Corporate Debt Maturity Matters For Monetary Policy*

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November 15, 2021

Abstract

We provide novel empirical evidence that firms' investment is more responsive to surprise changes in monetary policy when a higher fraction of their debt matures. In a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity, two channels explain this finding: (1.) Firms with more maturing debt roll over more debt and are therefore more exposed to fluctuations in the real interest rate (*roll-over risk*). (2.) Firms with shorter debt maturity have higher default risk in equilibrium and therefore react more strongly to changes in the real burden of outstanding nominal debt (*debt overhang*). The aggregate effectiveness of monetary policy depends on the joint distribution of debt maturity and default risk across firms.

Keywords: monetary policy, investment, corporate debt, debt maturity.
JEL classifications: E32, E44, E52.

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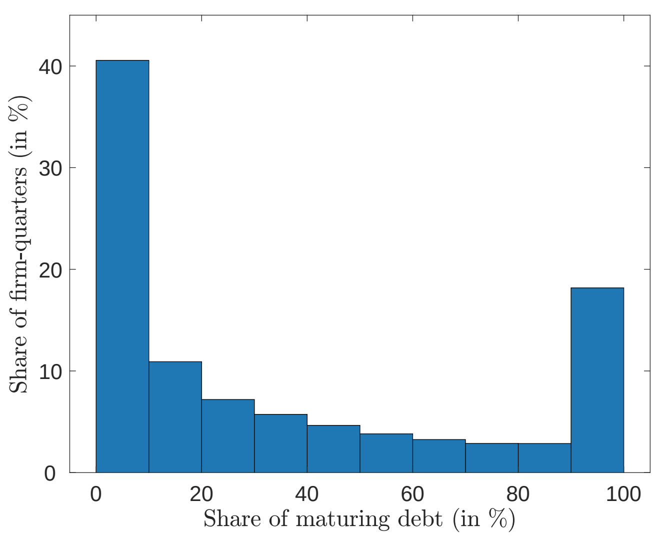
"Suffice it here to note that over-indebtedness (...) is not a mere one-dimensional magnitude to be measured simply by the number of dollars owed. It must also take account of the distribution in time of the sums coming due. Debts due at once are more embarrassing than debts due years hence; (...) Thus debt embarrassment is great (...) for early maturities.'

-Irving Fisher (1933): "The debt-deflation theory of great depressions,"
Econometrica, 1(4), page 345.

1 Introduction

Corporate debt has reached historically high levels.[1] But not all debt is created equal. A large part of debt is issued long-term and need not be repaid until several years in the future. Another part of debt is due in the short-run. Maturing debt exposes firms to changes in financing conditions, which may affect their capital investment. Figure 1 shows the vast heterogeneity of debt maturity across listed U.S. firms. For half of the firms, less than 20% of their debt comes due within the next twelve months. At the other extreme of the distribution, more than 80% of debt matures within the next year for 20% of firms. In this paper, we show that debt maturity shapes firms' investment response to monetary policy.

Figure 1: Maturing debt share across firms



Note: The figure shows the firm-level distribution of the share of debt which matures within the next twelve months across listed U.S. non-financial firms between 1995Q1 and 2017Q4.

Debt maturity matters for monetary policy for two reasons. The first reason is *roll-over risk*. Firms that borrow at shorter maturities need to roll over their debt more frequently and are therefore more exposed to surprise changes in interest rates. Long-term debt insures

[1]In the U.S., even before the Covid-19 crisis the ratio of debt securities and loans of non-financial businesses over GDP reached record levels above 70% in 2018. At the onset of the pandemic-induced recession, this ratio increased further peaking at 90% in Q2 of 2020. Similar developments can be observed in several advanced and emerging economies (Bank for International Settlements, 2020).

firms against this roll-over risk. The second reason is *debt overhang*. Surprise changes in inflation affect the real burden of outstanding nominal debt which matters for default risk and investment. This debt overhang channel of monetary policy is stronger if outstanding debt has longer remaining maturity (Gomes et al., 2016). Whether firms with shorter or longer debt maturity are more responsive to monetary policy shocks is therefore theoretically ambiguous.

To understand the role of debt maturity for monetary policy, this paper makes an empirical and a theoretical contribution. Empirically, we show that firms react more strongly to monetary policy shocks in periods when a large fraction of their debt matures. We then develop a heterogeneous firm model to rationalize the evidence and to study its implications for the effectiveness of monetary policy.

In the empirical analysis, we combine balance sheet data of U.S. listed firms with detailed bond-level data. This allows us to construct the empirical distribution of bond maturity across firms and time. We complement this data with high-frequency identified monetary policy shocks and estimate their effect on firm-level investment using panel local projections. The corporate bonds in our sample have an average maturity at issuance of about eight years and all bonds in our baseline specification are non-callable. Whether a particular bond matures shortly before or after a monetary policy shock has therefore typically been decided several years before a shock occurs.

We find that firms' investment response to a monetary policy shock is amplified by a high share of maturing bonds at the time of the shock This result is statistically and economically significant. Eight quarters after a contractionary one-standard deviation monetary policy shock, capital growth is 0.2 percentage points lower for firms with a one-standard deviation higher share of maturing bonds at the time of the shock compared to the average firm. With an investment-capital ratio of 10%, our estimate implies a 2 percentage points lower differential investment response. Importantly, this result holds even if we control for permanent differences across firms and for various time-varying firm characteristics such as leverage and liquidity. A placebo exercise shows that a large share of maturing bonds in the quarter before the shock has no statistically significant effect on firms' investment responses.

To study the implications of these empirical results for the effectiveness of monetary policy, we develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. In the model, firms finance investment using equity and nominal debt. Debt has a tax advantage relative to equity but introduces the risk of costly default. Firms can choose a mix of short-term and long-term debt. Long-term debt saves roll-over costs but creates a debt overhang problem which increases future leverage and default risk.

A quantitative version of our model replicates key empirical moments that characterize the investment and financing behavior of listed U.S. firms, including the rich cross-sectional heterogeneity in debt maturity. The effects of debt overhang cause more distortions for firms with high default risk, which consequently choose to borrow at shorter maturities. Through this mechanism, the model replicates key characteristics of the empirical firm size and age distributions: Smaller and younger firms have higher default risk and higher shares of maturing debt. As firms grow, average default risk decreases, debt maturity becomes longer, and maturing debt shares fall.

As in the data, a contractionary monetary policy shock leads to a stronger negative investment response by firms with a higher share of maturing debt. Both *roll-over risk* and *debt overhang* contribute to this result. Firms with more maturing debt roll over more debt and are therefore more exposed to fluctuations in the real interest rate. At the same time, firms with high maturing debt shares have a higher default risk and are therefore more sensitive to fluctuations in the real burden of outstanding nominal debt. The model replicates the slow-moving differential investment response found in the data. It generates about 60% of the maximum empirical investment response of firms.

Our results imply that the aggregate effects of monetary policy depend on the joint distribution of debt maturity and default risk in the economy. Aggregate firm investment is likely to react more strongly to monetary policy shocks when a higher share of firm debt matures and when average default risk is high.

Related literature This paper provides an empirical and theoretical analysis of the role of debt maturity for the transmission of monetary policy. It thereby contributes to three related strands of the literature.

First, our work contributes to empirical studies of the link between debt maturity and firm investment during recessions. Duchin et al. (2010) and Almeida et al. (2012) show that firms with more maturing debt at the onset of the Financial Crisis of 2007–2008 reduced investment by more. In addition, Benmelech et al. (2019), Kalemli-Ozcan et al. (2018), and Buera and Karmakar (2021) find stronger investment declines associated to higher shares of maturing debt during the Great Depression 1929–1933 and from the 2010–2012 European sovereign debt crisis. We complement these event studies by providing evidence on how debt maturity shapes the investment response to identified monetary policy shocks.

A second related body of work studies the role of financing conditions in explaining heterogeneous effects of monetary policy across firms. Ippolito et al. (2018) find that firms with floating-interest rate loans adjust investment more strongly in response to monetary policy shocks relative to firms with fixed-rate debt. While that paper does not explicitly study debt maturity, the result is consistent with a roll-over risk channel of monetary policy. Other related papers that document the empirical role of size, age, leverage, or asset liquidity in shaping the effects of monetary policy include Gertler and Gilchrist (1994), Cloyne et al. (2018), Jeenas (2019), Ottonello and Winberry (2020), and Anderson and Cesa-Bianchi (2020). In addition, Darmouni et al. (2020) investigate how reliance on bond finance shapes firm responses to to monetary policy. We contribute to this evidence by investigating the role of debt maturity.[2]

Third, the theoretical contribution of this paper is to develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. Existing quantitative models of monetary policy do not allow for differences in debt maturity across firms. Our framework features long-term bonds as in Gomes et al. (2016), to which we add persistent firm-level heterogeneity and endogenous debt maturity along the lines of Jungherr and Schott (2021), and a role for firm net worth as in Bernanke et al. (1999) or Ottonello and Winberry (2020). Thereby our paper contributes to a large literature using heterogeneous firm models with financial frictions to study cross-sectional differences in firm-level

[2]A related complementary paper is Gurkaynak et al. (2019), who show that stock prices are more responsive to monetary policy when debt maturity is short. Inverting the question, Fabiani et al. (2021) show that tighter monetary policy shortens corporate debt maturity.

responses to aggregate shocks (e.g. Bernanke et al., 1999; Cooley and Quadrini, 2006; Covas and Den Haan, 2012; Khan and Thomas, 2013; Gilchrist et al., 2014; Khan et al., 2016; Begenau and Salomao, 2018; Crouzet, 2018; Arellano et al., 2019; Ottonello and Winberry, 2020; Arellano et al., 2020). Because firms issue only one-period debt in these models, all firms have identical exposure to roll-over risk and no significant exposure to debt overhang.[3]

Firm heterogeneity is the focus of all papers described above. A parallel literature investigates the role of household heterogeneity for the transmission of monetary policy (e.g. Gornemann et al., 2016; Kaplan et al., 2018; Bayer et al., 2019). Debt maturity matters for households as well, as shown by Auclert (2019) who identifies cross-sectional differences in exposure to roll-over risk and Fisherian debt deflation as sources of heterogeneous effects of monetary policy.

The paper is organized as follows. In Section 2, we describe the data set, the estimation strategy, and the empirical results. Section 3 develops a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. We characterize equilibrium firm behavior in Section 4 highlighting the role of roll-over risk and debt overhang for firms' investment response to monetary policy. Section 5 presents results from the quantitative model and compares them to the data. Concluding remarks follow.

2 Empirical Evidence

In this section, we show that firms' investment responds more strongly to monetary policy shocks in periods when a large fraction of their debt matures.

2.1 Data

Bond-level data. We obtain comprehensive and detailed bond-level information from the Mergent Fixed Income Securities Database (FISD). It contains key characteristics of publicly-offered U.S. bonds such as issue date, maturity date, amount issued, principal, coupon, and whether the bond is callable. It also records ex-post reductions in the amount of outstanding bonds as well as the reason for the reduction, e.g., a call, reorganization, or default. Our empirical analysis focuses on fixed-coupon, non-callable, non-convertible, non-exchangeable bonds denominated in USD.[4] Appendix A provides further details on the data.

[3]Net worth is the only endogenous state variable in one-period debt models. If firms are allowed to issue long-term debt, the existing stock of previously issued debt enters the firm problem as additional state variable. For quantitative models which explore the implications of long-term debt for firm financing and investment, see also Crouzet (2017), Caggese et al. (2019), Gomes and Schmid (2021), Karabarbounis and Macnamara (2020), Poeschl (2020), or Jungherr and Schott (2022). For continuous-time approaches to modeling debt maturity in corporate finance, see DeMarzo and He (2021) or Dangl and Zechner (2021). None of these models studies the role of debt maturity for monetary policy.

[4]In general, different characteristics of debt contracts may differently shape firm responses to monetary policy. Not conditioning on these characteristics may render our empirical estimates less precise. Callable bonds in particular specify conditions under which they can be repurchased before maturity. The maturity of such bonds is subject to a survivorship bias. Firms that decide not to repay their bonds before maturity may differ in their default risk, which may also affect their response to monetary policy shocks. In Section 2.3, we discuss separate results for callable and variable-coupon bonds.

Merging bonds with firms. Merging FISD bond-level data with Compustat firm-level balance-sheet data is not straightforward. The bond-level data records the firm identifier (cusip) at the time of issuance, but cusip identifier often change over time. To make matters worse, the ownership of a firm changes over time due to M&A. Ultimately, we link the historical firm cusip at the issuance to the current Compustat gvkey identifier by combining the CRSP-Compustat linking table (for a link between gvkey and permno), CRSP data (for a link between permno, current cusip and historical cusip), and the ThomsonReuters M&A database. This allows us to construct a mapping of a bond in every quarter of its lifetime to a unique firm. We provide a detailed explanation of the linkage procedure in Appendix A.

Firm-level data. We use quarterly firm balance sheet data from Compustat. We exclude firms in sectors public administration, finance, insurance, real estate, and utilities. We further exclude firm-quarters in which no bond is maturing or outstanding. The remaining observations account for 70.0% of total sales and 72.9% of total fixed assets. We compute the firm-quarter specific dollar value of maturing and outstanding bonds and the average bond maturity weighted by the outstanding value of bonds. The value of maturing bonds only includes bonds held until maturity. We deflate outstanding bonds and maturing bonds by the CPI. A central object of our empirical analysis is the maturing bond share, which we compute as the value of maturing bonds relative to total debt in the preceding quarter[5]

$$\mathcal{M}_{it} = \frac{\text{maturing bonds}_{it}}{\text{total debt}_{it-1}} \times 100, \tag{2.1}$$

where i denotes a firm and t a quarter. Our baseline $\mathcal{M}_{it}$ only considers the maturing value of fixed-coupon non-callable bonds. We use fixed assets in the balance sheet data and construct capital stocks by applying a perpetual inventory method.[6]

Monetary policy shocks. We use high-frequency price changes of federal fund futures around FOMC meetings to identify monetary policy shocks. Our baseline shocks are based on the three-months ahead federal funds future and 30-minute event windows, as in Gertler and Karadi (2015). We exclude unscheduled meetings and conference calls, which helps to mitigate the problem that monetary surprises may contain private central bank information about the state of the economy (Meier and Reinelt, 2020). We further follow Jarociński and Karadi (2020) and use sign restrictions to separate information effects from conventional monetary policy shocks. Finally, the daily shocks are aggregated to quarterly frequency. Daily shocks are assigned fully to the current quarter if they occur on the first day of the quarter. If they occur within the quarter, they are partially assigned to the current and subsequent quarter.

Descriptive statistics. Our sample covers the period from 1995Q1 through 2017Q4. Table 1 reports descriptive statistics of key firm-level observables. Our sample of bond-issuing firms includes about 50,000 firm-quarter observations. On average, bonds are the

[5]Because the quarterly series of firm debt displays large transitory volatility, we compute firm debt as average debt over the current and the preceding three quarters. Our main results are dampened and less significant with the raw debt series, see Section 2.3.

[6]Our results hold robust when using deflated fixed assets instead of using the perpetual inventory method.

primary type of debt contract. They account for more than 62% of total debt. Bonds are issued with long maturities. On average, the remaining time until maturity is more than 8 years. Hence, only a small fraction of bonds matures per quarter. On average, maturing bonds correspond to about 0.15% of total debt. At the same time, there is substantial heterogeneity in this ratio across firms. We also consider an alternative approach to measure debt maturity using only Compustat data, for which we compute the share of debt in current liabilities over total debt. Note that debt in current liabilities include short-term debt as well as various types of long-term debt contract with remaining maturity of at most 12 months. This short-term debt share is about 11% on average. Finally, the table documents the distribution of leverage and liquidity across firms in our sample.

Table 1: Descriptive statistics

	mean	sd	min	max	count
Outstanding bonds share *(in % of debt)*	62.11	28.76	0.01	100.00	50,463
Maturing bonds share $\mathcal{M}_{it}$ *(in % of debt)*	0.15	1.60	0.00	75.82	50,463
Average maturity *(in years)*	8.43	5.75	0.00	99.83	50,463
Debt due $\leq$ 12 months *(in % of debt)*	11.44	17.16	0.00	100.00	50,290
Leverage *(debt/assets in %)*	37.99	23.51	0.00	1,174.95	50,319
Liquidity *(cash/assets in %)*	7.93	9.57	0.00	92.14	50,433

Note: The table provides descriptive statistics for bond-issuing firms from 1995Q1 through 2017Q4. The outstanding bonds share is the sum of bond principals outstanding (from FISD) over total debt (in Compustat: `dlcq+dlttq`). The maturing bonds share is $\mathcal{M}_{it}$ as defined in equation (2.1). Average maturity is the principal-weighted remaining maturity (from FISD). Debt due $\leq$ 12 months is `dlcq/(dlcq+dlttq)`. Leverage is `(dlcq+dlttq)/atq` and liquidity is `cheq/atq`.

2.2 Investment responses to monetary policy shocks

Empirical specifications. We estimate panel local projections of firm-level log changes in the capital stock on the interaction of monetary policy shocks and the share of bonds maturing. Formally, we estimate

$$\begin{aligned}\Delta^{h+1}\log k_{it+h} = \; & \alpha_i^h + \alpha_{st}^h + \beta_0^h x_{it} + \beta_1^h x_{it}\varepsilon_t^{\mathrm{MP}} + \beta_2^h x_{it}\Delta\mathrm{gdp}_{t-1} \\ & + \Gamma_0^h Z_{it-1} + \Gamma_1^h Z_{it-1}\varepsilon_t^{\mathrm{MP}} + \Gamma_2^h Z_{it-1}\Delta\mathrm{gdp}_{t-1} + \nu_{it+h}^h, \end{aligned} \tag{2.2}$$

for $h = 0, \ldots, 16$ quarters. On the left-hand side, k_{it} denotes the real capital stock of firm i in quarter t and $\Delta^{h+1}\log k_{it+h} = \log k_{it+h} - \log k_{it-1}$ is the cumulative capital growth between $t-1$ and $t+h$. On the right-hand side, α_i^h and α_{st}^h are firm and sector-quarter fixed effects, x_{it} is the key variable of interest, $\varepsilon_t^{\mathrm{MP}}$ is a monetary policy shock, $\Delta\mathrm{gdp}_{t-1}$ is lagged real GDP growth, and Z_{it-1} a vector of control variables.

Main empirical finding. We start with a parsimonious baseline specification of (2.2), in which $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$. The primary coefficient of interest is β_1^h which captures the effect of a higher maturing bonds share $\mathcal{M}_{it}$ on the response of the $h+1$ period cumulative capital growth to a contractionary monetary policy shock. Panel (a) of Figure 2 shows the estimated β_1^h coefficients, which are the key empirical finding of this paper: After contractionary monetary policy shocks, capital growth shows a larger negative response for firms with a larger share of maturing bonds in the same quarter as the shock. This differential response is statistically different from zero at the 5% significance level at horizons between 6 and 10 quarters after the shock.

Because the average response of capital growth to contractionary monetary policy is negative, our finding means that the capital growth response is amplified in the presence of a large share of maturing bonds.[7] Firms with more maturing bonds are more responsive to changes in monetary policy. To interpret the quantitative magnitude, note that the β_1^h estimates in Figure 2 are standardized. For $h = 8$ quarters after the shock, $\beta_1^h = -0.21$ means the cumulative capital growth response to a one-standard deviation increase in $\varepsilon_t^{\mathrm{MP}}$ is approximately 0.21 percentage points (p.p.) lower for firms with a one standard deviation higher share of maturing bonds. With an investment-capital ratio of 10%, this translates into a differential investment response of 2.1%.

The estimated coefficient β_1^h in the baseline specification used in panel (a) may be biased due to omitted variables. For example, firm with a higher average fraction of bonds maturing may be systematically different from other firms in some dimensions, which then also explain different capital growth responses to monetary policy shocks. We can address this concern by focusing on within-firm time series variation in the maturing bond share. Further, firms with a currently higher fraction of bonds maturing may differ from other firms in their reliance on bond finance or average bond maturity. An additional concern is that firm-time differences in leverage, liquidity, distance to default, and total assets may be associated with different capital growth responses. Finally, firms that are more responsive to monetary policy shocks, may also be more responsive to other business cycle shocks. To address all these concerns, we consider a second, saturated specification of (2.2), which focuses on within-firm variation and which controls for various alternative explanations. Formally, we set $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$, where $\overline{\mathcal{M}}_i$ is the firm-specific average share of bonds maturing. Z_{it-1} includes leverage, distance to default, liquidity, average maturity of outstanding bonds (weighted by bond volume), real sales growth, and log real total assets (all in deviation from their respective firm-specific averages).

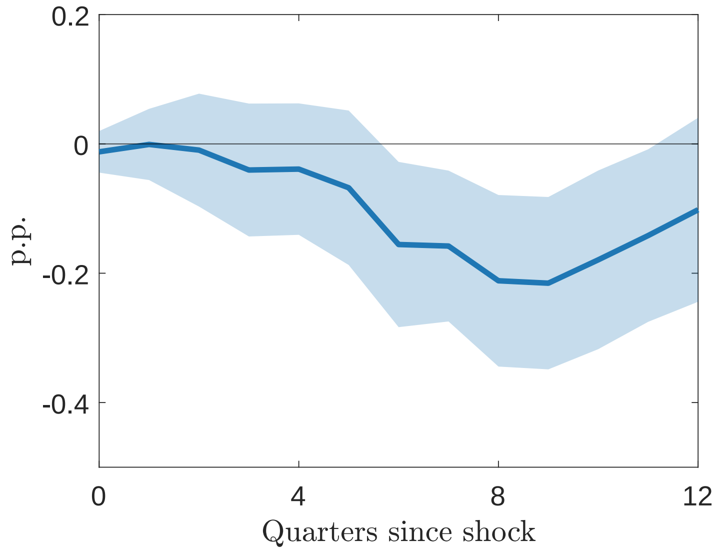
Panel (b) of Figure 2 shows the estimated β_1^h coefficients for this specification of equation (2.2). The estimates reconfirm the finding in panel (a). Again, capital growth shows a larger negative response for firms with a larger share of maturing bonds in the same quarter as the shock. Compared to (a), the estimates in (b) tend to be larger and more precisely estimated. Overall, however, the differences in the β_1^h estimates between panels (a) and (b) are statistically insignificant, which suggests limited omitted variable bias in the baseline estimates of panel (a). For a full regression table of all estimated coefficients in the saturated specification of equation (2.2) used for panel (b), see Table 6 in the Appendix.

Repay or refinance. Our main finding documents that firms are more responsive to monetary policy shocks if a larger share of their bonds mature in the same quarter. An intuitive explanation is that these firms are exposed to changing financing conditions precisely

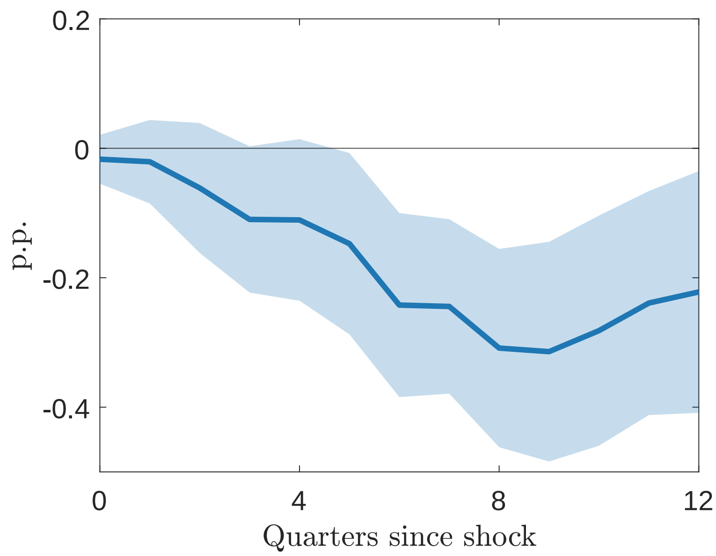
[7] Figure 15 in the Appendix shows the estimated average response of capital growth.

