistent with our empirical findings on firm borrowing responses in Table 5. Our quantitative model also replicates this result, which is shown in the Online Appendix D Figure 3 Panel (a), where lowering the interest rate increases the share of long-term debt.

5. Conclusion

We show that a firm's debt maturity structure affects its investment response to monetary policy. Empirically, conditional on debt level measured by leverage, firms with longer debt maturities respond less to expansionary monetary policy shocks. Theoretically, we build a model with firm default that is quantitatively consistent with our empirical results. Firms with longer maturity are less responsive to monetary shocks because their marginal financing cost for investment is higher due to higher future default risk. Complementary to existing studies showing that *leverage* (Ottonello and Winberry, 2020; Lakdawala and Moreland, 2021; Auer et al., 2019), *age* (Cloyne et al., 2018), *liquidity* (Jeenas, 2018), *credit risk* (Palazzo and Yamarthy, 2020), *bond v.s. bank lending* (Darmouni et al., 2020), *asset pledgeability* (Silva, 2019), and *creditor rights* (Vats, 2020) can determine firm-level responses to monetary shocks, we provide both empirical evidence and a quantitative theory for another relevant financial dimension: *debt maturity*.

We show that besides the level of debt, the most studied perspective, the split between long-term debt versus short-term debt significantly affects firm-level responses to monetary policy shocks. Since firms borrow and invest differently when there is a monetary policy shock, the effectiveness of monetary policy depends on firms' debt maturity. The result suggests that the heterogeneous effects in the cross-section could be of independent interest to policymakers who are concerned about the distributional effects of monetary policy across firms. The result also suggests that the effectiveness of a monetary policy may vary across time when the characteristics of firms are changing. For instance, the same expansionary monetary policy shock may have a weaker impact since average debt maturity, as shown in Fig. 1, is increasing over time. The effect of monetary policy on aggregate investment, therefore, depends on the maturity of the debt held by firms.

While we find that endogenous debt maturity structure has important effect on investment response to monetary policy, there are some important abstractions in our analysis. First, we have abstracted from the fact that long-term debt contracts are written in nominal terms. When firms finance using nominal long-term debt, higher inflation decreases firms' real liabilities and default risk (Gomes et al., 2016; Corhay and Tong, 2021). Heterogeneity in debt maturity could result in heterogeneous responses through the channel of inflation. Second, we do not study unconventional monetary policy in the current paper. The unconventional monetary policy has more significant effects on long-term bonds than on short-term bonds (Swanson, 2015; Bustamante, 2019; Lakdawala and Moreland, 2021). Firms with different debt maturity could respond differently to unconventional monetary shocks in the post-global financial crisis. Bringing these features into future analyses should prove fruitful.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2022.104095.

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