Figure 2: Differential capital growth response to MP shocks for high $\mathcal{M}_{it}$ firms

(a) Baseline specification



(b) Within-firm and controls



Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panel (a), $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$. In panel (b), $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

when they need to issue new debt. Hence it matters what fraction of maturing debt is refinanced by new debt. To investigate the average debt refinancing, we regress changes in total debt on the value of maturing bonds (both deflated). A zero coefficient means full debt refinancing. A coefficient of minus one means full debt repayment.

The first two columns of Table 2 show that about 50% of the maturing bond is refinanced on average. The point estimates are fairly similar whether or not an industry-time fixed effect is included. However, the point estimates are not very precise, consistent with non-trivial heterogeneity in debt refinancing across firms. The last two columns Table 2 repeat the exercise but replace the value of maturing bonds with reductions in the total real value of current liabilities. Current liabilities (`dlcq` in Compustat) is the sum of short-term liabilities and long-term liabilities maturing in the subsequent 12 months. This is broader than maturing bonds, which we measure through FISD data, but mixes debt contracts, e.g., bank loans and bonds, and maturities. If a firm's short-term debt remains constant, reductions in current liabilities will capture time variation in the maturity of total long-term debt. We find again that about 50% of maturing debt is refinanced on average. Overall, the evidence suggests firms are on average right in between full repayment and full refinancing.

Table 2: Repay or refinance maturing debt

	Δ debt	Δ debt	Δ debt	Δ debt
Value of maturing bonds	-0.604	-0.527		
	(0.390)	(0.374)		
Reduction in current liabilities			-0.514	-0.563
			(0.0914)	(0.0829)
Industry-quarter FE	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
R^2	0.028	0.144	0.163	0.276
N	50,287	50,262	50,287	50,262

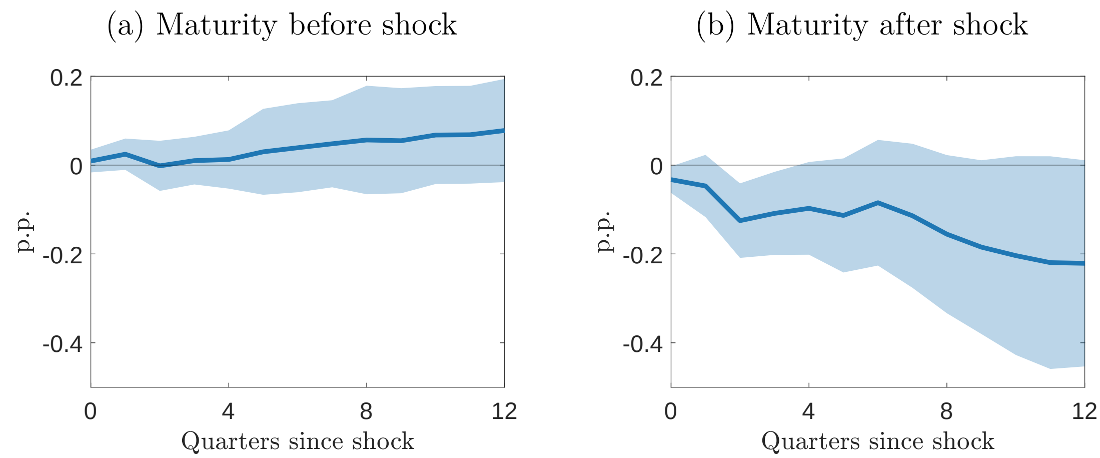
Note: Regressions of the change in real total debt on the real value of maturing bonds and the real reduction in current liabilities, respectively, for 1995Q1-2017Q4. Columns 2 and 4 include a one-digit industry-quarter FE. Standard errors (in parentheses) are clustered by firm and quarter.

Timing of bond maturity. Figure 3 studies the role of the timing of bond maturity. First, we consider a quasi-Placebo test. Do firms that differ in their share of maturing bonds in the quarter before the shock differ in their response to the shock? Panel (a) of Figure 3 documents an insignificant relationship between the capital growth response to monetary policy shocks and a firm's share of bonds maturing in the preceding quarter. The point estimate is positive. This is possibly because firms, which refinanced before the shock, have a relatively small fraction of debt debt maturing in subsequent quarters, which renders them relatively less exposed to future changes in financing conditions.[8] In panel (b), we consider the differential effect of a large share of bonds maturing subsequent to the shock. Because

[8] In fact, Figure 16 in the Appendix shows a significantly positive β_1^h coefficient once we focus on within-firm variation and add controls.

the effects of monetary policy shocks are not strictly transitory, we would expect these firms to respond more strongly than other firms. This is indeed what we find. However, the estimates of β_1^h tend to be smaller and less significant compared to Figure 2 (a). This may reflect mean reversion of the effects of monetary policy. In addition, the extra time between the monetary policy shock and bond maturity may allow firms to adjust their financing mix in a way that dampens the adverse effects of the shock.

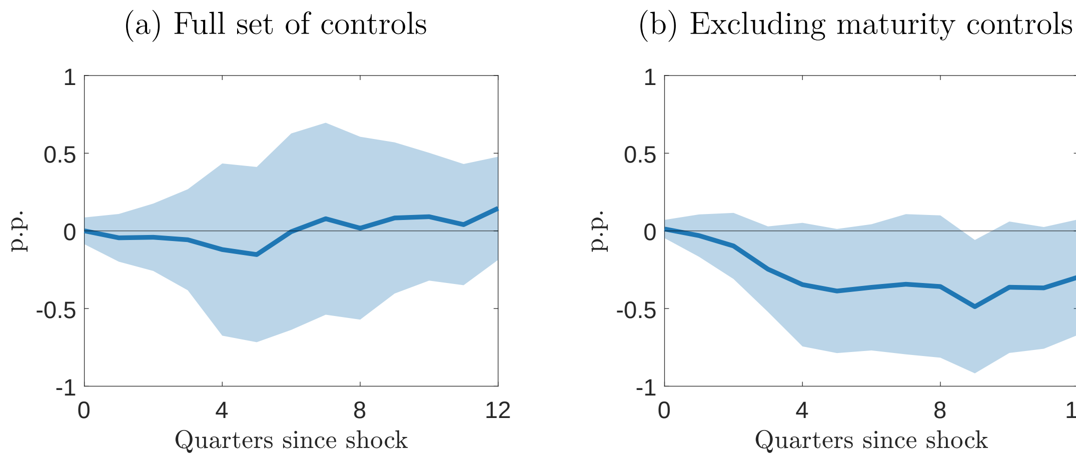
Figure 3: Timing of bond maturity



Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panels (a) and (b), x_{it} are the share of bonds maturing before and after the monetary shock, respectively. In panel (a), $x_{it} = \mathcal{M}_{it-1}$. In panel (b), $x_{it} = \sum_{j=1}^{3}$ maturing bonds$_{it+j}$/total debt$_{it-1}$. In both panels, $Z_{it-1} = \varnothing$. The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

Leverage. We next study how leverage shapes the response of capital growth to monetary policy. A large literature has investigated whether firms with higher leverage are more or less responsive to monetary policy shocks. However, how much debt a firm holds may be irrelevant if debt only matures in the long-run. Put differently, a firm's responsiveness to monetary policy shocks may be less shaped by debt which matures in the far future, but rather by debt maturing in the near future. To investigate the role of leverage for firm responses to monetary policy shocks, we estimate equation 2.2 when x_{it} is leverage. Panel (a) of Figure 4 shows the estimated β_1^h coefficients when including all controls of our saturated specification as well as $\mathcal{M}_{it}$. In contrast, panel (b) of Figure 4 omits the bond maturity controls. While the β_1^h estimates in (b) are significantly negative, the estimates in (a) are insignificant. This evidence suggests that total amount of debt is less relevant for monetary transmission than the maturing amount of debt. Note that the point estimates in panel (b) have the opposite sign of the estimates in Ottonello and Winberry (2020). One difference between our analyses is that we focus on a sample of bond-issuing firms. When we repeat the estimation of (b), for which we have not used bond-level information, on a sample that includes firms without bonds, we recover the result in Ottonello and Winberry (2020) that firms with higher leverage are less responsive, see Figure 17 in the Appendix.

Figure 4: Leverage when controlling for debt maturity



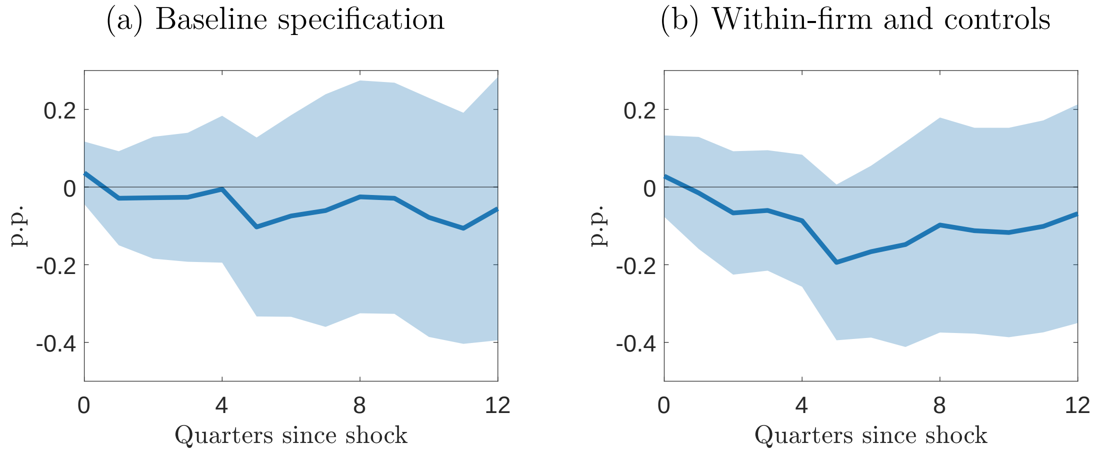
Note: The lines show the estimated β_1^h coefficients based on equation (2.2) with $x_{it} = \ell_{it} - \bar{\ell}_i$ where ℓ_{it} is leverage. In panel (a), Z_{it-1} includes the maturing bond share, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). In panel (b), Z_{it-1} excludes the maturing bond share and average maturity. The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

Compustat-based proxy for $\mathcal{M}_{it}$. Our empirical analysis builds on detailed bond-level data from FISD. This data allows us to construct the firm-quarter specific volume of bonds maturing in the same quarter when conditioning on bond characteristics. An alternative approach is to use information on current liabilities from Compustat, which is the sum of short-term liabilities and long-term liabilities maturing in the subsequent 12 months. We can use this to construct $\widetilde{\mathcal{M}}_{it}$, defined as the fraction of current liabilities over total debt in the preceding quarter. Figure 5 replicates our main findings in Figure 2 when using $\widetilde{\mathcal{M}}_{it}$ instead of the maturing bond share $\mathcal{M}_{it}$. The β_1^h coefficients are insignificant in the baseline specification, see panel (a). When exploiting within-firm variation and adding controls, panel (b), the point estimates of β_1^h are similar to our main finding but again the estimates are fairly imprecise. These findings suggest that the various different types of debt contracts (bank loans and corporate bonds) and maturities (short and long) combined in current liabilities have heterogeneous implications for capital growth responsiveness to monetary policy. It is therefore important to condition on debt characteristics when studying the interaction between debt maturity and monetary policy.

2.3 Extensions and robustness

Other outcomes. Our main finding is that capital growth is more responsive to monetary policy shocks if a higher share of bonds matures in the quarter of the shock. Does a higher

Figure 5: Compustat $\widetilde{\mathcal{M}}_{it}$ based on current liabilities



Note: The lines show the estimated β_1^h coefficients based on equation (2.2). We define $\widetilde{\mathcal{M}}_{it}$ = current liabilities$_{it}$/total debt$_{it-1}$. In panel (a), $x_{it} = \widetilde{\mathcal{M}}_{it}$ and $Z_{it-1} = \varnothing$. In panel (b), $x_{it} = \widetilde{\mathcal{M}}_{it} - \overline{\widetilde{\mathcal{M}}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

maturing bond share also affect other firm-level responses? Figure 18 in the Appendix shows the differential responses of debt and sales. To be precise, we show the β_1^h estimates when replacing the left-hand side in equation (2.2) by log differences in the real value of total debt and the real value of sales, respectively. We find that both debt and sales decline by more for firms with a higher maturing bond share. The estimates are significantly different from zero at the 10% level.

Monetary policy shocks. Our main findings are robust to a variety of alternative monetary policy shock series. Our baseline shock series $\varepsilon_t^{\mathrm{MP}}$ are based on 30-minute changes in the three-months-ahead federal funds future in a 30-minute window around regular FOMC meetings, sign-restricted following Jarociński and Karadi (2020). Figure 19 compares these baseline shocks with changes in 2-quarter, 3-quarter, and 4-quarter ahead eurodollar futures, using both the raw future price changes and the sign-restricted price changes.

Great Recession and ZLB. Our main findings are robust to excluding the Great Recession period or the post-Great Recession period largely characterized by a binding effective zero lower bound on monetary policy. Panel (a) of Figure 20 shows the β_1^h estimates in equation (2.2) when the sample of shocks stops at the height of the Great Recession in 2008Q2. Panel (b) shows the β_1^h estimates when excluding only 2008Q3-2009Q2.

Denominators in $\mathcal{M}_{it}$. In equation 2.1 we have defined the maturing bond share $\mathcal{M}_{it}$ as the ratio of bonds maturing in period t over the total stock of debt at the end of period $t-1$. This means $\mathcal{M}_{it}$ is an inverse measure of debt maturity. We consider three alternative $\mathcal{M}_{it}$

for which we replace total debt in the denominator by capital, sales, and assets. Dividing by assets makes the $\mathcal{M}_{it}$ a measure of leverage based only on maturing bonds. Panels (a)-(c) of Figure 21 shows the related β_1^h estimates. For all these alternative $\mathcal{M}_{it}$, we use the backward-looking four-quarter average of capital, sales, and assets. In panel (d), we show the β_1^h estimates when using the simple lag level of debt, capital, sales, assets, respectively. Our main finding is broadly robust against these alternative definitions of $\mathcal{M}_{it}$.

Dummy specification. Our baseline specification includes a linear interaction between monetary policy shocks and the maturing bond share. Instead, we consider a specification in which monetary policy shocks are interacted with a dummy variable that is one if the maturing bond share is above a threshold. As thresholds, we consider 0% and 15%. Figure 22 in the Appendix shows that this leads to broadly similar conclusions.

Callable and variable-coupon bonds. Our main findings are based the maturing value of non-callable and fixed-coupon bonds. That is, the numerator of $\mathcal{M}_{it}$ excludes the maturing value of callable and variable-coupon bonds. This approach avoids mixing different types of debt contract, which may shape the firm response to monetary policy differently. In particular, a callable bonds is not called before maturity for a reason. Figure 23 shows the β_1^h estimates if we construct $\mathcal{M}_{it}$ only using callable or variable-coupon bonds, respectively, see panels (a) and (c). The estimates are highly insignificant. Alternatively, we sum up over the maturing amount of non-callable and callable bonds, or over fixed and variable-coupon bonds, see panels (b) and (d). In this case, the estimates are broadly consistent with the main estimates in Figure 2.

3 Model Setup

The previous section established empirically that the investment response to monetary policy shocks is stronger for firms with a larger share of maturing debt. In order to understand the implications of this result for the aggregate effects of monetary policy, we develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. The model generates rich heterogeneity in firms' maturity choice.

At the heart of the model is a continuum of heterogeneous firms which produce output using capital and labor. Capital is financed through equity and nominal debt. Debt has a tax advantage relative to equity but introduces the risk of costly default. Firms can choose a mix of short-term debt and long-term debt. Long-term debt saves roll-over costs but generates debt overhang, which increases leverage and default risk. This part of the model builds on Jungherr and Schott (2021) with the additional features of costly equity issuance and nominal debt.

In addition to production firms, the economy consists of retail firms, capital producers, a representative household, and a government. Retail firms buy homogeneous production goods, turn them into differentiated retail goods and sell them to a final goods sector. They are monopolistically competitive and set prices subject to Rotemberg adjustment costs. Capital producers convert final goods into capital. The representative household works, consumes final goods, and saves by buying equity and debt securities issued by production firms. The government collects a corporate income tax and conducts monetary policy by setting the nominal riskless interest rate.

3.1 Production firms: Setup

A production firm i generates a quantity y_{it} of homogeneous production goods using capital k_{it} and labor l_{it} at time t:

$$y_{it} = z_{it}\left(k_{it}^{\psi} l_{it}^{1-\psi}\right)^{\zeta}, \quad \text{with:} \quad \zeta, \psi \in (0,1) \tag{3.1}$$

Firm-level productivity z_{it} is a persistent random variable which is realized at the end of period $t-1$ with conditional probability distribution $\pi(z_{it}|z_{it-1})$. Earnings before interest and taxes are

$$p_t y_{it} - w_t l_{it} + (\varepsilon_{it} - \delta) Q_t k_{it} - f, \tag{3.2}$$

where p_t is the price of the homogeneous production good (expressed in terms of the final good), w_t is the real wage rate, ε_{it} is a firm-specific shock to capital quality, δ is the depreciation rate, Q_t is the price of capital goods, and f is a fixed cost of production. The capital quality shock ε_{it} is i.i.d. with mean zero and continuous probability distribution $\varphi(\varepsilon)$. It is realized in period t after production has taken place. An example of a negative capital quality shock is an unforeseen change in technology or consumer demand which reduces the value of existing firm-specific capital.

The firm can finance capital with equity, short-term debt, and long-term debt. All debt is nominal.

Definition. Short-term debt: A short-term bond issued at the end of period t is a promise to pay one unit of currency in period $t+1$ together with a nominal coupon c. The quantity of nominal short-term bonds sold by firm i and due in period $t+1$ is $\tilde{B}^S_{it+1}$.

In the following, we will use the real face value of debt expressed in terms of time t final goods (the numéraire): $\tilde{b}^S_{it+1} \equiv \tilde{B}^S_{it+1}/P_t$, where P_t denotes the price of the final good in period t. If at the end of period t the firm sells short-term bonds of real face value $\tilde{b}^S_{it+1}$ at price p^S_{it}, it raises the amount $\tilde{b}^S_{it+1} p^S_{it}$ on the bond market.

Definition. Long-term debt: A long-term bond issued at the end of period t is a promise to pay a nominal coupon c in period $t+1$. In addition, the firm repays a fraction $\gamma \in (0,1)$ of the principal in period $t+1$. In period $t+2$, a fraction $1-\gamma$ of the bond remains outstanding. The firm pays a coupon $(1-\gamma)c$ and repays the fraction γ of the remaining principal. In this manner, payments decay geometrically over time. The maturity parameter γ controls the speed of decay. The quantity of nominal long-term bonds chosen by the firm at the end of period t is $\tilde{B}^L_{it+1}$.

This computationally tractable specification of long-term debt goes back to Leland (1994). Let $\tilde{b}^L_{it+1}$ be the real face value of period $t+1$ long-term debt: $\tilde{b}^L_{it+1} \equiv \tilde{B}^L_{it+1}/P_t$, and let B_{it} denote the stock of previously issued nominal long-term bonds outstanding at the end of period t. If the firm sells a quantity $\tilde{B}^L_{it+1} - B_{it}$ of additional long-term bonds, it increases the real face value of long-term debt by

$$\frac{(\tilde{B}^L_{it+1} - B_{it})}{P_t} = \left(\tilde{b}^L_{it+1} - \frac{B_{it}}{P_t}\frac{P_{t-1}}{P_{t-1}}\right) = \left(\tilde{b}^L_{it+1} - \frac{b_{it}}{\pi_t}\right), \tag{3.3}$$

where $b_{it} \equiv B_{it}/P_{t-1}$, and $\pi_t \equiv P_t/P_{t-1}$ is the inflation rate. The corresponding amount raised on the bond market is

$$\left(\tilde{b}^L_{it+1} - \frac{b_{it}}{\pi_t}\right) p^L_{it}. \tag{3.4}$$

Definition. Debt issuance cost: The firm pays a quadratic issuance cost whenever it sells new short-term or long-term debt. Repurchasing outstanding long-term debt (by choosing $\tilde{b}^L_{it+1} < b_{it}/\pi_t$) is costless. Total debt issuance costs $H(\tilde{b}^S_{it+1}, \tilde{b}^L_{it+1}, b_{it}/\pi_t)$ are therefore

$$H\left(\tilde{b}^S_{it+1}, \tilde{b}^L_{it+1}, \frac{b_{it}}{\pi_t}\right) = \eta\left(\tilde{b}^S_{it+1} + \max\left\{\tilde{b}^L_{it+1} - \frac{b_{it}}{\pi_t}, 0\right\}\right)^2. \tag{3.5}$$

The issuance cost makes short-term debt unattractive because it needs to be constantly rolled over. Long-term debt matures slowly over time and therefore allows maintaining a given stock of debt at a lower level of bond issuance per period.[9]

The firm finances next period's capital stock k_{it+1} through retained earnings, by raising outside equity from shareholders, and by selling new short- and long-term debt. Let q_{it} denote the real market value of firm assets in place at the end of period t, and let e_{it} denote net equity issuance, that is, the net cash flow from shareholders to the firm:

$$e_{it} = Q_{it}k_{it+1} - q_{it} - \tilde{b}^S_{it+1}p^S_{it} - \left(\tilde{b}^L_{it+1} - \frac{b_{it}}{\pi_t}\right)p^L_{it} \tag{3.6}$$

A negative value of e_{it} indicates a net dividend payment from the firm to shareholders. While dividend payout is costless, issuing equity is costly.[10]

Definition. Equity issuance cost: The firm pays a quadratic issuance cost whenever it raises outside equity (as in Hennessy and Whited, 2007). Net dividend payout ($e_{it} < 0$) is costless. Equity issuance costs $G(e_{it})$ are therefore

$$G\left(e_{it}\right) = \nu\left(\max\left\{e_{it}, 0\right\}\right)^2 \tag{3.7}$$

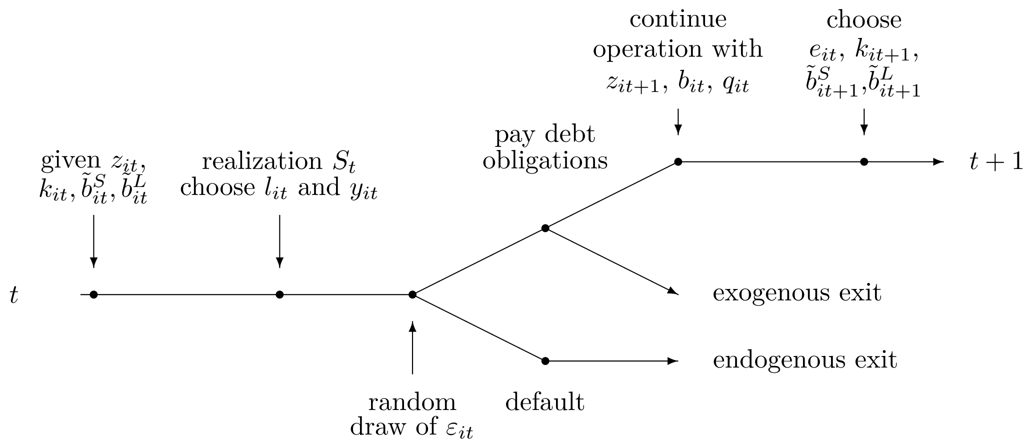
Firm earnings are taxed at rate τ. Debt coupon payments are tax deductible. After production, taxation, and payment of debt, the real market value of firm assets in period t is therefore

$$q_{it} = Q_t k_{it} - \frac{\tilde{b}^S_{it}}{\pi_t} - \frac{\gamma\tilde{b}^L_{it}}{\pi_t} + (1-\tau)\left[p_t y_{it} - w_t l_{it} + (\varepsilon_{it} - \delta)Q_t k_{it} - f - \frac{c(\tilde{b}^S_{it} + \tilde{b}^L_{it})}{\pi_t}\right] \tag{3.8}$$

[9] Debt issuance costs capture underwriting fees charged by investment banks to bond issuing firms. Altnklç and Hansen (2000) provide empirical evidence that marginal debt issuance costs are increasing in debt issuance.

[10] Using data on underwriting spreads, Altnklç and Hansen (2000) provide empirical evidence on increasing marginal equity issuance costs. Besides underwriting fees, the equity issuance cost function $G(e_{it})$ can be thought of as also capturing costs from adverse selection on the stock market (*cf.* Myers and Majluf, 1984).

Figure 6: Timing



The real face value of nominal short- and long-term debt depends on inflation π_t. The fact that coupon payments are tax deductible lowers total tax payments by the amount $\tau c(\tilde{b}^S_{it} + \tilde{b}^L_{it})/\pi_t$. This is the benefit of debt. The downside is that the firm cannot commit to repaying its debt.

Definition. Limited liability: Shareholders are protected by limited liability. They are free to default and hand over the firm's assets to creditors for liquidation. Default is costly. Creditors recover only a fraction $1 - \xi$ of firm assets.

A defaulting firm exits the economy. In addition, there is exogenous exit. With probability κ, a non-defaulting firm exogenously leaves the economy. In this case, the exiting firm repurchases any outstanding stock of long-term debt at the market value $(b_{it}/\pi_t)p^L_{it}$. The remaining firm value $q_{it} - (b_{it}/\pi_t)p^L_{it}$ is paid out to shareholders.

The timing is summarized in Figure 6. Firm i enters period t with given levels of productivity z_{it}, capital k_{it}, short-term debt $\tilde{b}^S_{it}$, and long-term debt $\tilde{b}^L_{it}$. The aggregate state of the economy S_t (specified below) is realized. The firm chooses labor l_{it} and produces output y_{it}. The idiosyncratic capital quality shock ε_{it} is realized and the firm decides whether to default. Exogenous exit occurs with probability κ. Continuing firms have an amount $b_{it} = (1-\gamma)\tilde{b}^L_{it}$ of long-term debt outstanding and a market value of firm assets q_{it}. After the realization of next period's productivity level z_{it+1}, firm i chooses next period's capital k_{it+1}, short-term debt $\tilde{b}^S_{it+1}$, and long-term debt $\tilde{b}^L_{it+1}$.

3.2 Production firms: Labor demand and default decision

Given productivity z_{it} and capital k_{it}, as well as the aggregate state S_t, the firm's labor demand is determined by a simple first order condition:

$$l_{it} = \frac{\zeta(1-\psi)p_t y_{it}}{w_t} = \left(\frac{\zeta(1-\psi)p_t z_{it} k_{it}^{\psi\zeta}}{w_t}\right)^{\frac{1}{1-\zeta(1-\psi)}} \tag{3.9}$$

After producing output y_{it}, the firm-specific capital quality shock ε_{it} is realized. This determines q_{it}, the asset value after production. In addition, a firm knows the remaining amount of outstanding long-term debt, b_{it}, but has not yet learned its future productivity level z_{it+1}.

The firm maximizes shareholder value, that is, the expected real present value of net cash flows to shareholders. If the firm does not default, expected shareholder value is

$$(1-\kappa)\,\hat{\mathbb{E}}\,V_t\left(q_{it}, b_{it}, z_{it+1}, S_t\right) + \kappa\left(q_{it} - \frac{b_{it}}{\pi_t}\,\hat{\mathbb{E}}\,p_{it}^L\right), \tag{3.10}$$

where the expectation $\hat{\mathbb{E}}$ is taken over future firm productivity z_{it+1} conditional on z_{it}. With probability $1-\kappa$, the firm continues to operate. Shareholder value is $V_t\left(q_{it}, b_{it}, z_{it+1}, S_t\right)$ in this case. Exogenous exit occurs with probability κ.

Limited liability protects shareholders from large negative realizations of ε_{it}. As is shown below, both q_{it} and the firm-specific price of long-term debt p_{it}^L are functions of ε_{it}. If (3.10) is strictly increasing in ε_{it}, there exists a unique threshold realization $\bar{\varepsilon}_{it}$ which sets shareholder value (3.10) to zero:

$$\bar{\varepsilon}_{it}: \quad (1-\kappa)\,\hat{\mathbb{E}}\,V_t\left(q_{it}, b_{it}, z_{it+1}, S_t\right) + \kappa\left(q_{it} - \frac{b_{it}}{\pi_t}\,\hat{\mathbb{E}}\,p_{it}^L\right) = 0 \tag{3.11}$$

If ε_{it} is smaller than $\bar{\varepsilon}_{it}$, full repayment would result in negative expected shareholder value, whereas default provides an outside option of zero. In that case, the firm optimally defaults on its debt liabilities. The threshold value $\bar{\varepsilon}_{it}$ depends on q_{it} and b_{it}. High levels of debt $\tilde{b}_{it}^S$ and $\tilde{b}_{it}^L$ relative to capital k_{it} can increase the default threshold $\bar{\varepsilon}_{it}$ and thereby the probability of default.

3.3 Production firms: Creditors' problem

The firm's choice of capital k_{it+1} and debt $\tilde{b}_{it+1}^S$ and $\tilde{b}_{it+1}^L$ crucially depends on the two bond prices p_{it}^S and p_{it}^L. Low bond prices imply high credit spreads which increase the firm's cost of capital. Creditors are perfectly competitive. As all firm debt is held by the representative household, bonds are priced using the stochastic discount factor of the representative household $\Lambda_{t,t+1}$. If the firm does not default in period $t+1$, short-term creditors receive a real amount $(1+c)\tilde{b}_{it+1}^S/\pi_{t+1}$, and long-term creditors are paid $(\gamma + c)\tilde{b}_{it+1}^L/\pi_{t+1}$. In case of default, the value of the firm's assets is

$$\underline{q}_{it+1} \equiv Q_{t+1}k_{it+1} + (1-\tau)\left[p_{t+1}y_{it+1} - w_{t+1}l_{it+1} + (\varepsilon_{it+1} - \delta)Q_{t+1}k_{it+1} - f\right] \tag{3.12}$$

At this point, creditors liquidate the firm's assets and receive $(1-\xi)\underline{q}_{it+1}$. Short- and long-term debt have equal seniority. The break-even price of nominal short-term debt (in terms of the time t numéraire) is therefore

$$p_{it}^S = \mathbb{E}\,\Lambda_{t,t+1}\left[\left[1-\Phi(\bar{\varepsilon}_{it+1})\right]\frac{1+c}{\pi_{t+1}} + \frac{(1-\xi)}{\tilde{b}_{it+1}^S + \tilde{b}_{it+1}^L}\int_{-\infty}^{\bar{\varepsilon}_{it+1}} \underline{q}_{it+1}\varphi(\varepsilon)d\varepsilon\right], \tag{3.13}$$

where $1-\Phi(\bar{\varepsilon}_{it+1})$ is the probability that $\varepsilon_{it+1} > \bar{\varepsilon}_{it+1}$. The price of short-term debt depends on firm behavior at time $t+1$, in particular on the risk of default $\Phi(\bar{\varepsilon}_{it+1})$. In contrast, the price of long-term debt p^L_{it} also depends on the future market value of long-term debt $p^L_{it+1} = g_{t+1}(q_{it+1}, b_{it+1}, z_{it+2}, S_{t+1})$:

$$p^L_{it} = \mathbb{E}\,\Lambda_{t,t+1}\Bigg[\int_{\bar{\varepsilon}_{it+1}}^{\infty} \frac{\gamma + c + (1-\gamma)\, g_{t+1}(q_{it+1}, b_{it+1}, z_{it+2}, S_{t+1})}{\pi_{t+1}}\, \varphi(\varepsilon)\, d\varepsilon + \frac{(1-\xi)}{\tilde{b}^S_{it+1} + \tilde{b}^L_{it+1}} \int_{-\infty}^{\bar{\varepsilon}_{it+1}} \underline{q}_{it+1}\, \varphi(\varepsilon)\, d\varepsilon\Bigg], \tag{3.14}$$

where the expectation $\mathbb{E}$ is taken over the aggregate state S_{t+1} and future firm productivity z_{it+2}. If the firm does not default in period $t+1$, it repays a fraction γ of the outstanding debt plus the coupon c. A fraction $1-\gamma$ of the debt remains outstanding. Because the future price of long-term debt p^L_{it+1} depends on future firm behavior, it is a function of the future state of the firm: $p^L_{it+1} = g_{t+1}(q_{it+1}, b_{it+1}, z_{it+2}, S_{t+1})$. The firm cannot directly control future firm behavior, but if can influence q_{it+1} and b_{it+1} through today's choice of capital k_{it+1} and debt $\tilde{b}^S_{it+1}$ and $\tilde{b}^L_{it+1}$.

3.4 Production firms: Investment and financing choice

Given creditors' demand for firm debt, the firm chooses capital k_{it+1} and debt $\tilde{b}^S_{it+1}$ and $\tilde{b}^L_{it+1}$. The firm anticipates that shareholder value in period $t+1$ will be positive if ε_{it+1} is higher than the threshold value $\bar{\varepsilon}_{it+1}$ and zero otherwise. Given the value of assets in place q_{it}, existing debt b_{it}, productivity z_{it+1}, and the aggregate state S_t, the firm solves:

$$\max_{\substack{e_{it} \geq \underline{e}, k_{it+1}, \\ \tilde{b}^S_{it+1}, \tilde{b}^L_{it+1}}} \; -e_{it} - G(e_{it}) - H\left(\tilde{b}^S_{it+1}, \tilde{b}^L_{it+1}, b_{it}/\pi_t\right) + \mathbb{E}\,\Lambda_{t,t+1} \int_{\bar{\varepsilon}_{it+1}}^{\infty} \left[(1-\kappa)\, V_{t+1}\left(q_{it+1}, b_{it+1}, z_{it+2}, S_{t+1}\right) + \kappa \left(q_{it+1} - \frac{b_{it+1}}{\pi_{t+1}}\, p^L_{it+1}\right)\right] \varphi(\varepsilon) d\varepsilon \tag{3.15}$$

$\Lambda_{t,t+1}$ is the stochastic discount factor of the representative household. The firm's choice of e_{it} is bounded from below: $e_{it} \geq \underline{e}$, with $\underline{e} < 0$. This constitutes an upper limit for dividend payments.[11]

In equilibrium, a firm maximizes shareholder value (3.15) subject to creditors' bond pricing equations (3.13) and (3.14). Because we assume that the firm has no ability to commit to future actions, it must take its own future behavior as given and chooses today's policy as a best response. In other words, the firm plays a game against its future selves. As in Klein et al. (2008), we restrict attention to the Markov perfect equilibrium, i.e. we

[11]If the stock of existing debt b_{it} is sufficiently large, the firm may find it optimal to choose a corner solution and pay out the entire asset value of the firm as dividend: $e_{it} = -q_{it}$. In practice, it is illegal to pay dividends which substantially exceed firm earnings and deplete a firm's stock of capital. We choose the value of the constraint $\underline{e}$ such that it rules out this corner solution but is not binding in equilibrium. The exact value of $\underline{e}$ does not affect equilibrium variables.

consider policy rules which are functions of the payoff-relevant state variables. The time-consistent policy is a fixed point in which the future firm policy coincides with today's firm policy.

The value $V_t(q_{it}, b_{it}, z_{it+1}, S_t)$ can be computed recursively. Time subscripts are dropped in the recursive formulation of the problem. Each period, the firm chooses a policy vector $\phi(q, b, z', S) = \{e, k', \tilde{b}^{S'}, \tilde{b}^{L'}\}$ which solves

$$V(q, b, z', S) = \max_{\phi(q,b,z',S)=\left\{\substack{e\geq\underline{e},k', \\ \tilde{b}^{S'},\tilde{b}^{L'}}\right\}} -e - G(e) - H\left(\tilde{b}^{S'}, \tilde{b}^{L'}, b/\pi\right)$$

$$+\mathbb{E}\,\Lambda \int_{\bar{\varepsilon}'}^{\infty} \left[(1-\kappa)\, V(q', b', z'', S') + \kappa\left(q' - \frac{b'}{\pi'}\, g(q', b', z'', S')\right)\right] \varphi(\varepsilon) d\varepsilon \tag{3.16}$$

$$\text{s.t.:}\quad q' = Q'k' - \frac{\tilde{b}^{S'}}{\pi'} - \frac{\gamma \tilde{b}^{L'}}{\pi'} + (1-\tau)\left[p'y' - w'l' + (\varepsilon' - \delta)Q'k' - f - \frac{c(\tilde{b}^{S'} + \tilde{b}^{L'})}{\pi'}\right]$$

$$y' = z'\left(k'^{\psi} l'^{1-\psi}\right)^{\zeta}$$

$$l' = \left(\frac{\zeta(1-\psi)p'z'k'^{\psi\zeta}}{w'}\right)^{\frac{1}{1-\zeta(1-\psi)}}$$

$$\bar{\varepsilon}' :\quad (1-\kappa)\,\hat{\mathbb{E}}\, V(q', b', z'', S') + \kappa\left(q' - \frac{b'}{\pi'}\,\hat{\mathbb{E}}\, g(q', b', z'', S')\right) = 0$$

$$e = Qk' - q - \tilde{b}^{S'} p^S - \left(\tilde{b}^{L'} - \frac{b}{\pi}\right) p^L$$

$$b' = (1-\gamma)\tilde{b}^{L'}$$

$$p^S = \mathbb{E}\,\Lambda\left[[1 - \Phi(\bar{\varepsilon}')]\frac{1+c}{\pi'} + \frac{(1-\xi)}{\tilde{b}^{S'} + \tilde{b}^{L'}} \int_{-\infty}^{\bar{\varepsilon}'} \underline{q}'\ \varphi(\varepsilon) d\varepsilon\right]$$

$$p^L = \mathbb{E}\,\Lambda\left[\int_{\bar{\varepsilon}'}^{\infty} \frac{\gamma + c + (1-\gamma)\, g(q', b', z'', S')}{\pi'}\,\varphi(\varepsilon) d\varepsilon + \frac{(1-\xi)}{\tilde{b}^{S'} + \tilde{b}^{L'}} \int_{-\infty}^{\bar{\varepsilon}'} \underline{q}'\ \varphi(\varepsilon) d\varepsilon\right]$$

3.5 Production firms: Firm distribution

At the beginning of period t, the continuum of production firms is characterized by a distribution over capital k_{it}, debt $\tilde{b}^S_{it}$ and $\tilde{b}^L_{it}$, and productivity z_{it}: $\tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)$. Together with the aggregate state S, the beginning-of-period distribution $\tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)$ determines the end-of-period distribution over assets q_{it}, outstanding debt b_{it}, and next period's productivity z_{it+1}:

$$\mu_t(q, b, z') = \Gamma\Big(\ \tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)\,,\ S\ \Big) =$$

$$\int_0^{\infty}\int_0^{\infty}\int_0^{\infty}\int_0^{\infty}\int_{\bar{\varepsilon}}^{\infty} \tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)\, \pi(z'|z)\, \mathcal{I}(q, b, k, \tilde{b}^S, \tilde{b}^L, z, \varepsilon, S)\, (1-\kappa)\, \varphi(\varepsilon)\, d\varepsilon\, dk\, d\tilde{b}^S\, d\tilde{b}^L\, dz$$
$$+ \mathcal{M}(q, b, z')\,, \tag{3.17}$$

where the indicator function $\mathcal{I}(q, b, k, \tilde{b}^S, \tilde{b}^L, z, \varepsilon, S) = 1$ if the firm's market value of assets is $q = q(k, \tilde{b}^S, \tilde{b}^L, z, \varepsilon, S)$ and its stock of existing debt is $b = (1-\gamma)\tilde{b}^L$. Firms exit the economy endogenously because of default and exogenously at rate κ. Entrants start without existing assets or debt ($q = b = 0$) and with initial productivity $z' = z^e$. The function $\mathcal{M}(q, b, z')$ is equal to the mass of entrants at $q = b = 0$ and $z' = z^e$, and zero otherwise. The aggregate mass of firms is always one because in each period the mass of entrants is equal to the time-varying mass of exiting firms. Next period's firm distribution $\tilde{\mu}_{t+1}(k', \tilde{b}^{S'}, \tilde{b}^{L'}, z')$ is

$$\tilde{\mu}_{t+1}(k', \tilde{b}^{S'}, \tilde{b}^{L'}, z') = \tilde{\Gamma}\Big(\mu_t(q, b, z')\,,\, S\Big) = \int_0^\infty \int_0^\infty \mu_t(q, b, z')\, \mathcal{I}(k', \tilde{b}^{S'}, \tilde{b}^{L'}, q, b, z', S)\, dq\, db\,, \tag{3.18}$$

where the indicator function $\mathcal{I}(k', \tilde{b}^{S'}, \tilde{b}^{L'}, q, b, z', S) = 1$ if the firm's choice of next period's capital stock $k' = k'(q, b, z', S)$ and its choice of next period's debt levels is $\tilde{b}^{S'} = \tilde{b}^{S'}(q, b, z', S)$ and $\tilde{b}^{L'} = \tilde{b}^{L'}(q, b, z', S)$.

3.6 Retail firms and final goods sector

The remainder of the model setup closely follows Bernanke et al. (1999) and Ottonello and Winberry (2020). To keep the model tractable and transparent, we have separated firm heterogeneity from nominal frictions by modeling production firms as price takers. We now introduce nominal rigidities through a constant unit mass of retail firms. These retail firms buy undifferentiated goods from production firms, repackage them, and sell them as differentiated varieties to the final goods sector. The amount of retail goods $\tilde{y}_{jt}$ produced by retailer $j \in [0, 1]$ is

$$\tilde{y}_{jt} = y_{jt}\,, \tag{3.19}$$

where y_{jt} is the quantity of undifferentiated production goods used by retailer j. Period profits are

$$\tilde{p}_{jt}\tilde{y}_{jt} - p_t y_{jt} - \frac{\lambda}{2}\left(\frac{\tilde{p}_{jt}}{\tilde{p}_{jt-1}} - 1\right)^2 Y_t\,, \tag{3.20}$$

where $\tilde{p}_{jt}$ is the price of variety j and p_t is the price of undifferentiated production goods which is equal for all production firms. Rotemberg-style costs of price adjustment are expressed as a fraction of aggregate real output Y_t.

Retail goods are bought by a perfectly competitive final goods sector which produces final goods Y_t at constant returns to scale:

$$Y_t = \left[\int_0^1 \tilde{y}_{jt}^{\frac{\rho-1}{\rho}}\, dj\right]^{\frac{\rho}{\rho-1}}\,, \quad \text{where} \quad \rho > 1 \tag{3.21}$$

Profit maximization in the final goods sector yields a downward sloping demand curve for variety j:

$$\tilde{y}_{jt} = \left(\frac{P_t}{\tilde{p}_{jt}}\right)^{\rho} Y_t\,, \quad \text{where} \quad P_t = \left[\int_0^1 \tilde{p}_{jt}^{1-\rho} dj\right]^{\frac{1}{1-\rho}} \tag{3.22}$$

Imperfect substitutability among different varieties gives each retailer some amount of market power. Optimal dynamic price setting by retailer j gives the following first order condition for $\tilde{p}_{jt}$:

$$\tilde{y}_{jt} - \rho\left(\frac{\tilde{p}_{jt} - p_t}{\tilde{p}_{jt}}\right)\tilde{y}_{jt} - \lambda\frac{Y_t}{\tilde{p}_{jt-1}}\left(\frac{\tilde{p}_{jt}}{\tilde{p}_{jt-1}} - 1\right) + \mathbb{E}\,\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{\tilde{p}_{jt}}\left(\frac{\tilde{p}_{jt+1}}{\tilde{p}_{jt}} - 1\right)\frac{\tilde{p}_{jt+1}}{\tilde{p}_{jt}} = 0 \quad (3.23)$$

From symmetry ($\tilde{p}_{jt} = P_t$ and $\tilde{y}_{jt} = Y_t$), it follows:

$$1 - \rho\left(\frac{P_t - p_t}{P_t}\right) - \lambda\frac{1}{P_{t-1}}\left(\frac{P_t}{P_{t-1}} - 1\right) + \mathbb{E}\,\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{P_t Y_t}\left(\frac{P_{t+1}}{P_t} - 1\right)\frac{P_{t+1}}{P_t} = 0 \quad (3.24)$$

The final good is the numéraire: $P_t = 1$. Using $\pi_t = P_t/P_{t-1}$, we derive as the New Keynesian Phillips Curve:

$$1 - \rho\,(1 - p_t) - \lambda\,\pi_t(\pi_t - 1) + \mathbb{E}\,\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{Y_t}\,\pi_{t+1}(\pi_{t+1} - 1) = 0 \quad (3.25)$$

This nonlinear equation relates retailers' markup $1/p_t$ to contemporaneous inflation π_t as well as to expected future inflation π_{t+1} and expected real output growth Y_{t+1}/Y_t. After a positive shock to aggregate demand, the relative price of undifferentiated production goods p_t increases and the markup $1/p_t$ falls. Retailers respond by raising prices which increases inflation through (3.25). A higher value of the price adjustment cost parameter λ dampens the contemporary response of inflation.

3.7 Capital producers

There is a representative capital good producer who adjusts the aggregate stock of capital from $(1-\delta)K_t$ to K_{t+1} using an amount I_t of final goods with decreasing returns:

$$K_{t+1} = \Phi\left(\frac{I_t}{K_t}\right)K_t + (1-\delta)K_t\,, \quad \text{where} \quad \Phi\left(\frac{I_t}{K_t}\right) = \frac{\delta^{\frac{1}{\phi}}}{1 - \frac{1}{\phi}}\left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\phi}} - \frac{\delta}{\phi - 1}\,, \quad (3.26)$$

and $\phi > 1$. $I_t = \delta K_t$ implies $K_{t+1} = K_t$ for any ϕ. Furthermore, $K_{t+1} \to K_t$ as $\phi \to 1$ for any I_t. Profit maximization pins down the price of capital goods:

$$Q_t = \left(\frac{\frac{I_t}{K_t}}{\delta}\right)^{\frac{1}{\phi}} \quad (3.27)$$

This implies for the steady state price of capital goods when $I_t = \delta K_t$: $Q_t = 1$.

3.8 Government and monetary policy

The government collects a corporate income tax and pays out the proceeds to the representative household as a lump-sum transfer. In addition, the government conducts monetary policy by setting the nominal riskless interest rate r_t^{nom} according to the Taylor rule:

$$\ln(1 + r_t^{nom}) = \ln\frac{1}{\beta} + \varphi_m \ln \pi_t + \varepsilon_t^m\,, \quad (3.28)$$

where $\beta \in (0,1)$ is the representative households' discount rate of future utility. The parameter φ_m is the inflation weight of the reaction function, and the stochastic component ε_t^m is driven by monetary shocks η_t^m following:

$$\varepsilon_t^m = \rho_m \varepsilon_{t-1}^m + \eta_t^m \,, \quad \text{with:} \quad \eta_t^m \sim N(0, \sigma_m^2) \tag{3.29}$$

3.9 Households

We close the model by introducing a representative household that owns all equity and debt claims issued by firms and receives all income in the economy (including profits by retail firms and capital producers). Government revenue from taxation is paid out to the household as a lump-sum transfer. The household works and consumes final goods. The household saves by buying equity and debt securities issued by production firms.

Future utility is discounted at rate β. We assume additive-separable preferences over consumption C_t and labor L_t. Period utility is

$$\ln(C_t) - \frac{L_t^{1+\theta}}{1+\theta}, \quad \text{with:} \quad \theta > 0 \tag{3.30}$$

The stochastic discount factor of the representative household is accordingly:

$$\Lambda_{t,t+1} \;=\; \beta \, \frac{C_t}{C_{t+1}} \tag{3.31}$$

3.10 General equilibrium

The aggregate state of the economy S_t consists of the firm distribution $\tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)$ and the stochastic component of the Taylor rule ε_t^m: $S_t = \{\tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z), \varepsilon_t^m\}$.

Definition. Given the aggregate state $S_t = \{\tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z), \varepsilon_t^m\}$, the equilibrium consists of *(i)* an end-of-period distribution $\mu_t(q, b, z')$, *(ii)* a policy vector $\phi(q, b, z', S) = \{e, k, \tilde{b}^S, \tilde{b}^L\}$, a value function $V(q, b, z', S)$, and bond price functions p^S and p^L, *(iii)* a production goods price p_t, inflation π_t, and a price of capital goods Q_t, *(iv)* household consumption C_t and aggregate labor supply L_t, and *(v)* a stochastic discount factor $\Lambda_{t,t+1}$, a nominal interest rate r_t^{nom} and a wage rate w_t, such that for all periods t and for all realizations of the monetary shock η_t^m:

1. $\mu_t(q, b, z') = \Gamma(\tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z), S)$ as in (3.17), and $\tilde{\mu}_{t+1}(k', \tilde{b}^{S\prime}, \tilde{b}^{L\prime}, z') = \tilde{\Gamma}(\mu_t(q, b, z'), S)$ as in (3.18)

2. $\phi(q, b, z', S)$, $V(q, b, z', S)$, p^S, and p^L solve the firm problem (3.16).

3. The Phillips curve (3.25), the capital goods price (3.27), and the Taylor rule (3.28) hold

4. The representative household chooses C_t and L_t optimally:
   $1 = \mathbb{E}\,\Lambda_{t,t+1}(1 + r_t^{nom})/\pi_{t+1}$ and $w_t = L_t^{\theta} C_t$

5. The labor market, the market for capital goods, and the final goods market clear.

Labor market clearing implies that

$$L_t = \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty l(k, \tilde{b}^S, \tilde{b}^L, z, S)\, \tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)\, dk\, d\tilde{b}^S\, d\tilde{b}^S\, dz \tag{3.32}$$

The capital goods market clears if and only if

$$K_{t+1} = \int_0^\infty \int_0^\infty \int_{-\infty}^\infty k'(q, b, z', S)\, \mu_t(q, b, z')\, dq\, db\, dz' \tag{3.33}$$

The aggregate amount of final goods produced is

$$Y_t = \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty y(k, \tilde{b}^S, \tilde{b}^L, z, S)\, \tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)\, dk\, d\tilde{b}^S\, d\tilde{b}^S\, dz \tag{3.34}$$

The amount of final goods available for consumption and investment (as well as for covering debt and equity issuance costs) is reduced by the fixed cost of operation and default costs:

$$\begin{aligned} Y_t^{net} \equiv \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty \Big[& y(k, \tilde{b}^S, \tilde{b}^L, z, S) - f \\ & - \xi \int_{-\infty}^{\bar{\varepsilon}(k, \tilde{b}^S, \tilde{b}^L, z, S)} \underline{q}(k, \tilde{b}^S, \tilde{b}^L, z, S, \varepsilon)\, \varphi(\varepsilon)\, d\varepsilon \Big]\, \tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)\, dk\, d\tilde{b}^S\, d\tilde{b}^S\, dz \end{aligned} \tag{3.35}$$

The market for final goods clears if and only if:

$$\begin{aligned} Y_t^{net} = {} & C_t + I_t \\ & + \int_0^\infty \int_0^\infty \int_{-\infty}^\infty \left[G\left(e(q, b, z', S)\right) + H\left(\tilde{b}^{S'}(q, b, z', S), \tilde{b}^{L'}(q, b, z', S), b/\pi\right) \right] \mu_t(q, b, z')\, dq\, db\, dz', \end{aligned} \tag{3.36}$$

where C_t is household consumption and aggregate investment I_t is given by (3.26):

$$I_t = K_t \left[\frac{\phi - 1}{\phi}\, \delta^{-\frac{1}{\phi}} \left(\frac{K_{t+1}}{K_t} - 1 + \delta\, \frac{\phi}{\phi - 1} \right) \right]^{\frac{\phi}{\phi - 1}}, \tag{3.37}$$

where

$$K_t = \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty k\, \tilde{\mu}_t(k, \tilde{b}^S, \tilde{b}^L, z)\, dk\, d\tilde{b}^S\, d\tilde{b}^S\, dz. \tag{3.38}$$

4 Characterization

In this section, we describe how firms choose investment, leverage, and debt maturity. We highlight how firms' investment response to monetary policy shocks depends on debt maturity through firm-specific exposure to *roll-over risk* and *debt overhang*.

4.1 Production firms: First order conditions

The firm problem (3.16) can be expressed in terms of only three choice variables: the scale of production k' and the amounts of short-term debt $\tilde{b}^{S'}$ and long-term debt $\tilde{b}^{L'}$. Accordingly, the equilibrium behavior of firms is characterized by three first order conditions. For simplicity, we discuss these optimality conditions assuming that there is no exogenous exit ($\kappa = 0$). The general case of $\kappa \in [0, 1]$ together with all derivations can be found in Appendix C.

Capital. Choosing capital involves trading off resources today against resources tomorrow. In addition, a firm's capital choice also affects default risk and therefore bond prices. The firm's first order condition with respect to capital k' is:

$$\left[1+\frac{\partial G(e)}{\partial e}\right]\left[-Q+\tilde{b}^{S'}\frac{\partial p^S}{\partial k'}+\left(\tilde{b}^{L'}-\frac{b}{\pi}\right)\frac{\partial p^L}{\partial k'}\right]+\mathbb{E}\,\Lambda\int_{\bar{\varepsilon}'}^{\infty}\frac{\partial q'}{\partial k'}\left[1+\frac{\partial G(e')}{\partial e'}\right]\varphi(\varepsilon)d\varepsilon=0 \tag{4.1}$$

The cost of one unit of capital is equal to the price of capital goods Q. For a given quantity of short-term and long-term debt, an increase of capital is a net injection of equity into the firm. The associated cost is therefore $[1+\partial G(e)/\partial e]\,Q$. Because equity tends to reduce default risk and to increase creditors' recovery value in case of default, a marginal increase of k' can raise today's bond prices ($\partial p^S/\partial k'>0$ and $\partial p^L/\partial k'>0$) and thereby increase the firm's bond market revenue. The second benefit is the direct gain from higher expected future firm assets: $\partial q'/\partial k$. Because of diminishing returns in production, this benefit is decreasing in the level of capital.

An existing stock of debt b/π can decrease investment. If $\partial p^L/\partial k'>0$, the firm's marginal benefit of k' is falling in b/π. This is because a higher market price of long-term debt p^L benefits shareholders only to the extent that it increases the firm's revenue from selling new long-term debt. The fact that lower default risk also increases the market value of existing debt is not internalized by the firm. This is the classic *debt overhang* effect described by Myers (1977). If a firm's default risk is high, debt overhang has a larger impact on its behavior because the sensitivity of the firm's bond price to its actions is larger (i.e. the derivative $\partial p^L/\partial\tilde{b}^k$ is larger at higher levels of default risk).

Short-term debt. The firm's capital structure choice between equity and debt is determined by the trade-off between the tax benefit of debt, expected default costs, and debt issuance costs. The firm's first order condition with respect to short-term debt $\tilde{b}^{S'}$ is

$$\begin{aligned}\left[1+\frac{\partial G(e)}{\partial e}\right]\left[p^S+\tilde{b}^{S'}\frac{\partial p^S}{\partial\tilde{b}^{S'}}+\left(\tilde{b}^{L'}-\frac{b}{\pi}\right)\frac{\partial p^L}{\partial\tilde{b}^{S'}}\right]-\frac{\partial H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)}{\partial\tilde{b}^{S'}}\\+\mathbb{E}\,\Lambda\int_{\bar{\varepsilon}'}^{\infty}\frac{\partial q'}{\partial\tilde{b}^{S'}}\left[1+\frac{\partial G(e')}{\partial e'}\right]\varphi(\varepsilon)d\varepsilon=0\end{aligned} \tag{4.2}$$

Selling short-term debt transfers resources from the future to the present. In exchange for a promised future payment $(1+c)/\pi'$ which lowers future firm assets ($\partial q'/\partial\tilde{b}^{S'}<0$), the firm obtains p^S already today. Because coupon payments are tax deductible, it costs shareholders only $(1-\tau)c$ to increase the promised payment to creditors by c. One important downside of debt is that it raises default risk and thereby reduces the firm's bond market revenue ($\partial p^S/\partial\tilde{b}^{S'}<0$ and $\partial p^L/\partial\tilde{b}^{S'}<0$). In addition, the firm incurs the debt issuance cost $H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)$.

Debt overhang also affects the firm's choice of debt. Because $\partial p^L/\partial\tilde{b}^{S'}<0$, the firm's choice of $\tilde{b}^{S'}$ is increasing in the the stock of existing debt b/π. As explained above, the firm does not internalize potential default costs which pertain to the holders of existing long-term debt. While the firm fully internalizes the tax benefits of additional debt, it only internalizes part of the associated costs through today's bond market revenue. As discussed above, debt overhang has a stronger effect on firm behavior if default risk is high (i.e. the derivative $\partial p^L / \partial \tilde{b}^{S'}$ is more negative at higher levels of default risk).[12]

Long-term debt. As for the case of short-term debt, issuing long-term debt saves future taxes but is costly because of default risk and debt issuance costs. The firm's first order condition with respect to $\tilde{b}^{L'}$ is:

$$\left[1 + \frac{\partial G(e)}{\partial e}\right] \left[p^L + \tilde{b}^{S'} \frac{\partial p^S}{\partial \tilde{b}^{L'}} + \left(\tilde{b}^{L'} - \frac{b}{\pi}\right) \frac{\partial p^L}{\partial \tilde{b}^{L'}}\right] - \frac{\partial H(\tilde{b}^{S'}, \tilde{b}^{L'}, b/\pi)}{\partial \tilde{b}^{L'}}$$
$$+ \mathbb{E}\,\Lambda \int_{\bar{\varepsilon}'}^{\infty} \left[\frac{\partial q'}{\partial \tilde{b}^{L'}} \left[1 + \frac{\partial G(e')}{\partial e'}\right] + \frac{\partial b'}{\partial \tilde{b}^{L'}} \frac{\partial V(q', b', z'', S')}{\partial b'}\right] \varphi(\varepsilon) d\varepsilon \;=\; 0 \qquad (4.3)$$

There are two important differences between (4.3) and the first order condition with respect to short-term debt $\tilde{b}^S$ in (4.2). First of all, increasing long-term debt $\tilde{b}^{L'}$ today raises tomorrow's stock of outstanding debt ($\partial b' / \partial \tilde{b}^{L'} = 1 - \gamma$) and thereby reduces tomorrow's roll-over costs $H(\tilde{b}^{S''}, \tilde{b}^{L''}, b'/\pi')$ which increases future shareholder value $V(q', b', z'', S')$. This is a benefit of borrowing at long maturities.

The second important difference between an increase in $\tilde{b}^{S'}$ and in $\tilde{b}^{L'}$ is the impact on the firm's price of long-term debt p^L. Whereas a higher level of short-term debt $\tilde{b}^{S'}$ affects p^L only through tomorrow's value of firm assets q', a higher amount of long-term debt $\tilde{b}^{L'}$ also affects p^L through tomorrow's stock of outstanding debt b'. As discussed above, a higher stock of outstanding debt b' generates *debt overhang* which can reduce future investment and increase future borrowing. Taken together, this increases future leverage and default risk and reduces the firm's price of long-term debt p^L already today. As the impact of debt overhang on future leverage is larger for firms with higher default risk, this downside of borrowing at long maturities is particularly large for firms with high default risk.

4.2 Debt maturity and the investment effect of monetary policy

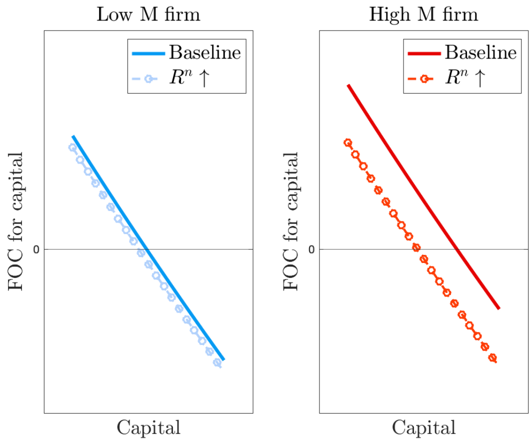
The empirical results of Section 2 show that firms with a larger share of maturing debt respond more strongly to monetary policy shocks. In this section, we identify two channels through which debt maturity generates heterogeneity in firms' investment response: *roll-over risk* and *debt overhang*.

Consider a contractionary monetary policy shock, i.e. a surprise increase in the nominal riskless rate r_t^{nom}. This reduces aggregate demand. The representative household consumes less today relative to expected future consumption: The stochastic discount factor $\Lambda = \beta\, C/C'$ falls on expectation and the real interest rate $1/\,\mathbb{E}\,\Lambda - 1$ rises. Financing any given stock of firm capital through equity or debt has become more costly now. Ceteris paribus, this reduces the benefit of investment for all firms in the economy.

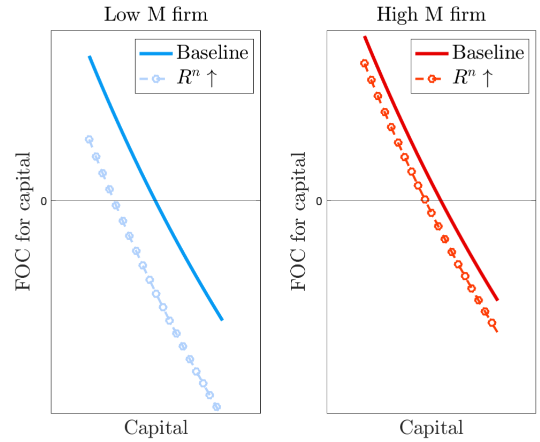
Debt maturity generates heterogeneity in firms' investment response through the state variable b. Comparing two otherwise identical firms, the firm which choose a higher share

[12] In the sovereign debt literature (e.g. Hatchondo et al., 2016), this incentive to increase indebtedness at the expense of existing creditors is also known as *debt dilution*.

Figure 7: Debt maturity and the investment effect of monetary policy



(a) Roll-over risk



(b) Debt overhang

Note: Panel (a) evaluates the first-order condition for capital for different values of k' and two different interest rates r_t^{nom}. All other firm-level choices are held constant. Panel (b) shows the effect of an increase in default risk for firms with different maturing debt shares on the first-order condition for capital.

of long-term debt $\tilde{b}^L$ yesterday has a higher amount of outstanding long-term debt today $b = (1-\gamma)\tilde{b}^L$ implying a lower share of maturing debt. The amount of outstanding long-term debt b enters the firm problem (3.16) through the cash flow from shareholders to the firm, $e + G(e) + H(\tilde{b}^{S'}, \tilde{b}^{L'}, b/\pi)$, where equity issuance e is tied to b through (3.6):

$$e = Qk' - q - \tilde{b}^{S'} p^S - \left(\tilde{b}^{L'} - \frac{b}{\pi}\right) p^L \tag{4.4}$$

The role of b in generating heterogeneity in firms' investment response can be decomposed into two channels.

1. **Roll-over risk:** A rise of the real interest rate and a fall of the stochastic discount factor Λ reduce the firm's bond prices p^S and p^L. If credit spreads increase together with the riskless interest rate, this implies a further decline in p^S and p^L. This lowers the firm's bond market revenue and increases the amount of equity e which shareholders need to inject into the firm for given choices k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$.

   If two firms choose identical constant amounts of total debt but differ in their choice of debt maturity, the firm which chooses a higher share of long-term debt has a lower share of maturing debt and lower values of debt issuance per period $\tilde{b}^{S'}$ and $\tilde{b}^{L'} - b/\pi$. From (4.4), it is clear that this dampens the impact of a fall in bond price p^S and p^L on e because the pass-through of interest rate changes to bond market revenue is smaller. While the shock to the real rate changes the *marginal* cost of new financing for all firms, the *average* interest rate on existing and new debt changes by less for firms with a lower share of maturing debt. To the extent that equity issuance e matters for the firm's choice of k' (e.g. because of increasing equity issuance costs $G(e)$), this dampens the impact on firm capital k'. Short-term debt exposes firms to interest rate fluctuations. Long-term debt provides insurance against *roll-over risk*.

Besides increasing the real interest rate, a contractionary monetary shock also reduces inflation π. This surprise drop in π increases the real value of outstanding nominal long-term debt b/π. Through this mechanism, *Fisherian debt deflation* further reduces debt issuance for high-b firms and thereby amplifies firms' heterogeneous exposure to *roll-over risk*.[13]

2. **Debt overhang:** After an increase of the real interest rate and a fall of the stochastic discount factor Λ, the marginal benefit of capital in firms' first order condition (4.1) falls while the amount of outstanding debt b/π remains unchanged (or even rises if π falls). Relative to the firm's reduced scale of production k', the real burden of a given stock of existing debt b/π rises and thereby strengthens the impact of *debt overhang* on investment k' and debt $\tilde{b}^{S'}$ and $\tilde{b}^{S'}$. As a consequence, firms with a larger stock of existing debt b/π and a lower share of maturing debt accept a stronger increase in leverage and default risk and a larger fall of capital k' in response to a contractionary monetary policy shock.[14]

   As discussed above, the impact of *debt overhang* is stronger if the bond price p^L is more sensitive to firm behavior. This is the case for firms with high default risk as for them a small increase in leverage can have a large effect on default risk. It is therefore a low share of maturing debt and a high pre-shock level of default risk which exposes firms to larger investment responses.

   If inflation π falls after the contractionary monetary policy shock, *Fisherian debt deflation* further amplifies firms' heterogenous exposure to *debt overhang* by increasing the real debt burden b/π of outstanding nominal debt.

5 Quantitative Analysis

The Markov perfect equilibrium of this model can only be computed using numerical methods. In this section, we lay out our computational approach, discuss the calibration strategy, and present quantitative results.

5.1 Solution method

There are three key challenges to the solution of the model. The first is the high dimensionality of the state space. The state vector $\{k, b^S, b^L, z, S\}$ includes not only three endogenous variables, but also the time-varying firm distribution $\mu(\cdot)$, which is part of the aggregate state S of the economy. To reduce the dimensionality of the problem, in the computational

[13] In a HANK model with household heterogeneity, Auclert (2019) identifies how surprise changes in the real interest rate and inflation affect household net worth. Using his terminology in our heterogeneous firm model, firms with high b have small negative "unhedged interest rate exposure" and a large negative "net nominal position".

[14] The amplification of aggregate shocks through debt overhang is studied in more detail in Gomes et al. (2016) and Jungherr and Schott (2022).

solution we define the state vector at the end of a period, at the moment the investment decision is made. The state vector thereby reduces to $\{b, q, z, S\}$, where b defines outstanding long-term bonds, q denotes assets in place (defined in (3.8)), z is idiosyncratic productivity, and S is the aggregate state of the economy. In this way, the dimensionality of the problem is significantly reduced and we can use global methods to solve a fully non-linear solution of the steady state of the model. This solution is found using value function iteration and interpolation as in Jungherr and Schott (2021). From the global solution to the dynamic firm problem in (3.16) without aggregate fluctuations, we define firms' equilibrium policies $\phi(q, b, z, S) = \{k, \tilde{e}, \tilde{b}^S, \tilde{b}^L\}$, which, together with the stochastic process characterizing idiosyncratic uncertainty generate the stationary firm distribution $\mu(q, b, z)$.

A second difficulty consists in finding the equilibrium price of risky long-term debt, p^L. Optimal firm behavior depends on p^L, which itself depends on current and future firm behavior. A firm that cannot commit to future actions must take into account how today's choices will affect its future behavior. We solve this fixed point problem by computing the solution to a finite-horizon problem. Starting from a final date, we iterate backward until all firm-level quantities and bond prices have converged. We then use the first-period equilibrium firm policy as the equilibrium policy of the infinite-horizon problem. This means that we iterate simultaneously on the value and the long-term bond price (as in Hatchondo and Martinez, 2009). The presence of the idiosyncratic i.i.d. capital quality shock ε with continuous probability distribution $\varphi(\varepsilon)$ facilitates the computation of p^L (*cf.* Chatterjee and Eyigungor, 2012).

Finally, we study the dynamics following aggregate monetary policy shocks η_t^m using local dynamics around the model's steady state as in Reiter (2009). We apply a numerical first-order perturbation method along the lines of Schmitt-Grohé and Uribe (2004).

5.2 Calibration

A number of parameters can be set externally using standard values from the literature on firm dynamics and the New Keynesian business cycle literature. Other parameters which are key for firm financing and investment are internally calibrated as explained below.

Externally calibrated parameters The model period is one quarter. We set $\beta = 0.99$ which implies a quarterly steady state nominal riskless interest rate $r^{nom} = 1.01\%$. Because inflation is zero, i.e. $\pi = 1$, the steady state real interest rate is equal to the nominal rate in the absence of aggregate shocks. The debt coupon is fixed at $c = r^{nom}$ which implies that the steady state equilibrium price of a riskless short-term and long-term bond are both equal to one. The preference parameter θ is chosen to generate a Frisch elasticity of 2 as in Arellano et al. (2019).

The production technology parameters ζ and ψ are taken from Bloom et al. (2018). The quarterly depreciation rate δ is 2.5%. We follow Gomes et al. (2016) in setting the tax rate $\tau = 0.4$ and the repayment rate of long-term debt $\gamma = 0.05$.[15] The choice of γ implies a Macaulay duration of $(1 + r^{nom})/(\gamma + r^{nom}) = 16.8$ quarters or 4.2 years. This

[15] The parameter τ should be thought of as capturing additional benefits of using debt over equity (e.g. limiting agency frictions between shareholders and firm managers as in Arellano et al., 2019).

Table 3: Externally calibrated parameters

Parameter	Description	Value
β	preference parameter	0.99
c	debt coupon	$1/\beta - 1$
θ	inverse Frisch elasticity	0.5
ζ	production technology	0.75
ψ	production technology	0.33
δ	depreciation rate	0.025
γ	repayment rate long-term debt	0.05
τ	corporate income tax	0.4
ρ	demand elasticity retail goods	10
λ	price adjustment cost parameter	90
ϕ	capital goods technology	4
φ_m	Taylor rule	1.25
ρ_m	Taylor rule	0.5

is a conservative choice relative to the average duration of 6.5 years calculated by Gilchrist and Zakrajšek (2012) for a sample of US corporate bonds with remaining term to maturity above one year.

Following Kaplan et al. (2018), we set the elasticity of substitution for retail good varieties $\rho = 10$ implying a steady state markup of 11 percent. The price adjustment cost parameter λ, the parameter of the capital goods technology ϕ, and the Taylor rule parameters φ_m and ρ_m are taken from Ottonello and Winberry (2020). The externally set parameters are summarized in Table 3.

Internally calibrated parameters The remaining eight parameters are σ_ε, ξ, η, ν, ρ_z, σ_z, κ, and f. Their values are chosen to match key empirical moments that are informative about the financing and investment behavior of firms. These parameters are calibrated using the steady state of the model. The internal calibration is summarized in Table 4. While the model is highly non-linear and all parameters are jointly identified, we provide some intuition for their identification. The probability distribution of the firm-specific capital quality shock ε is taken to be Normal with zero mean and standard deviation σ_ε. Average leverage depends on the standard deviation of the capital quality shock σ_ε because a higher earnings volatility induces firms to reduce leverage in order to contain the risk of default. The average credit spread is directly affected by the default cost ξ. The debt issuance cost parameter η is pinned down by the average share of debt with remaining maturity of less than one year because higher debt issuance costs make short-term debt less attractive and thereby reduce the equilibrium share of maturing debt. The equity issuance cost parameter ν targets the average size of annual equity issuance relative to firm assets.[16] The probability of exogenous

[16] Our empirical target is a four-quarter moving average of equity issuance over firm assets. This reduces the skewness of the equity issuance distribution, which is skewed towards rare, but large positive spikes in the data. Model moments are time-aggregates for comparability.

Table 4: Internally calibrated parameters

Parameter	Value	Target	Data	Model
σ_ε	0.66	Average firm leverage	34.4%	29.3%
ξ	0.90	Average credit spread on long-term debt	3.1%	3.3%
η	0.0045	Average share of maturing debt	35.5%	33.6%
ν	0.0005	Average equity issuance / assets	11.4%	14.6%
ρ_z	0.983	Median of average capital growth	1.0%	1.2%
σ_z	0.184	Median of s.d. of capital growth	8.3%	9.7%
κ	0.0151	Total exit rate	2.2%	2.3%
f	0.274	Steady state value of entry	-	0

Note: The data sample is 1995-2017. Firm-level data on leverage, the share of maturing debt, equity issuance, and capital growth is from Compustat. Firm-level credit spreads are computed using data from Compustat and FISD. The average equity issuance to asset ratio is computed annually in the data and in the model. Capital growth moments are quarterly. The quarterly exit rate is from Ottonello and Winberry (2020).

exit κ affects the total exit rate (in the model exit can occur exogenously, or endogenously through default). The parameters ρ_z and σ_z govern the evolution of idiosyncratic productivity shocks. Firm-level productivity z follows a productivity ladder with discrete support $\{Z_1, ..., Z_j, ..., Z_J\}$. Entrants start at the lowest productivity level $z^e = Z_1$. Incumbent firms with last period's productivity level $z = Z_j$ increase their productivity with probability $1 - \rho_z$:

$$z' = \begin{cases} Z_j & \text{with probability } \rho_z \\ Z_{\min\{j+1,J\}} & \text{with probability } 1-\rho_z \end{cases} \tag{5.1}$$

Once a firm has reached the highest productivity level Z_J, it remains there until it defaults or exits the economy exogenously. The support of the natural logarithm of z is $\pm\sigma_z$. This productivity process has two desirable features. It captures the positive skewness of empirical firm growth and it facilitates the computation of the Markov perfect equilibrium.[17,18] The two parameters ρ_z and σ_z are important for matching the mean and the standard deviation of firm-level capital growth rates. Finally, the fixed cost of operation f is chosen such that the steady state value of entry $V(0, 0, z^e, S)$ is equal to zero.

From Table 4 the model matches the data very well. In the steady state, the average firm leverage ratio (debt over assets) is about 30% and around one third of firm debt has remaining maturity of less than a year. The average annual credit spread on long-term debt is

[17]Large negative firm growth is rare in the data. The model generates a realistic distribution of firm growth - including negative growth - through changes in the endogenous state variables b and q.

[18]Negative productivity shocks decrease firm value, while the existing stock of debt b remains unchanged. If a negative change in z is sufficiently large, the incentive to pay out firm assets to shareholders at the expense of existing creditors causes the constraint $e \geq \underline{e}$ in (3.16) to bind for any value of $\underline{e}$. The productivity process described above does not feature large negative jumps in $V(q, b, z, S)$ and thereby avoids this problem. The constraint $e \geq \underline{e}$ is never binding in equilibrium. An alternative would be to use a standard AR(1) firm productivity process. Because in this case the dividend payout constraint would bind for many firms, the particular form of this constraint would affect model results.

close to 3 percent. While not targeted, our calibration results in an average quarterly default rate of 0.8%, the same value as in Bernanke et al. (1999).[19] Equity issuance costs for firms with positive equity issuance constitute on average 0.17% of firm output. The corresponding number for debt issuance is 0.03%. The stochastic process of firm-level productivity generates positive skewness of capital growth: The median skewness of within-firm capital growth is 0.21 in the model which still lies below the corresponding value in the data (0.74).

5.3 Steady state results

Before proceeding to study the response of the economy to aggregate monetary policy shocks, we present a series of untargeted moments from the global solution of the economy's steady state. We show that the model succeeds in generating realistic distributions of leverage, credit spreads, and debt maturity across firms, both unconditionally, and conditionally on firm size and age.

Table 5 compares the unconditional distributions of key financial variables in the data and the model. We compute the mean, and the 25th, 50th, and 75th percentiles of leverage, long-term credit spreads, and the maturing debt shares across firms in the stationary distribution and compare them to their empirical counterparts. The means were targeted in the calibration of the model, yet Table 5 shows that the model also generates a significant amount of the dispersion across firms. The interquartile ranges of leverage and credit spreads generated by the model are very close to the data. The cross-sectional dispersion in maturing debt shares is smaller than in the data, however here, too, the model generates a significant amount of variation across firms.

We now study the distributions of these key financial variables, conditional on firm size. Size is a key dimension of firm heterogeneity and plays a prominent role in many empirical studies of firm financing behavior. We measure size by total firm assets. To create Figure 8, firms are grouped into size quartiles, over which we then compute medians for all reported variables. The data is shown as the light blue bars. The error bands represent 95% confidence intervals. The red bars show the corresponding values in the model.

There are four, robust empirical results, which the model is able to replicate: First, larger firms have higher leverage ratios than smaller firms. Second, larger firms pay significantly lower credit spreads.[20] Third, larger firms have lower shares of maturing debt. Fourth, larger firms are older.

The model replicates these empirical regularities through heterogeneity in firm profitability. Firms with higher idiosyncratic productivity levels are larger. Due to the presence of a fixed cost, they also more profitable than smaller firms. The higher profitability implies that for a given level of leverage, the risk of default is smaller. This, in turn, means that larger, more profitable firms, can take on more debt (and enjoy the tax advantage of debt), at lower credit spreads. Larger firms also borrow at longer maturities. This is because the lower default risk reduces the distortions induced by debt overhang.[21]

[19] Hovakimian et al. (2011) report a quarterly default rate of 1.0% from Moody's expected default frequency across rated and unrated Compustat firms.

[20] Most small firms in Compustat are unrated and we cannot assign a credit spread to them. This explains the large confidence interval for the bottom quartile in the credit spread distribution of Figure 8.

[21] In the model, the positive size-age relationship is generated by idiosyncratic productivity. The higher

Table 5: Unconditional distributions

	Mean	Percentile		
		25	50	75
Data				
Leverage	34.4	1.0	19.4	40.3
Credit spread on long-term debt	3.1	1.6	3.1	4.3
Share of maturing debt	35.5	1.8	18.1	67.2
Model				
Leverage	29.3	11.3	16.2	45.1
Credit spread on long-term debt	3.3	1.8	4.0	4.6
Share of maturing debt	33.6	23.1	33.1	39.2

Note: Leverage is total firm debt over assets; *Credit spread on long-term debt* is the annualized credit spread on long-term debt; *Share of maturing debt* is the share of firm debt with remaining maturity of less than one year. All values are in %. Data moments are from Compustat and FISD (time period 1995-2017). Model moments are computed from the stationary distribution of the model.

We also show these distributions conditional on firm age, a second key dimension of firm heterogeneity.[22] The blue bars in Figure 9 show that empirically, older firms have higher leverage ratios, lower maturing debt shares, and pay lower credit spreads, while firm size is increasing in age. These patterns are in line with the predictions of the model. Conditional on survival, older firms are more productive and increase their scale of production. Higher profitability allows them to borrow more debt at lower credit spreads and at longer maturities.[23]

Taken together, Table 5, and Figures 8 and 9 show that the model is successful in replicating salient features of both the unconditional and conditional distributions of financial variables. This implies that the model provides an appropriate framework to study the aggregate and heterogeneous responses to monetary policy shocks, which we turn to next.

5.4 Aggregate response to monetary policy

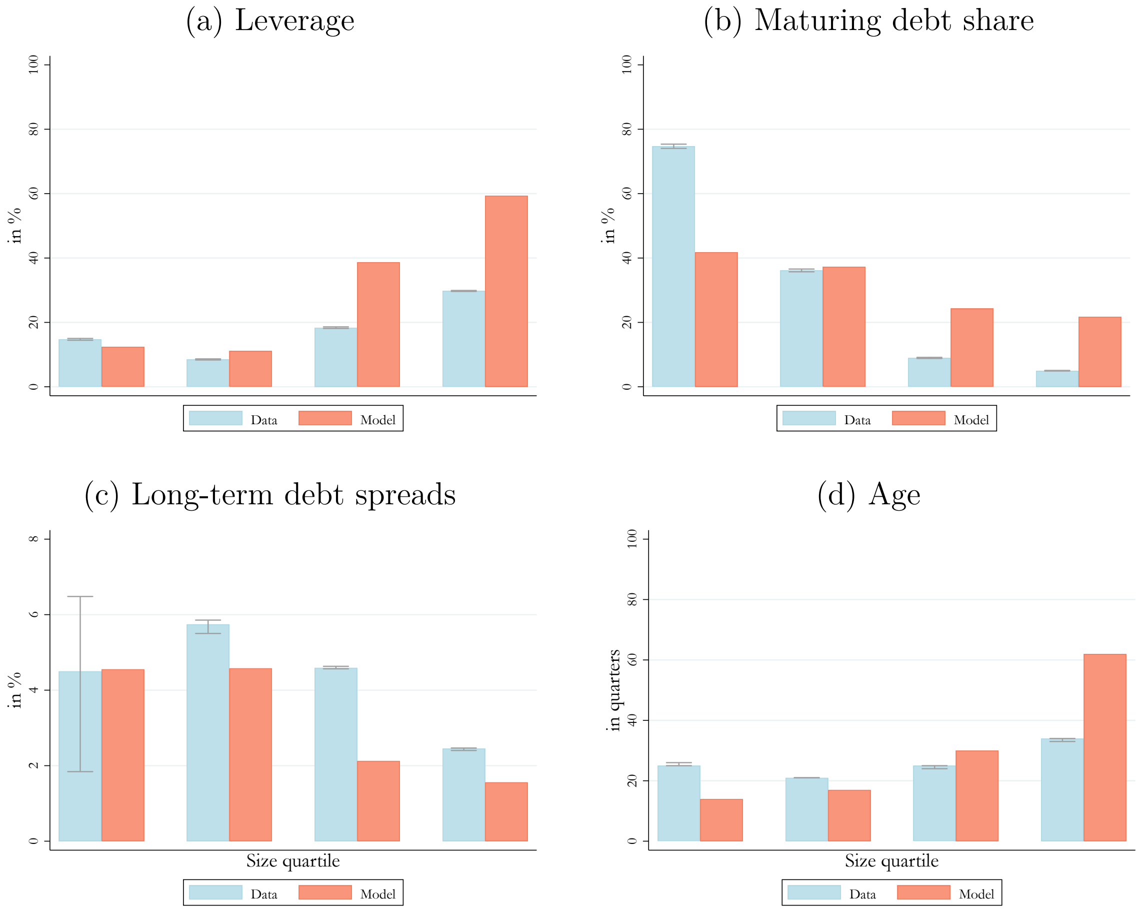
Figure 10 shows impulse response functions of key aggregate variables following a contractionary monetary policy shock. The shock increases the nominal interest rate by 30bp.

implied profitability decreases default rates. Therefore, conditional on survival, productivity increases with age.

[22]In the data, we measure firm age as time passed since a firm's initial public offering (IPO). Our data set does not contain a firm's actual creation date but it includes the IPO date for many publicly listed firms. This variable allows us to track firm characteristics over time since the initial listing on the stock market.

[23]See also Jungherr and Schott (2021) for related results on the cross-sectional relationship between leverage, debt maturity, and credit spreads in a model without equity issuance costs and without aggregate uncertainty.

Figure 8: Firm variables conditional on size

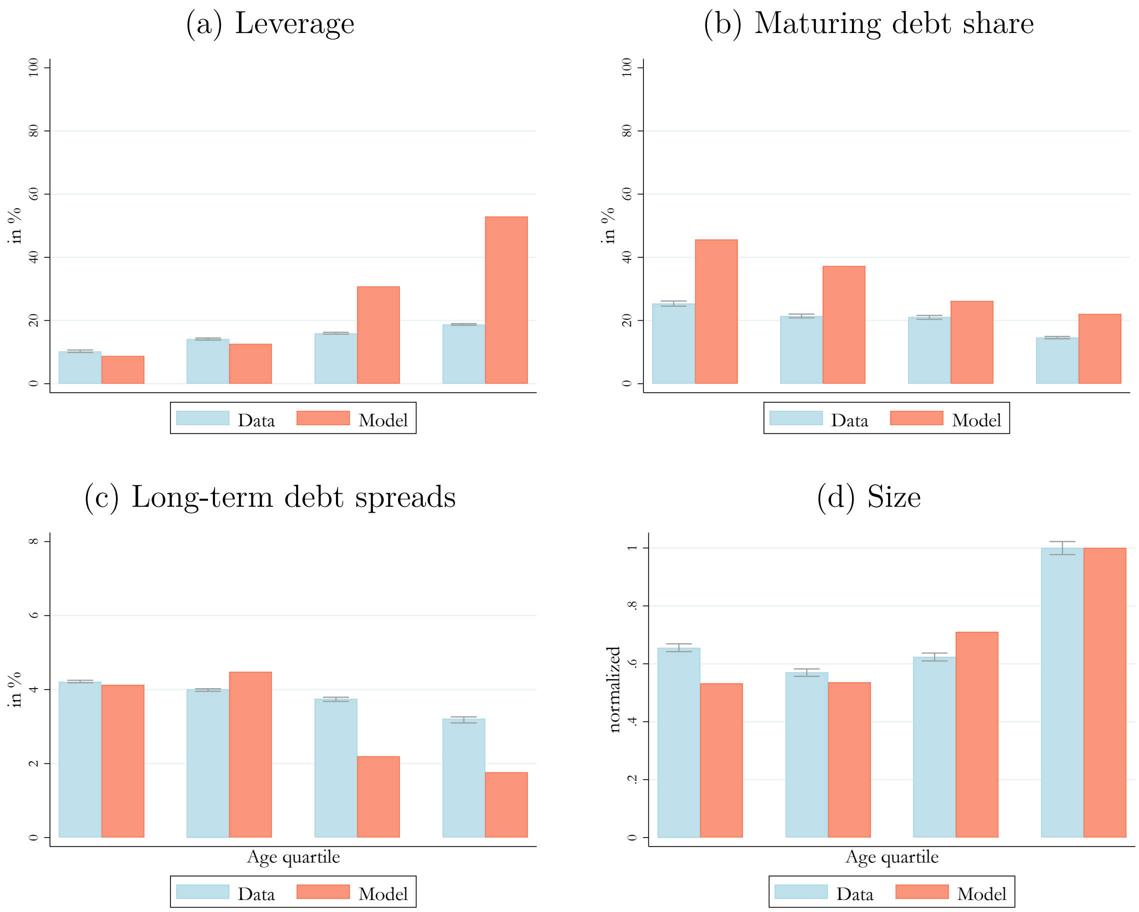


Note: For each variable, median values are shown by size quartile. *Size* is defined as total assets. Data moments are shown together with 95% confidence intervals. *Leverage* is total firm debt over assets; *Share of maturing debt* is the share of firm debt with remaining maturity of less than one year; *Credit spread on long-term debt* is the annualized credit spread on long-term debt; *age* in the data is quarters since IPO date. Data moments are from Compustat and FISD (time period 1995-2017). Model moments are computed from the stationary distribution of the model.

Because prices are sticky, the real interest rate increases as well. This leads to a decline in aggregate investment and a fall in consumption demand. The lower demand for goods lowers inflation. The production good price p, the price of capital Q, and the real wage w all fall following the shock.

Key financial variables are plotted in the second row of Figure 10. Following the shock, leverage increases, resulting in higher default rates, and higher credit spreads. After the contractionary monetary policy shock, two things occur which explain these patterns. First, firms' optimal scale decreases and investment falls as a consequence. Second, the decrease in the inflation rate grows the real burden of existing debt. Together, these effects worsen the debt overhang problem, as explained in Section 4.2. More debt overhang sets into motion an adverse feedback loop. Firms respond with higher default rates, reinforced by a decrease in profitability due to lower equilibrium prices p and Q. This effect is immediate and occurs

Figure 9: Firm variables conditional on age

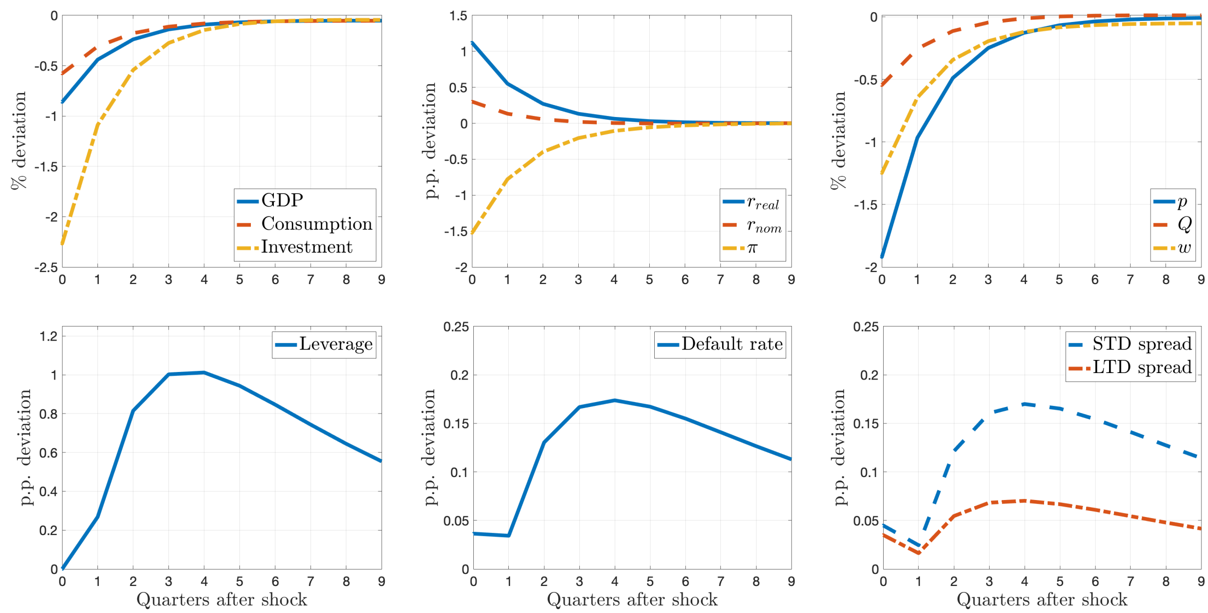


Note: For each variable, median values are shown by age quartile. In the data, *age* is quarters since IPO date. Data moments are shown together with 95% confidence intervals. *Leverage* is total firm debt over assets; *Share of maturing debt* is the share of firm debt with remaining maturity of less than one year; *Credit spread on long-term debt* is the annualized credit spread on long-term debt; *Size* is total firm assets and is normalized to one for the highest age quartile. Data moments are from Compustat and FISD (time period 1995-2017). Model moments are computed from the stationary distribution of the model.

in the same period as the monetary policy shock. The higher default risk in turn drives up credit spreads. Higher spreads increase the cost of capital, further decreasing aggregate investment, and aggravating the debt overhang problem yet again. In addition, because inflation only reverts back to its long-run mean slowly, Fisherian debt deflation continues to increase firms' outstanding real stock of debt. This channel also contributes to the debt overhang problem, which leads to higher default rates, leverage, and spreads.

It is noteworthy that the short-term debt spread increases by more than the long-term debt spread. This is because the price of short-term debt p_t^S only depends on default risk at time $t+1$ whereas the price of long-term debt p_t^L depends on default risk in all future periods. Because the increase in default risk is transitory, the long-term spread responds by less than the short-term spread. On the aggregate this leads to a reallocation from short-term debt to long-term debt.

Figure 10: Aggregate response to a contractionary monetary policy shock



Note: In the second panel, π denotes the inflation rate. In the third panel, p, Q, and w respectively denote the production goods price, the price of capital, and the real wage rate. The default rate and credit spreads in the third and fourth panels are annualized. Leverage in the last panel is the annualized average of firm-level total debt divided by total capital.

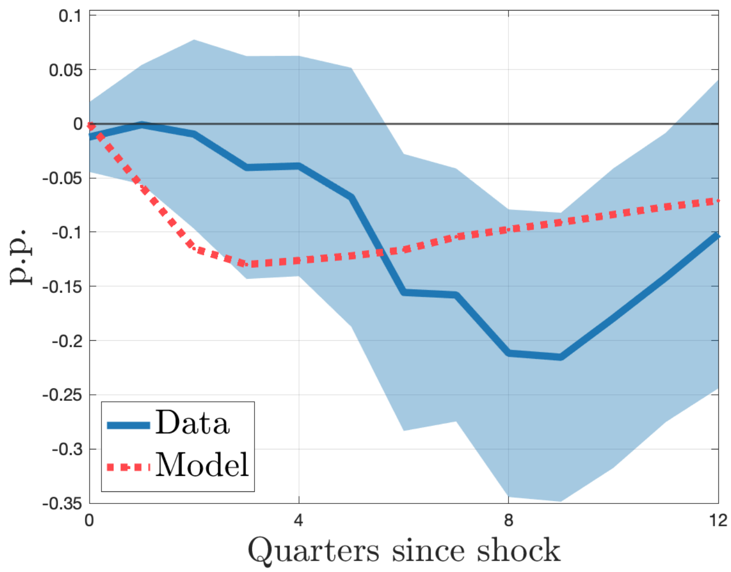
5.5 Heterogeneous responses to monetary policy

We now turn to the heterogenous responses of monetary policy shocks, and in particular to the question how debt maturity affects the investment response to monetary policy. We start by showing the model equivalent of our main empirical result, the differential investment response to monetary policy shocks of firms with a higher maturing debt share. To do so, we generate a large panel of firms in the model and compute the marginal effect of a monetary policy shock for firm investment.[24] In Figure 11, this marginal effect is plotted for the twelve quarters following a monetary policy shock. The red, dashed line corresponds to the coefficients obtained from model-generated data. The blue line shows the values of B^h from the regression model specified in (2.2), together with 95% confidence bands. Both lines show the estimated marginal effects of a monetary policy shock for firm-level capital growth of a one standard deviation higher maturing debt share at different horizons.

The model replicates our key empirical result: Firms with a one standard-deviation higher share of maturing debt reduce investment by more in reaction to a contractionary monetary policy shock. The model also generates the hump-shaped differential investment

[24]More precisely, we first simulate a panel of firms for 50 quarters without a monetary policy shock. Keeping the idiosyncratic shock histories constant, we simulate the panel again, this time *with* the monetary policy shock. The difference between the two simulations allows us to compute the marginal effect of the monetary policy shock. To the extent possible, we apply the same sample selection as we did for the empirical analysis. Results are not very sensitive to this. We choose a large enough number of firms so that sampling error does not affect our results.

Figure 11: Differential investment response to MP shocks for high maturing bond share



Note: The red dashed line shows the model-estimated differential percentage response of capital to a one-standard deviation contractionary monetary policy shock for firms with a one-standard deviation higher share of maturing bonds. The blue solid line shows the same coefficients together with 95% error bands clustered by firms and quarters from the data.

response found in the data. Although the monetary policy shock is largest on impact (*cf.* Figure 10), the largest marginal effect of debt maturity on firms' investment responses occurs three quarters after the shock. Quantitatively, the peak negative investment response in the model amounts to 60.3% of the estimated peak empirical response. With the exception of the coefficient two quarter after the shock, all coefficients estimated from model-generated data lie within the empirical 95% confidence band of the empirical coefficients.

What explains this result? The heterogeneity in investment responses can be understood with the help of Figure 12. Here, we show the effects of a monetary policy shock for two typical firms. The first firm has a very low maturing debt share, the second firm has a maturing debt share that is more than three times higher. In line with Figure 11, the high-M firm reacts to a monetary policy shock with a much larger reduction in capital. This is shown as the red, dashed line in panel (a) of Figure 12. Five quarters after the shock, capital is about 1% lower than it would have been without the monetary policy shock. In contrast, the low-M firm (represented by the blue, solid lines) only shows a mild initial decrease in capital. A few periods after the shock, general equilibrium effects even lead to a positive response of capital.

There are two key channels that explain this differential capital response. The first is rollover-risk. Recall the definition of equity issuance in (4.4), which is reprinted here for convenience:

$$e = Qk - q - \underbrace{\left(\tilde{b}^S p^S \downarrow + \left(\tilde{b}^L - \frac{b}{\pi}\right) p^L \downarrow\right)}_{\text{bond market revenue}} \tag{5.2}$$

In response to the monetary policy shock, equilibrium bond prices fall. This leads to a decrease in bond market revenue, which is more sizeable if firms roll over a large fraction of debt. This is the exactly the case for the red, high-M firm. Panel b) in Figure 12 shows that bond market revenue falls by almost three times more for the firm with a large fraction of maturing debt. This implies that, *ceteris paribus*, equity issuance must increase by more, which drives up marginal equity issuance costs, and hence the cost of capital.

The second channel is debt overhang. This channel is strongest when firms have high levels of outstanding debt *and* high default risk. High levels of outstanding debt imply that the real burden of debt relative to capital is larger. Higher default risk implies that bond prices are more sensitive to changes in firm behavior.

The blue, low-M firm is more profitable, and therefore has a lower default rate than the less profitable high-M firm.[25] The monetary policy shock lowers inflation, thereby increases the real burden of debt, and reduces firm profitability through falling output and capital prices. Because of its higher default risk, the shock has a bigger effect on equilibrium bond prices for the high-M firm. Consequently, default rates and leverage increase by more.

Panel c) of Figure 12 shows that on impact, default rates remain virtually unchanged for the low-M firm. Importantly, this implies that although this firm has a higher absolute value of outstanding debt, its low default rate implies that it suffers *less* from the debt overhang problem. By contrast, default rates significantly increase on impact for the red, high-M firm. Credit spreads go up and increase the cost of capital. This is how debt overhang leads to a larger negative capital response following a monetary policy shock.

Panel d) shows the effect of the monetary policy shock on leverage ratios. Debt deflation causes firms to only internalize a fraction of the total stock of debt when making financing and default decisions. As the real burden of outstanding debt grows, this fraction becomes smaller and the debt overhang problem grows. Firms respond by issuing more debt. The high-M firms, given the larger debt overhang problem, increase total debt by more, shown by the larger increase in leverage ratios.

Over time the decrease in the inflation rate increases the real burden of existing debt. In this way, the Fisherian debt deflation channel continues to increase the debt overhang problem for all firms. Because the low-M firm has high absolute debt levels, debt deflation eventually weighs more heavily on this firm's balance sheet and increases the default rate even for low-M firms. Debt deflation can thus explain the hump-shaped response of default rates and leverage.[26]

5.6 Decomposition

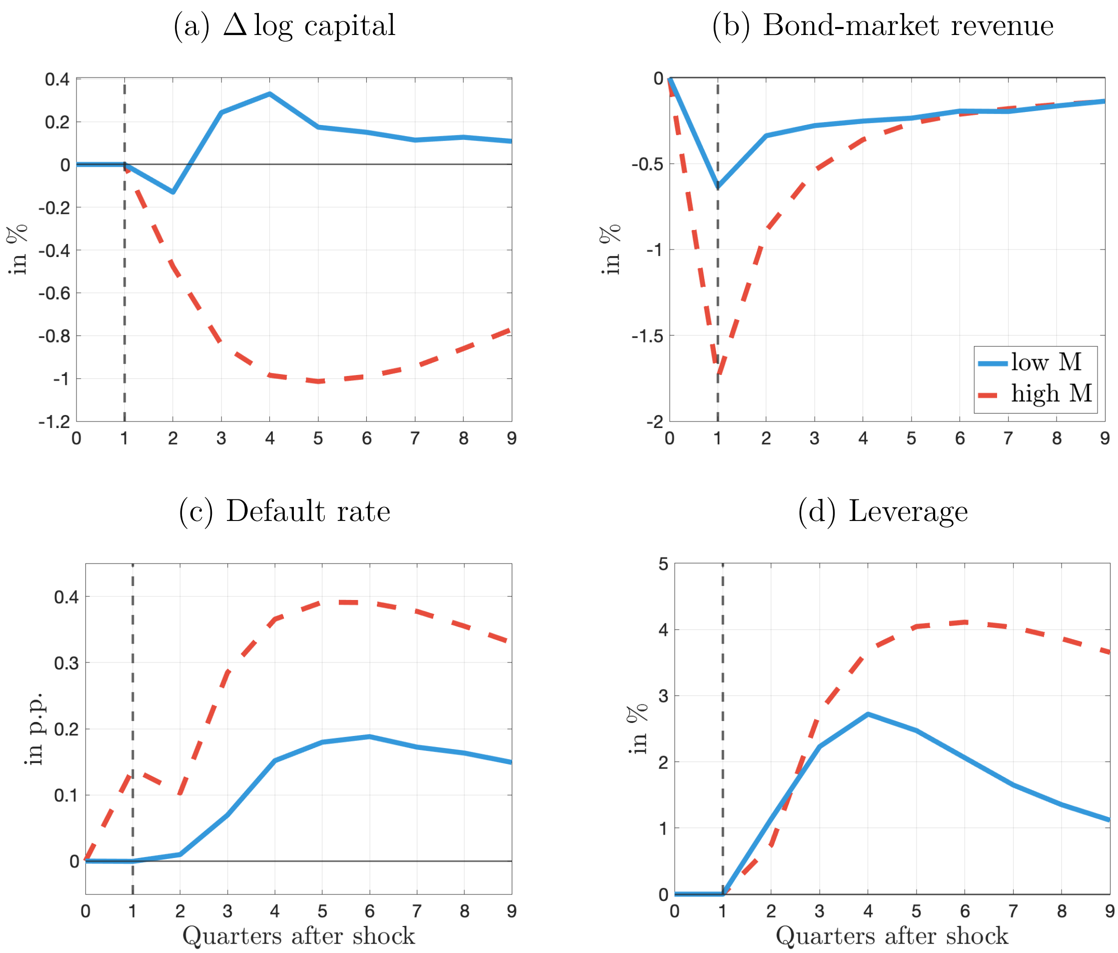
There are three channels that drive our results: Roll-over risk, debt overhang, and debt deflation.

To isolate the marginal contributions of each of the three channels we shut off their cyclical component one at a time. We are interested in what role the channels play in the determination of how a monetary policy shock affects firms' investment responses. In order to make the results comparable, we therefore keep the steady state of the economy unchanged.

[25] *cf.* Figure 8.

[26] The decrease in default rates of high-M firms in the second period after the shock is the result of a sizeable decrease in the amount of short-term debt issued.

Figure 12: Heterogeneous responses to a contractionary monetary policy shock



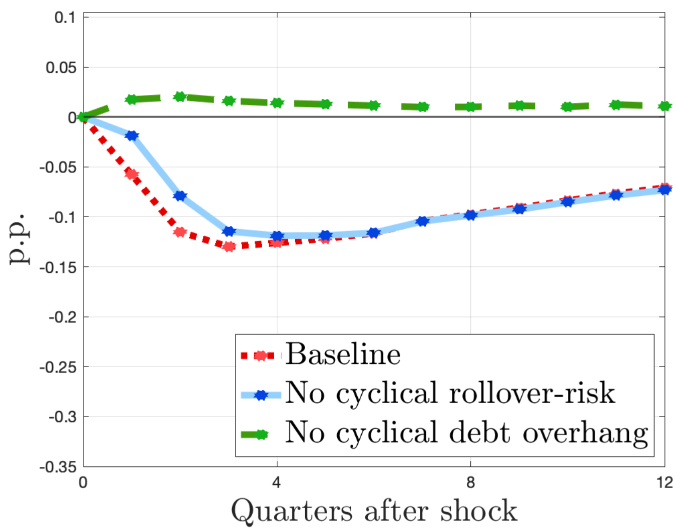
Note: All panels show marginal effects of a 30bp contractionary monetary policy shock for two types of firms. The blue, solid lines are for a typical firm with a low quarterly maturing debt share. The red, dashed lines are for a typical firm with a high maturing debt share. Panel a) shows the change in log capital, panel b) shows the bond market revenue, defined as $\tilde{b}^{S^*} p^S + \left(\tilde{b}^{L^*} - \frac{b^*}{\pi}\right) p^L$. Variables with an asterisk indicate steady-state values. Panel c) shows the effect on annual default rates, panel d) the effect on leverage ratios.

To turn off any cyclical role of rollover-risk, we hold marginal equity issuance costs constant at their steady-state value for any firm-state (b, q, z). This implies that when bond prices decline and equity issuance would *ceteris paribus* increase, this does not result in higher marginal cost of equity issuance. This benefits firms that are rolling over a high amount of debt at the time of the monetary policy shock. With the cyclical rollover-risk channel turned off, firms do not face a cash flow shock in response to monetary policy shocks.

To turn off the cyclical effect of debt overhang we study an economy in which leverage and long-term debt shares are held constant at their steady state values for any firm-state (b, q, z). In this way, the ratio of newly issued debt to outstanding debt does not change and the debt overhang problem has no cyclical element.[27]

[27]See Jungherr and Schott (2021) for a related discussion.

Figure 13: Decomposition of differential investment response to a contractionary monetary policy shock



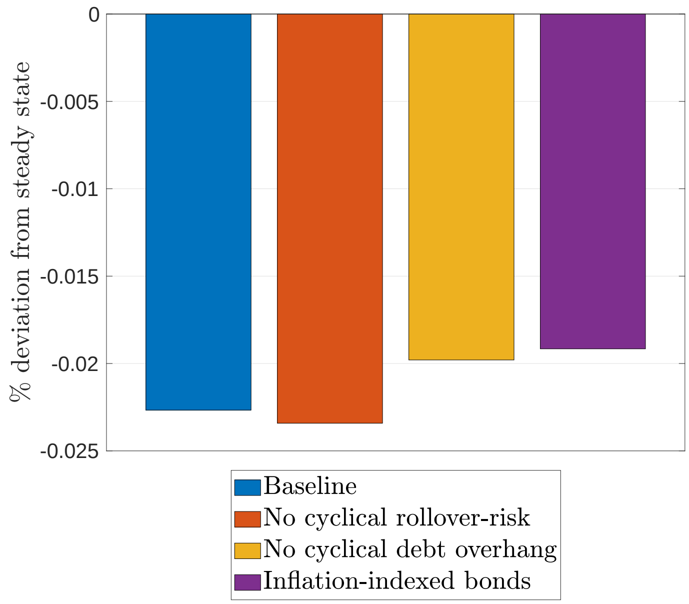
Note: All lines show model-estimated differential percentage response of capital to a one-standard deviation contractionary monetary policy shock for firms with a one-standard deviation higher share of maturing bonds. The red, dotted line repeats the baseline estimate from Figure 11. The blue, solid line shows results when cyclical roll-over risk is turned off. The green, dashed line shows results when cyclical debt overhang is turned off. The size of the monetary shock is chosen such that the nominal interest rate increases by 30bp in all cases.

Figure 13 shows the differential investment responses to monetary policy shocks for our baseline economy, together with the counterfactual scenarios where either cyclical roll-over risk or cyclical debt overhang is shut down. The graph shows that roll-over risk plays an important role in generating a heterogenous investment response to monetary policy shocks. Firms with a higher fraction of maturing debt must roll-over a larger fraction of debt. This exposes them to the increase in interest rates at the time of the shock, thereby increasing the marginal cost of capital and lowering investment. Debt overhang plays an even larger role in generating this heterogeneous response. When cyclical debt overhang is turned off, the link between firm behavior and bond prices is severed. Having an initially high default risk, which in equilibrium coincides with having a higher maturing debt share, no longer implies that the debt overhang problem worsens relative to low-default risk firms. Therefore, the heterogeneous investment response is significantly muted.[28] Note that this does not imply that eliminating debt overhang can completely eliminate a negative investment response to monetary policy shocks. It mutes an important part of the heterogenous response, but on aggregate, investment falls, even if cyclical debt overhang is eliminated.

Figure 14 decomposes the response of aggregate investment. In the baseline, investment falls by 2.27%. When cyclical debt overhang is eliminated, the investment response is dampened by about 12.7%. Neutralizing the cyclical rollover-risk channel increases the size of the

[28] In our counterfactual experiment that holds cyclical debt overhang constant, firms must keep both leverage and the maturing debt share constant. This arguably does more than simply turn off the cyclical debt overhang channel.

Figure 14: Initial aggregate investment response: Decomposition



Note: This figure shows the responses of aggregate investment in response to an exogenous monetary policy shock. The size of the shock is chosen such that the nominal interest rate increases by 30bp in all cases.

investment response by about 3.3%. The reason is that when marginal equity issuance costs are held constant, this *increases* the costs for firms that reduce equity issuance during the downturn. Finally, when all bonds are inflation-indexed, the aggregate investment response is 15.5% lower than in the baseline scenario.

6 Conclusion

This paper shows that debt maturity matters for firm-level and aggregate responses to monetary policy. Combining firm and bond-level data, we find that firms with a higher share of maturing debt have a significantly larger investment response to monetary policy shocks than other firms in the economy. We show that this differential investment response can be explained in a heterogeneous firm New Keynesian model with endogenous debt maturity. The model implies that the effectiveness of monetary policy depends on the maturity distribution of firm debt in the economy.

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Appendix A Data Construction

Bond-level data We obtain detailed bond-level data from Mergent FISD. The initial sample contains 442,431 bonds. We construct a sample of comparable bonds by dropping the following types of bonds: convertible (5,394), convertible on call (810), exchangeable (39,848), not denoted in US$ (6,160), (yankee) bonds issued by foreign entities (70,158), and bonds that mature less than one year after issuance (60,175). This leaves us with 320,437 bonds.[29] Of these bonds, for most of our analysis we exclude bonds that are callable (210,389) or have a variable coupon (71,484). We then create a monthly panel of bonds, which tracks the outstanding amount, computed as number of bonds issued times principal amount, throughout the life of the bond. Mergent FISD records the date, amount, and reason of reductions in the amount outstanding that occur before maturity, e.g., due to a a call, reorganization, or default. We use those records to adjust the outstanding amount in our bond panel. When the bond matures at its scheduled maturity date, we record the remaining amount of the bond at maturity as maturing amount.

Linking the bond panel to the firm panel To match bonds to the creditor firm in every period of the bond's lifetime, we proceed in three steps. First, we construct a mapping from gvkey to the historical firm cusip. The historical firm cusip is the firm cusip identifier valid in a given time period and gvkey is the Compustat firm identifier. We link the two identifiers by combining the Compustat–CRSP link table, which links gvkey and permno, with CRSP data, which links permno and historical cusip. The Compustat–CRSP link contains start and end dates for which the respective links are valid. We only use links which are classified as reliable, coded "C" or "P" flag in the link table. We join this link table with the CRSP data and keep records that fall within link validity. For some cusip we have a link to more than one gvkey (163,441 of 3,702,116 observations), which may arise due to the presence of subsidiary firms in CRSP. We drop ambiguous links if Compustat contains no sales for a gvkey (113,843 observations). For the remaining ambiguous links we keep the gvkey link to the firm with the largest sales.

Second, we cannot simply match the bond panel to the firm panel by using the historical cusip in both panels. In the bond panel, the historical firm cusip, encoded in the bond cusip, is the firm cusip at the time of bond issuance. In contrast, the firm panel records the historical firm cusip as the one valid in a given period, which may change over time. Reasons for changes in the historical cusip are changes in the firm name or the firm trading symbol. To match firm and bond panel, we use the so-called *header* firm cusip associated to the bond's initial *historical* firm cusip. The header cusip is the latest observed cusip in a firm's history. The mapping between header cusips and historical cusips over time is provided in CRSP data. We match the header cusip to both the firm and the bond panel. The link between bond and firm panel along the header cusip is ambiguous in a small number of cases (11,350 of 3,817,626 observations). We delete those bonds for which no link to gvkey is available in the CompustatCRSP table (7,445 observations) and drop the bonds with remaining ambiguous links (3,904 observations). Given the header cusip of the bond issuer, we can attach the historical cusip series throughout the lifetime of the bond using the same mapping. This identifier correctly reflects bond creditorship conditional on the bond not being sold to another firm intermittently.

Third, we account for M&A events. The Thomson–Reuters SDC database records events at which firms, as identified by historical cusip, are merged or acquired by another firm, also identified by historical cusip. This allows us to change a bond's firm identifier to the identifier of the acquiring

[29] In parentheses, we provide the number of bonds of each type. The bond types partially overlap, e.g., some yankee bonds are exchangeable.

firm. We prepare the SDC data as follows. While we take the reported effective date of M&A as the baseline change of bond ownership, we use the announcement date if the effective date is missing. We do not consider M&A events for which no date is reported, the M&A status is not reported as completed, the target firm is classified as a subsidiary, or if the acquiring firm does not buy the target firm fully. If an M&A event is associated to multiple buyers, we drop buyers that do not have associated gvkey's as per the Compustat-CRSP link table and drop remaining events of this sort entirely. With this data at hand, we merge M&A events to the bond panel. For bond-months at which the creditor was subject to an M&A event, we replace the historical firm cusip associated to the bond by the acquiring firm's cusip from the M&A date going forward. Because the acquiring firm may have changed its cusip after the M&A event, we need to repeat the steps outlined above to find the actual evolution of historical cusip for the new creditor firm. Having done so, we search for additional M&A events that may have happened after the first M&A event, now with the first acquiring firm being the target firm. We repeat this procedure until we find no M&A events that would imply a change in the cusip identifier.

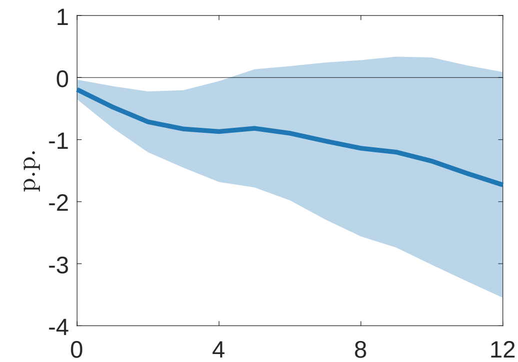
(Merged) firm-level data We use quarterly Compustat data on balance sheets of publicly listed US firms for the period 1995Q1 to 2017Q2. We drop firms in finance, insurance, and real estate (SIC codes 6000-699), public administration (9100-9729), and utilities (4900-4999). We drop firm-quarters with non-positive net plants, property, and equipment (PPE). We drop net PPE for a small number of spikes. These are quarter, in which the real absolute growth rate of PPE exceeds 50% and is followed by a reversal in the opposite direction of more than 50% in the following quarter. We fill one-quarter gaps in net PPE with linear interpolation.

We next match bonds to creditor firms' balance sheets by using the link between gvkey and the correct historical cusip for every quarter in which a bond is outstanding (as described above). We compute the sum of issued bonds, outstanding bonds, maturing bonds, the average volume-weighted maturity of outstanding bonds for each firm-quarter. We compute the maturing bond share as in equation (2.1) and trim it above 100%. Out of a total of 462,173 firm-quarter observations, we observe outstanding bonds for 56,257 , i.e., 12.1%. Firms with bonds are on average much larger than firms without bonds, and they account for 67.0% of total net PPE and 69.1% of total sales. Eventually, we focus on firms with at least 10 years of observations as in Ottonello and Winberry (2020). Excluding firms with less than 10 years of observations, we observe outstanding bonds for 47,971 out of the remaining 298,008 firm-quarter observations, i.e., 16.1%. In the restricted sample, firms with bonds account for 71.6% of total net PPE and 73.8% of total sales.

We construct capital stock series from PPE using a perpetual inventory method. Within firms, we identify spells for which net PPE is observed without gaps. For every spell, we initialize the capital stock with (deflated) gross PPE. For all following quarters within the spell, we define the capital stock as the previous value plus the change in nominal net PPE, deflated by the CPI. If not stated otherwise, all nominal variables are deflated to 2012 US$ by the CPI. Moreover, we use log total assets as a measure of firm size and the log difference in sales to measure sales growth. We also compute the distance to default as in Ottonello and Winberry (2020).

Appendix B Additional empirical results

Figure 15: Average response

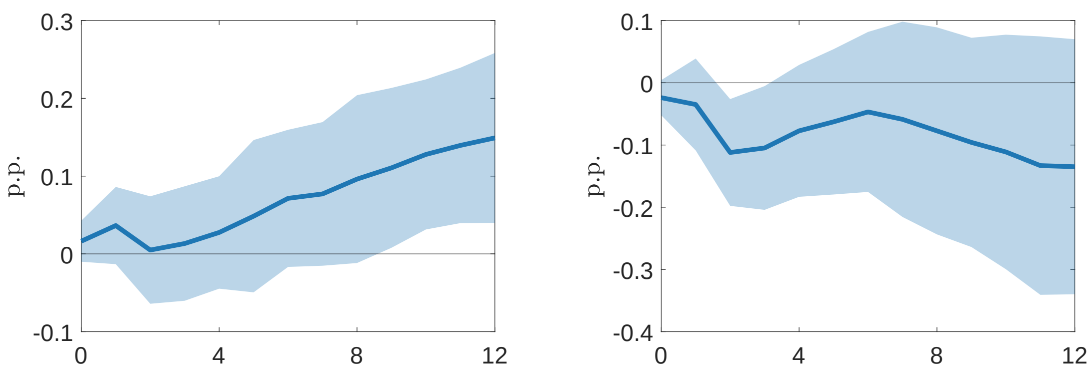


Note: The line shows the estimated β_1^h coefficients in $\Delta^{h+1} \log k_{it+h} = \alpha_i^h + \alpha_{sq}^h + \beta_1^h \varepsilon_t^{\mathrm{MP}} + \Gamma_1^h Z_{t-1} + \nu_{it}^h$, where α_i^h and α_{sq}^h are firm and sector-fiscal quarter fixed effects, $\varepsilon_t^{\mathrm{MP}}$ is a monetary policy shock, and Z_{t-1} a vector of macroeconomic control variables including four lags of real GDP growth and CPI inflation. The β_1^h estimates are standardized to capture the capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

Figure 16: Timing of bond maturity: within-firm + controls

(a) Maturity before shock

(b) Maturity after shock



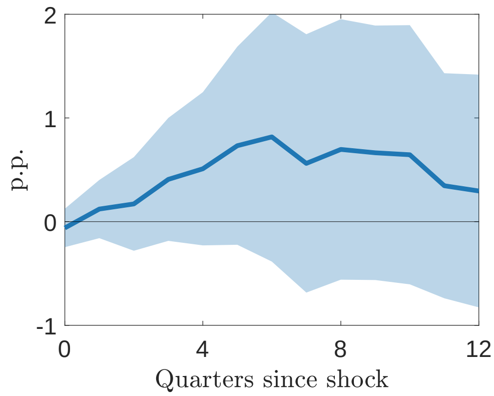
Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panels (a) and (b), x_{it} are the share of bonds maturing before and after the monetary shock, respectively. In panel (a), $x_{it} = \mathcal{M}_{it-1}$. In panel (b), $x_{it} = \sum_{j=1}^{3}$ maturing bonds$_{it+j}$/total debt$_{it-1}$. In both panels, Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

Table 6: Full list of coefficients for selected forecast horizons h

	h = 0	h = 4	h = 8	h = 12
$\mathcal{M}_{it}$	-0.0105	-0.101	-0.105	-0.0363
	(0.0257)	(0.0846)	(0.0917)	(0.108)
$\mathcal{M}_{it}$ × MP shock	-0.0169	-0.111*	-0.309***	-0.222**
	(0.0193)	(0.0637)	(0.0782)	(0.0953)
$\mathcal{M}_{it}$ × GDP growth	0.00310	0.181*	0.371**	0.267
	(0.0403)	(0.101)	(0.155)	(0.169)
Avg. bond maturity	0.000169	-0.170	-0.229	-0.243
	(0.0460)	(0.262)	(0.384)	(0.493)
Avg. bond maturity × MP shock	0.0219	-0.0231	-0.0557	-0.0519
	(0.0332)	(0.199)	(0.228)	(0.155)
Avg. bond maturity × GDP growth	0.0530	0.378	0.459	0.429
	(0.0567)	(0.287)	(0.385)	(0.357)
Distance to default	0.215**	0.877**	1.324**	1.901**
	(0.0916)	(0.380)	(0.563)	(0.732)
Distance to default × MP shock	0.148***	0.279	0.286	-0.173
	(0.0519)	(0.192)	(0.247)	(0.211)
Distance to default × GDP growth	0.0498	1.077***	1.469***	1.142*
	(0.0934)	(0.360)	(0.550)	(0.608)
Leverage	-0.162	-1.591***	-2.240**	-2.590**
	(0.132)	(0.594)	(1.024)	(1.206)
Leverage × MP shock	0.000334	-0.120	0.0173	0.145
	(0.0439)	(0.283)	(0.300)	(0.169)
Leverage × GDP growth	-0.228*	-0.414	-0.647	-0.669
	(0.126)	(0.328)	(0.643)	(0.774)
Liquidity	0.484***	1.120**	2.479***	2.909***
	(0.102)	(0.480)	(0.786)	(0.917)
Liquidity × MP shock	0.115*	-0.0486	-0.113	0.170
	(0.0615)	(0.160)	(0.259)	(0.353)
Liquidity × GDP growth	-0.182**	-0.00200	-0.868	-0.635
	(0.0866)	(0.388)	(0.688)	(0.695)
Sales growth	0.0941	0.994***	0.988***	1.124***
	(0.0695)	(0.186)	(0.225)	(0.266)
Sales growth × MP shock	0.0437	-0.106	-0.229	-0.314*
	(0.0624)	(0.127)	(0.199)	(0.174)
Sales growth × GDP growth	-0.0248	0.235	0.319	-0.0684
	(0.0795)	(0.238)	(0.321)	(0.326)
Size	-0.673***	-5.718***	-11.36***	-17.15***
	(0.183)	(0.880)	(1.690)	(2.285)
Size × MP shock	-0.0335	0.00290	-0.259	-0.594
	(0.102)	(0.349)	(0.430)	(0.518)
Size × GDP growth	0.0505	-0.198	0.242	0.663
	(0.177)	(0.549)	(0.997)	(1.074)
Firm FE	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes
R^2	.2	.38	.5	.59
N	13,119	12,716	12,253	11,791

Note: All estimated coefficients in equation (2.2) for $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} including leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). Standard errors (in parentheses) are clustered by firm and quarter.

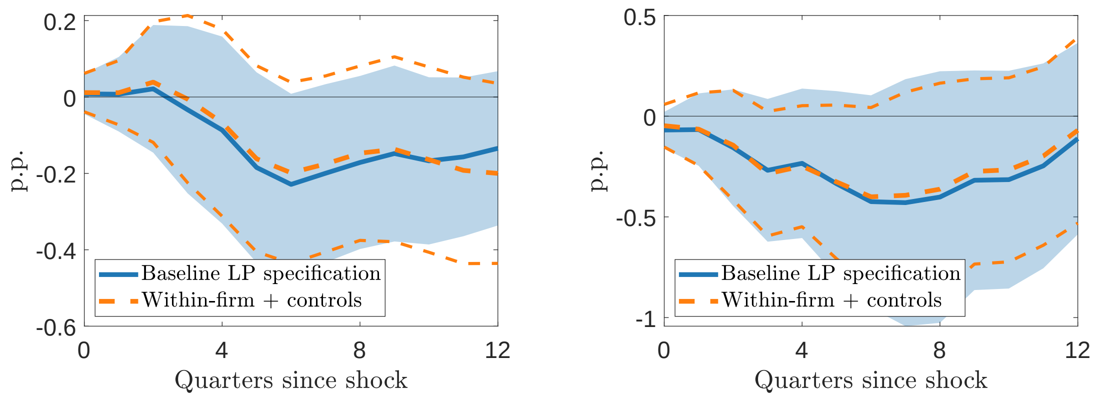
Figure 17: Leverage instead of bond maturity: including firms without bonds



Note: The line shows the estimated β_1^h coefficients based on equation (2.2), and with $x_{it} = \ell_{it} - \bar{\ell}_i$ where ℓ_{it} is leverage. Z_{it-1} includes the distance to default, liquidity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas indicate 95% confidence bands clustered by firms and quarters.

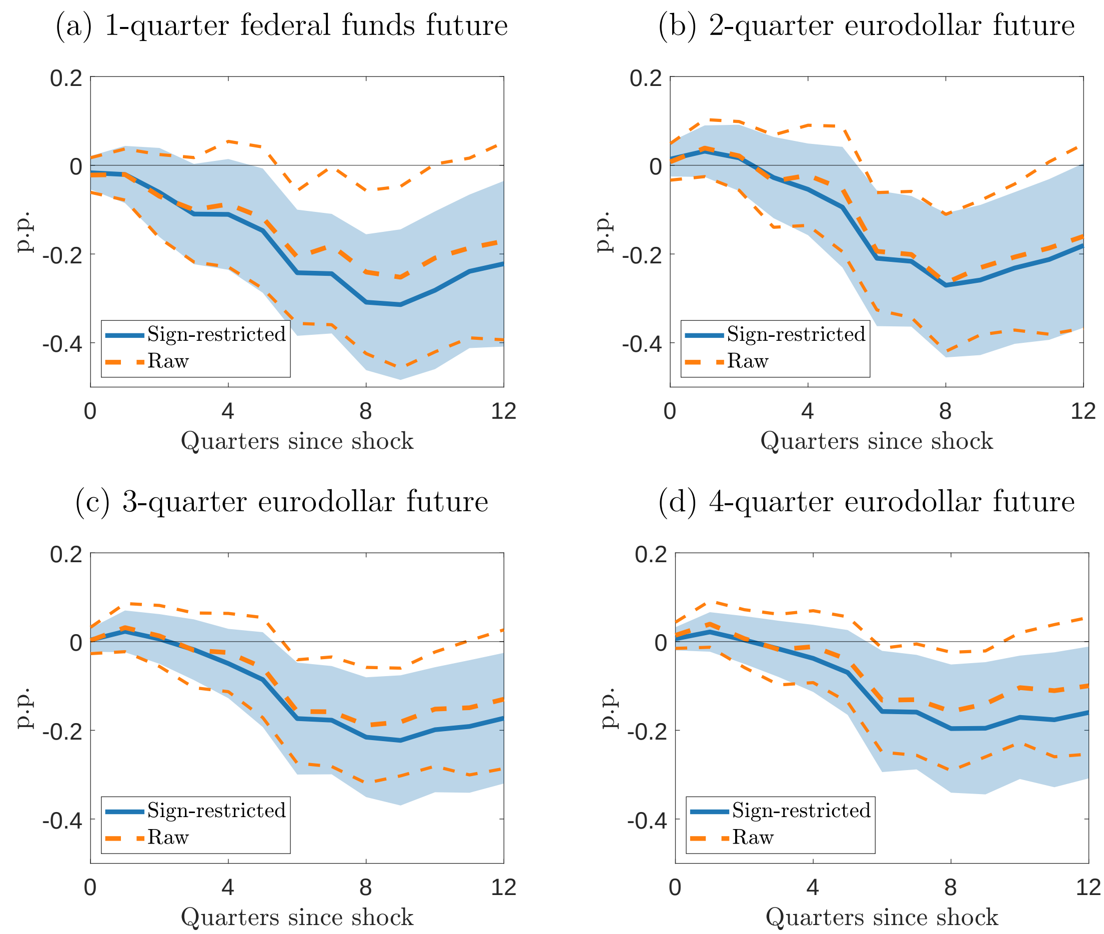
Figure 18: Other outcomes

(a) Sales (b) Debt



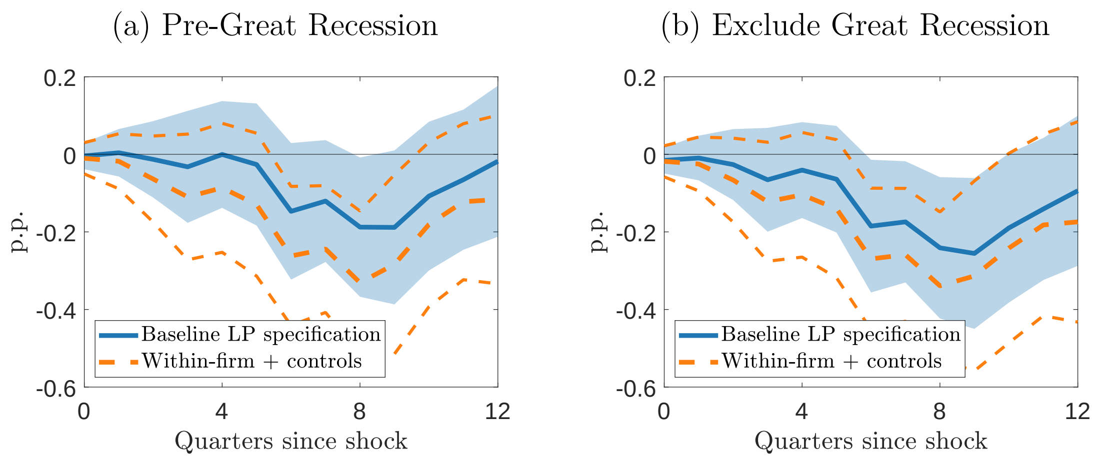
Note: The lines show the estimated β_1^h coefficients based on equation (2.2), but where the left-hand side is $\Delta^{h+1} \log \mathrm{sales}_{it+h}$ in panel (a) and $\Delta^{h+1} \log \mathrm{debt}_{it+h}$ in panel (b). In panels (a) and (b) the solid line is based on $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$, whereas the dashed line is based on $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential sales and debt growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas (and the outer dashed lines) indicate 95% confidence bands clustered by firms and quarters.

Figure 19: Alternative monetary policy shocks



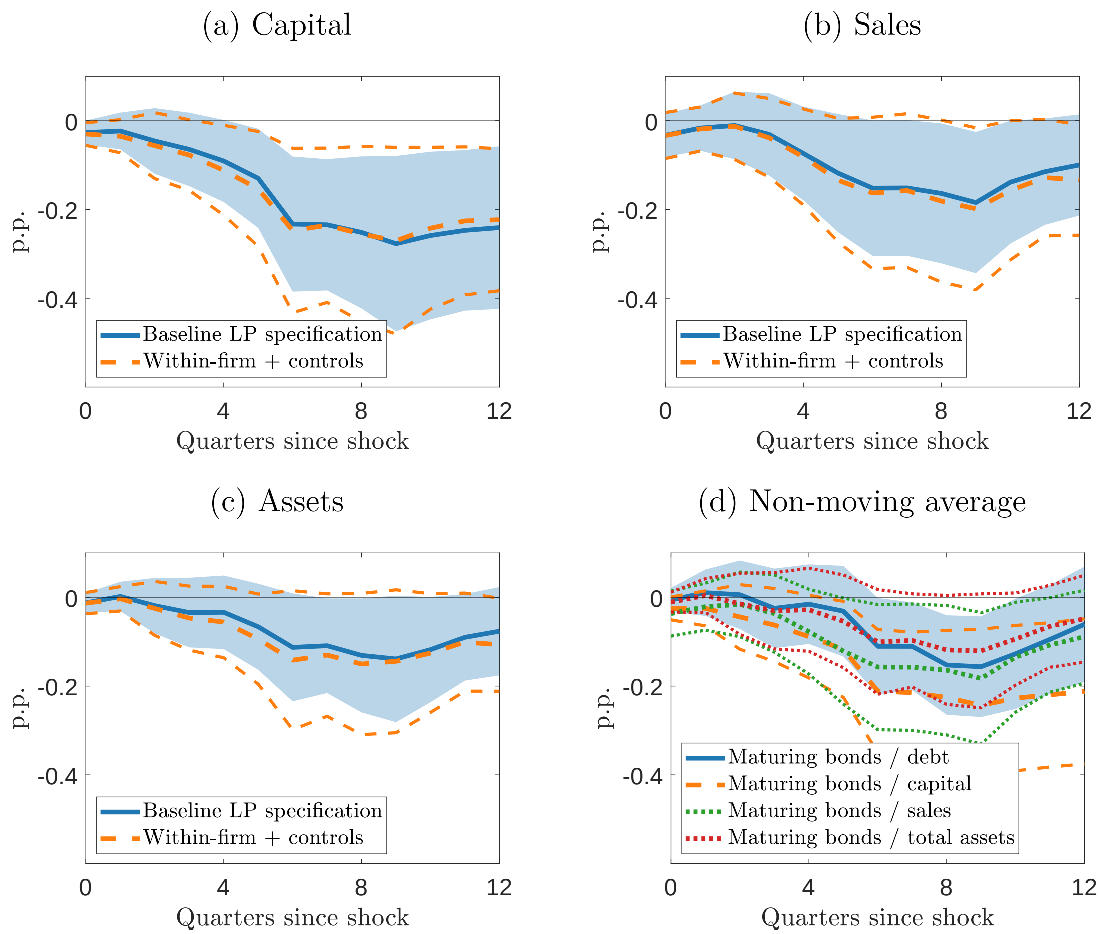
Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panel (a), $\varepsilon_t^{\text{MP}}$ is based on the change of the one-quarter ahead federal funds future in a 30 minute window around regular FOMC meetings, in (b) the two-quarter ahead eurodollar future, in (c) the three-quarter ahead eurodollar future, and in (d) the four-quarter ahead eurodollar future. In all panels, the solid line is based on $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$, whereas the dashed line is based on $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\text{MP}}$ associated with a one std higher x_{it}. Shaded areas (and the outer dashed lines) indicate 95% confidence bands clustered by firms and quarters.

Figure 20: Alternative samples



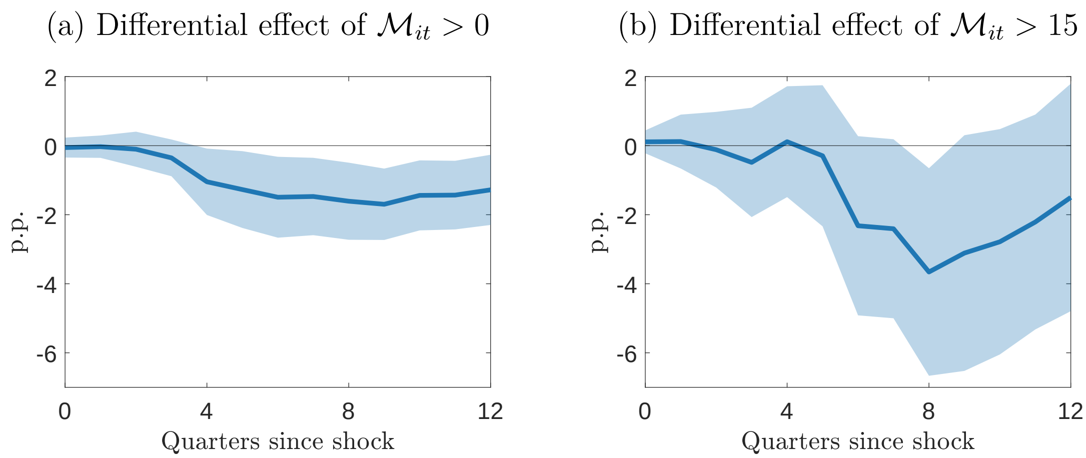
Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panel (a), we use only monetary policy shocks until 2008Q2. In panel (b), we exclude monetary policy shocks between 2008Q3 and 2009Q2. In all panels, the solid line is based on $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$, whereas the dashed line is based on $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\mathrm{MP}}$ associated with a one std higher x_{it}. Shaded areas (and the outer dashed lines) indicate 95% confidence bands clustered by firms and quarters.

Figure 21: Alternative denominators for $\mathcal{M}_{it}$



Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panel (a), we re-define $\mathcal{M}_{it}$ as the ratio of maturing bonds over the average capital stock in the preceding four quarters, in (b) the denominator is average sales, in (c) average assets, and in (d) we use as denominator debt, capital, sales, or assets in the preceding quarter, instead of constructing a moving average. In all panels, the solid line is based on $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$, whereas the dashed line is based on $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\text{MP}}$ associated with a one std higher x_{it}. Shaded areas (and the outer dashed lines) indicate 95% confidence bands clustered by firms and quarters.

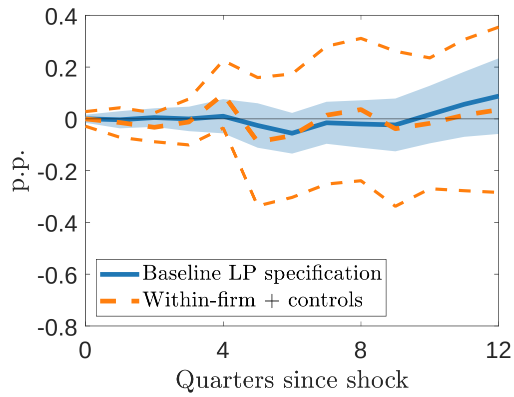
Figure 22: Dummy specification of bond maturity



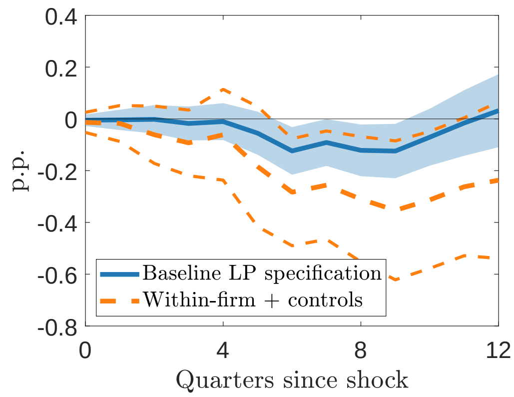
Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panel (a), $x_{it} = \mathbb{1}\{\mathcal{M}_{it} > 0\}$, where $\mathbb{1}\{\cdot\}$ is an indicator function. In panel (b), $x_{it} = \mathbb{1}\{\mathcal{M}_{it} > 15\}$. In both panels, $Z_{it-1} = \varnothing$. The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\text{MP}}$ associated with $x_{it} = 1$. Shaded areas (and the outer dashed lines) indicate 95% confidence bands clustered by firms and quarters.

Figure 23: Maturity of callable bond or bonds with variable coupon

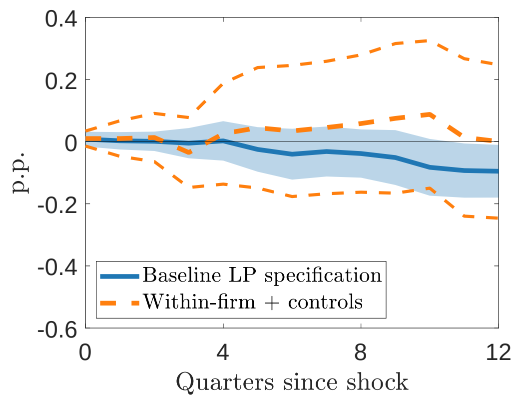
(a) Only callable bonds



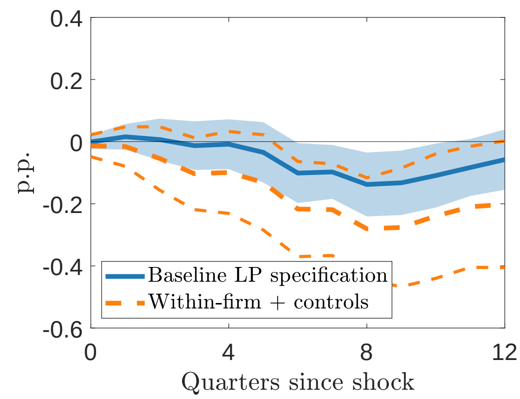
(b) Callable and non-callable bonds



(c) Only variable coupon bonds



(d) Variable and fixed coupon bonds



Note: The lines show the estimated β_1^h coefficients based on equation (2.2). In panel (a), we re-define $\mathcal{M}_{it}$ to only include the value of maturing callable bonds. In (b), we include both callable and non-callable bonds. In (c), we only include variable-coupon bonds. In (d), we include both variable-coupon and fixed-coupon bonds. In all panels, the solid line is based on $x_{it} = \mathcal{M}_{it}$ and $Z_{it-1} = \varnothing$, whereas the dashed line is based on $x_{it} = \mathcal{M}_{it} - \overline{\mathcal{M}}_i$ and Z_{it-1} includes leverage, distance to default, liquidity, average maturity, sales growth, and log assets (all demeaned). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (approx. in p.p.) to a one-std increase in $\varepsilon_t^{\text{MP}}$ associated with a one std higher x_{it}. Shaded areas (and the outer dashed lines) indicate 95% confidence bands clustered by firms and quarters.

Appendix C Model appendix

In this section of the appendix, we derive the first order conditions from Section 4 (Appendix C.1) and we identify model counterparts of the empirical moments targeted in Table 4 (Appendix C.2).

C.1 Characterization

In the following, we show that the firm problem (3.16) can be expressed in terms of three choice variables: the scale of production k', and the amounts of short-term debt $\tilde{b}^{S'}$ and long-term debt $\tilde{b}^{L'}$.

Equity issuance is given by (3.6):

$$e = Qk' - q - \tilde{b}^{S'} p^S - \left(\tilde{b}^{L'} - \frac{b}{\pi}\right) p^L \tag{A.1}$$

Applying (A.1) to (3.16) yields as the firm objective:

$$\begin{aligned} V(q,b,z',S) = q - Qk' + \tilde{b}^{S'} p^S + \left(\tilde{b}^{L'} - \frac{b}{\pi}\right) p^L - G\left(e\right) - H\left(\tilde{b}^{S'}, \tilde{b}^{L'}, \frac{b}{\pi}\right) \\ + \mathbb{E}\,\Lambda \int_{\bar{\varepsilon}'}^{\infty} \left[(1-\kappa)\, V\left(q', b', z'', S'\right) + \kappa \left(q' - \frac{b'}{\pi'}\, g(q', b', z'', S')\right)\right] \varphi(\varepsilon) d\varepsilon \end{aligned} \tag{A.2}$$

Equity and debt issuance costs are:

$$G\left(e\right) = \nu \,\left(\max\left\{e, 0\right\}\right)^2\,, \quad \text{and:} \quad H\left(\tilde{b}^{S'}, \tilde{b}^{L'}, \frac{b}{\pi}\right) = \eta \left(\tilde{b}^{S'} + \max\left\{\tilde{b}^{L'} - \frac{b}{\pi}, 0\right\}\right)^2 \tag{A.3}$$

Using (3.9), firm revenue net of labor costs can be written as:

$$p'y' - w'l' = A'k'^{\alpha}\,, \quad \text{where:} \tag{A.4}$$

$$A' \equiv \left(p'z'\right)^{\frac{1}{1-\zeta(1-\psi)}} \left(\frac{\zeta(1-\psi)}{w'}\right)^{\frac{\zeta(1-\psi)}{1-\zeta(1-\psi)}} \left[1-\zeta(1-\psi)\right], \quad \text{and:} \quad \alpha \equiv \frac{\psi\zeta}{1-\zeta(1-\psi)} \tag{A.5}$$

The default threshold $\bar{\varepsilon}'$ is defined by (3.11):

$$\bar{\varepsilon}: \quad (1-\kappa)\, \hat{\mathbb{E}}\, V\left(q', b', z'', S'\right) + \kappa \left(q' - \frac{b'}{\pi'}\, \hat{\mathbb{E}}\, g(q', b', z'', S')\right) = 0\,, \tag{A.6}$$

where $b' = (1-\gamma)\tilde{b}^{L'}$, and q' depends on ε' and the three choice variables k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$:

$$q' = Q'k' - \frac{\tilde{b}^{S'}}{\pi'} - \frac{\gamma\tilde{b}^{L'}}{\pi'} + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon' - \delta)Q'k' - f - \frac{c(\tilde{b}^{S'} + \tilde{b}^{L'})}{\pi'}\right] \tag{A.7}$$

The short-term bond price depends on $\bar{\varepsilon}'$, k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$:

$$p^S = \mathbb{E}\,\Lambda \left[[1-\Phi(\bar{\varepsilon}')]\frac{1+c}{\pi'} + \frac{(1-\xi)}{\tilde{b}^{L'} + \tilde{b}^{S'}} \int_{-\infty}^{\bar{\varepsilon}'} \Big[Q'k' + (1-\tau)\big(A'k'^{\alpha} + (\varepsilon' - \delta)Q'k' - f\big)\Big]\varphi(\varepsilon) d\varepsilon\right] \tag{A.8}$$

Because (A.6) and (A.7) pin down $\bar{\varepsilon}'$ through the firm's choice of k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$, the short-term bond price likewise only depends on the three choice variables k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$. The same reasoning applies to the price of long-term debt:

$$\begin{aligned} p^L = \mathbb{E}\,\Lambda\Big[&\int_{\bar{\varepsilon}'}^{\infty} \frac{\gamma + c + (1-\gamma) g\left(q', b', z'', S'\right)}{\pi'} \varphi(\varepsilon) d\varepsilon \\ &+ \frac{(1-\xi)}{\tilde{b}^{L'} + \tilde{b}^{S'}} \int_{-\infty}^{\bar{\varepsilon}'} \Big[Q'k' + (1-\tau)\big(A'k'^{\alpha} + (\varepsilon' - \delta)Q'k' - f\big)\Big]\varphi(\varepsilon)d\varepsilon\Big] \end{aligned} \tag{A.9}$$

It follows that the solution to (3.16) is found by choosing k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$ to maximize (A.2) subject to the default threshold in (A.6), the definitions of equity issuance in (A.1) and of q' in (A.7), and the bond prices in (A.8) and (A.9).

An interior solution to (3.16) is characterized by three first order conditions. The three choice variables affect the threshold value $\bar{\varepsilon}'$ through (A.6) and (A.7). Let $\mathbb{E}\left[\Delta\bar{\varepsilon}'\right]$ denote the effect of an anticipated marginal increase in $\bar{\varepsilon}'$ on the firm's objective (A.2) for *given* values of k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$, where:

$$\Delta\bar{\varepsilon}' \equiv \left[1 + \frac{\partial G(e)}{\partial e}\right]\left[\tilde{b}^{S'}\frac{\partial p^S(k', \tilde{b}^{S'}, \tilde{b}^{L'}, \bar{\varepsilon}')}{\partial \bar{\varepsilon}'} + \left(\tilde{b}^{L'} - \frac{b}{\pi}\right)\frac{\partial p^L(k', \tilde{b}^{S'}, \tilde{b}^{L'}, \bar{\varepsilon}')}{\partial \bar{\varepsilon}'}\right], \tag{A.10}$$

$$\text{where: } \frac{\partial p^S(k', \tilde{b}^{S'}, \tilde{b}^{L'}, \bar{\varepsilon}')}{\partial \bar{\varepsilon}'} = \mathbb{E}\,\Lambda\,\varphi(\bar{\varepsilon}')\left[-\frac{1+c}{\pi'} + \frac{1-\xi}{\tilde{b}^{S'} + \tilde{b}^{L'}}\Big[Q'k' + (1-\tau)\big(A'k'^{\alpha} + (\bar{\varepsilon}' - \delta)Q'k' - f\big)\Big]\right], \tag{A.11}$$

$$\begin{aligned} \text{and: } \frac{\partial p^L(k', \tilde{b}^{S'}, \tilde{b}^{L'}, \bar{\varepsilon}')}{\partial \bar{\varepsilon}'} = \mathbb{E}\,\Lambda\,\varphi(\bar{\varepsilon}')\Big[&- \frac{\gamma + c + (1-\gamma) g(q', b', z'', S')}{\pi'} \\ &+ \frac{1-\xi}{\tilde{b}^{S'} + \tilde{b}^{L'}}\Big[Q'k' + (1-\tau)\big(A'k'^{\alpha} + (\bar{\varepsilon}' - \delta)Q'k' - f\big)\Big]\Big] \end{aligned} \tag{A.12}$$

A higher threshold value $\bar{\varepsilon}'$ implies higher default risk. For *given* values of k', $\tilde{b}^{S'}$, and $\tilde{b}^{L'}$, higher default risk unambiguously reduces shareholder value. Higher expected default costs reduce the market price of short-term debt ($\partial p^S/\partial\bar{\varepsilon}'<0$) and long-term debt ($\partial p^L/\partial\bar{\varepsilon}'<0$). This lowers the revenue which the firm raises on the bond market and therefore requires higher equity issuance (or lower dividend payout) for a given stock of capital.

An important variable is shareholder value after the realization of ε:

$$EV \equiv (1-\kappa)\,V\left(q', b', z'', S'\right) + \kappa\left(q' - \frac{b'}{\pi'}\,g(q', b', z'', S')\right) \tag{A.13}$$

If future assets q' change, this affects EV according to:

$$\Delta EV \equiv \frac{\partial EV}{\partial q'} = (1-\kappa)\left[1 + \frac{\partial G(e')}{\partial e'}\right] + \kappa\left(1 - \frac{b'}{\pi'}\frac{\partial\, g(q', b', z'', S')}{\partial q'}\right) \tag{A.14}$$

An additional dollar tomorrow saves the marginal equity issuance cost $\partial G(e')/\partial e'$. This effect is missing in case of exogenous exit. Furthermore, higher firm assets may increase the market value of existing debt which firms need to pay to creditors in case of exogenous exit.

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

$$
\begin{aligned}
&\left[1+\frac{\partial G(e)}{\partial e}\right]\left[-\,Q+\left(\tilde{b}^{S'}+\tilde{b}^{L'}-\frac{b}{\pi}\right)\mathbb{E}\,\Lambda\,\frac{(1-\xi)}{\tilde{b}^{L'}+\tilde{b}^{S'}}\int_{-\infty}^{\bar{\varepsilon}'}\Big[Q'+(1-\tau)\big(A'\alpha k'^{\alpha-1}+(\varepsilon'-\delta)Q'\big)\Big]\varphi(\varepsilon)d\varepsilon\right.\\
&\qquad\left.+\left(\tilde{b}^{L'}-\frac{b}{\pi}\right)(1-\gamma)\,\mathbb{E}\,\frac{\Lambda}{\pi'}\int_{\bar{\varepsilon}'}^{\infty}\left[\frac{\partial q'}{\partial k'}\,\frac{\partial g(q',b',z'',S')}{\partial q'}\right]\varphi(\varepsilon)d\varepsilon\right]\\
&\qquad+\mathbb{E}\left[\frac{\partial\bar{\varepsilon}'}{\partial k'}\,\Delta\bar{\varepsilon}'+\Lambda\int_{\bar{\varepsilon}'}^{\infty}\frac{\partial q'}{\partial k'}\Delta EV\varphi(\varepsilon)d\varepsilon\right]\;=\;0\,,
\end{aligned}
\tag{A.15}
$$

where: $$\frac{\partial q'}{\partial k'}\;=\;Q'+(1-\tau)[A'\alpha k'^{\alpha-1}+(\varepsilon'-\delta)Q']\,,\quad\text{and:}\quad\frac{\partial q'}{\partial\bar{\varepsilon}'}\;=\;(1-\tau)Q'k'\,,\tag{A.16}$$

$$\frac{\partial\bar{\varepsilon}'}{\partial k'}\;=\;-\,\frac{\frac{\partial q'}{\partial k'}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}}\;=\;-\,\frac{Q'+(1-\tau)[A'\alpha k'^{\alpha-1}+(\bar{\varepsilon}'-\delta)Q']}{(1-\tau)Q'k'}\,,\tag{A.17}$$

and: $$\frac{\partial G(e)}{\partial e}\;=\;2\,\nu\,e\;=\;2\,\nu\left[Qk'-q-\tilde{b}^{S'}p^S-\left(\tilde{b}^{L'}-\frac{b}{\pi}\right)p^L\right]\quad\text{, if } e>0\text{, and zero otherwise.}\tag{A.18}$$

Short-term debt The firm's first order condition with respect to $\tilde{b}^{S'}$ is:

$$
\begin{aligned}
&\left[1+\frac{\partial G(e)}{\partial e}\right]\mathbb{E}\,\Lambda\left[\frac{1+c}{\pi'}\,[1-\Phi(\bar{\varepsilon}')]+\frac{(1-\xi)}{\tilde{b}^{L'}+\tilde{b}^{S'}}\int_{-\infty}^{\bar{\varepsilon}'}\Big[Q'k'+(1-\tau)\big(A'k'^{\alpha}+(\varepsilon'-\delta)Q'k'-f\big)\Big]\varphi(\varepsilon)d\varepsilon\right.\\
&\qquad-\left(\tilde{b}^{S'}+\tilde{b}^{L'}-\frac{b}{\pi}\right)\frac{1-\xi}{\left(\tilde{b}^{S'}+\tilde{b}^{L'}\right)^2}\int_{-\infty}^{\bar{\varepsilon}'}\Big[Q'k'+(1-\tau)\big(A'k'^{\alpha}+(\varepsilon'-\delta)Q'k'-f\big)\Big]\varphi(\varepsilon)d\varepsilon\\
&\qquad\left.+\left(\tilde{b}^{L'}-\frac{b}{\pi}\right)\frac{1-\gamma}{\pi'}\int_{\bar{\varepsilon}'}^{\infty}\left[\frac{\partial q'}{\partial\tilde{b}^{S'}}\,\frac{\partial g(q',b',z'',S')}{\partial q'}\right]\varphi(\varepsilon)d\varepsilon\right]\\
&\qquad-\frac{\partial H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)}{\partial\tilde{b}^{S'}}+\mathbb{E}\left[\frac{\partial\bar{\varepsilon}'}{\partial\tilde{b}^{S'}}\,\Delta\bar{\varepsilon}'+\Lambda\int_{\bar{\varepsilon}'}^{\infty}\frac{\partial q'}{\partial\tilde{b}^{S'}}\Delta EV\varphi(\varepsilon)d\varepsilon\right]=0\,,
\end{aligned}
\tag{A.19}
$$

where: $$\frac{\partial H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)}{\partial\tilde{b}^{S'}}=2\eta\left(\tilde{b}^{S'}+\max\left\{\tilde{b}^{L'}-\frac{b}{\pi},0\right\}\right)\,,\tag{A.20}$$

$$\frac{\partial q'}{\partial\tilde{b}^{S'}}\;=\;-\,\frac{1+(1-\tau)c}{\pi'}\,,\quad\text{and:}\quad\frac{\partial\bar{\varepsilon}'}{\partial\tilde{b}^{S'}}\;=\;-\,\frac{\frac{\partial q'}{\partial\tilde{b}^{S'}}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}}\;=\;\frac{1+(1-\tau)c}{\pi'(1-\tau)Q'k'}\tag{A.21}$$

Long-term debt The firm's first order condition with respect to $\tilde{b}^{L'}$ is:

$$\begin{aligned}
&\left[1+\frac{\partial G(e)}{\partial e}\right]\mathbb{E}\,\Lambda\Bigg[\int_{\bar{\varepsilon}'}^{\infty}\frac{\gamma+c+(1-\gamma)g\left(q',b',z'',S'\right)}{\pi'}\,\varphi(\varepsilon)d\varepsilon \\
&\quad+\frac{(1-\xi)}{\tilde{b}^{L'}+\tilde{b}^{S'}}\int_{-\infty}^{\bar{\varepsilon}'}\Big[Q'k'+(1-\tau)\big(A'k'^{\alpha}+(\varepsilon'-\delta)Q'k'-f\big)\Big]\varphi(\varepsilon)d\varepsilon \\
&\quad-\left(\tilde{b}^{S'}+\tilde{b}^{L'}-\frac{b}{\pi}\right)\frac{1-\xi}{\left(\tilde{b}^{S'}+\tilde{b}^{L'}\right)^{2}}\int_{-\infty}^{\bar{\varepsilon}'}\Big[Q'k'+(1-\tau)\big(A'k'^{\alpha}+(\varepsilon'-\delta)Q'k'-f\big)\Big]\varphi(\varepsilon)d\varepsilon \\
&\quad+\left(\tilde{b}^{L'}-\frac{b}{\pi}\right)\frac{1-\gamma}{\pi'}\int_{\bar{\varepsilon}'}^{\infty}\left[\frac{\partial b'}{\partial\tilde{b}^{L'}}\frac{\partial g(q',b',z'',S')}{\partial b'}+\frac{\partial q'}{\partial\tilde{b}^{L'}}\frac{\partial g(q',b',z'',S')}{\partial q'}\right]\varphi(\varepsilon)d\varepsilon\Bigg] \\
&\quad-\frac{\partial H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)}{\partial\tilde{b}^{L'}}+\mathbb{E}\left[\frac{\partial\bar{\varepsilon}'}{\partial\tilde{b}^{L'}}\,\Delta\bar{\varepsilon}'+\Lambda\int_{\bar{\varepsilon}'}^{\infty}\frac{\partial q'}{\partial\tilde{b}^{L'}}\Delta EV\,\varphi(\varepsilon)d\varepsilon\right] \\
&\quad+\mathbb{E}\,\Lambda\int_{\bar{\varepsilon}'}^{\infty}\Bigg[(1-\kappa)\,\frac{\partial b'}{\partial\tilde{b}^{L'}}\,\frac{\partial V(q',b',z'',S')}{\partial b'}\;-\;\frac{\kappa}{\pi'}\,\frac{\partial b'}{\partial\tilde{b}^{L'}}\,g(q',b',z'',S') \\
&\qquad\quad-\;\frac{\kappa}{\pi'}\,b'\left[\frac{\partial b'}{\partial\tilde{b}^{L'}}\,\frac{\partial g(q',b',z'',S')}{\partial b'}\;+\;\frac{\partial q'}{\partial\tilde{b}^{L'}}\,\frac{\partial g(q',b',z'',S')}{\partial q'}\right]\Bigg]\varphi(\varepsilon)d\varepsilon\;=\;0\,,
\end{aligned}\tag{A.22}$$

where: $$\frac{\partial\bar{\varepsilon}'}{\partial\tilde{b}^{L'}}=-\frac{\frac{\partial q'}{\partial\tilde{b}^{L'}}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}}-\frac{(1-\kappa)\,\frac{\partial b'}{\partial\tilde{b}^{L'}}\,\frac{\partial\hat{\mathbb{E}}V(q',b',z'',S')}{\partial b'}-\frac{\kappa}{\pi'}\,\frac{\partial b'}{\partial\tilde{b}^{L'}}\,\hat{\mathbb{E}}\,g(q',b',z'',S')-\frac{\kappa}{\pi'}\,b'\,\frac{\partial b'}{\partial\tilde{b}^{L'}}\,\frac{\partial\hat{\mathbb{E}}g(q',b',z'',S')}{\partial b'}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}\,\hat{\mathbb{E}}\,\Delta EV}\,,\tag{A.23}$$

$$\frac{\partial q'}{\partial\tilde{b}^{L'}}=-\frac{\gamma+(1-\tau)c}{\pi'}\,,\qquad\frac{\partial q'}{\partial\bar{\varepsilon}'}=(1-\tau)Q'k'\,,\qquad\frac{\partial b'}{\partial\tilde{b}^{L'}}=1-\gamma\,,\tag{A.24}$$

and: $$\frac{\partial H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)}{\partial\tilde{b}^{L'}}=2\eta\left(\tilde{b}^{S'}+\tilde{b}^{L'}-\frac{b}{\pi}\right)\,,\text{if }\tilde{b}^{L'}-\frac{b}{\pi}>0\,,\text{and zero otherwise.}\tag{A.25}$$

We derive the effect of a marginal increase in b' on $V\left(q',b',z'',S'\right)$. From (A.2) it follows:

$$\frac{\partial V(q,b,z',S)}{\partial b}=-\frac{1}{\pi}\frac{\partial H(\tilde{b}^{S'},\tilde{b}^{L'},b/\pi)}{\partial\frac{b}{\pi}}-\frac{p^{L}}{\pi}\left[1+\frac{\partial G(e)}{\partial e}\right]\tag{A.26}$$

This implies:

$$\frac{\partial V(q',b',z'',S')}{\partial b'}=-\frac{1}{\pi'}\left(\frac{\partial H(\tilde{b}^{S''},\tilde{b}^{L''},b'/\pi')}{\partial\frac{b'}{\pi'}}+g\left(q',b',z'',S'\right)\left[1+\frac{\partial G(e')}{\partial e'}\right]\right)\,,\tag{A.27}$$

where: $$\frac{\partial H(\tilde{b}^{S''},\tilde{b}^{L''},b'/\pi')}{\partial\frac{b'}{\pi'}}=-2\eta\left(\tilde{b}^{S''}+\tilde{b}^{L''}-\frac{b'}{\pi'}\right)\,,\text{if }\tilde{b}^{L''}-\frac{b'}{\pi'}>0\,,\text{and zero otherwise.}\tag{A.28}$$

$$\frac{\partial G(e')}{\partial e'}=2\,\nu\,e'=2\,\nu\left[Q'k''-q'-\tilde{b}^{S''}p^{S'}-\left(\tilde{b}^{L''}-\frac{b'}{\pi'}\right)g\left(q',b',z'',S'\right)\right]\,,\text{ if }e'>0\text{, and zero otherwise.}\tag{A.29}$$

C.2 Model moments

In this section, we provide details on the model counterparts of the empirical moments targeted in Table 4. The total amount of nominal firm debt D is the present value of future debt payments discounted at the quarterly nominal riskless interest rate r^{nom}:

$$\begin{aligned} D &\equiv \frac{1+c}{1+r^{nom}}\tilde{B}^S + \frac{\gamma+c}{1+r^{nom}}\tilde{B}^L + (1-\gamma)\frac{\gamma+c}{(1+r^{nom})^2}\tilde{B}^L + (1-\gamma)^2\frac{\gamma+c}{(1+r^{nom})^3}\tilde{B}^L + ... \\ &= \frac{1+c}{1+r^{nom}}\tilde{B}^S + \frac{\gamma+c}{1+r^{nom}}\tilde{B}^L \sum_{j=0}^{\infty}\left(\frac{1-\gamma}{1+r^{nom}}\right)^j = \frac{1+c}{1+r^{nom}}\tilde{B}^S + \frac{\gamma+c}{\gamma+r^{nom}}\tilde{B}^L \end{aligned} \tag{A.30}$$

Firm leverage is total debt over total assets: D/k. The share of maturing debt of a given firm is the present value of debt payments due (weakly) less than four quarters from today divided by the total amount of firm debt D:

$$\frac{1+c}{1+r^{nom}}\frac{\tilde{B}^S}{D} + \frac{\gamma+c}{1+r^{nom}}\frac{\tilde{B}^L}{D} + \frac{(1-\gamma)(\gamma+c)}{(1+r^{nom})^2}\frac{\tilde{B}^L}{D} + \frac{(1-\gamma)^2(\gamma+c)}{(1+r^{nom})^3}\frac{\tilde{B}^L}{D} + \frac{(1-\gamma)^3(\gamma+c)}{(1+r^{nom})^4}\frac{\tilde{B}^L}{D} \tag{A.31}$$

The Macaulay duration is the weighted average term to maturity of the cash flows from a riskless nominal bond divided by the price:

$$\mu = \frac{1}{P_r^L}\sum_{j=1}^{\infty} j(1-\gamma)^{j-1}\frac{c+\gamma}{(1+r^{nom})^j} = \frac{c+\gamma}{P_r^L}\frac{1+r^{nom}}{(\gamma+r^{nom})^2} \tag{A.32}$$

where P_r^L is the price of a riskless nominal long-term bond:

$$P_r^L = \sum_{j=1}^{\infty}(1-\gamma)^{j-1}\frac{c+\gamma}{(1+r^{nom})^j} = \frac{c+\gamma}{r^{nom}+\gamma} \tag{A.33}$$

It follows for the Macaulay duration:

$$\mu = \frac{1+r^{nom}}{\gamma+r^{nom}} \tag{A.34}$$

The short-term spread compares the annual gross return (in the absence of default) from buying a nominal short-term bond with the annualized quarterly nominal riskless rate r^{nom}:

$$\left(\frac{1+c}{p^S}\right)^4 - (1+r^{nom})^4 \tag{A.35}$$

The long-term spread compares the annual gross return (in the absence of default and assuming p^L is constant) from buying a long-term bond with the annualized quarterly riskless rate:

$$\left(\frac{\gamma+c+(1-\gamma)p^L}{p^L}\right)^4 - (1+r^{nom})^4 = \left(\frac{\gamma+c}{p^L}+1-\gamma\right)^4 - (1+r^{nom})^4 \tag{A.36}$$

Firm-level capital growth is measured as:

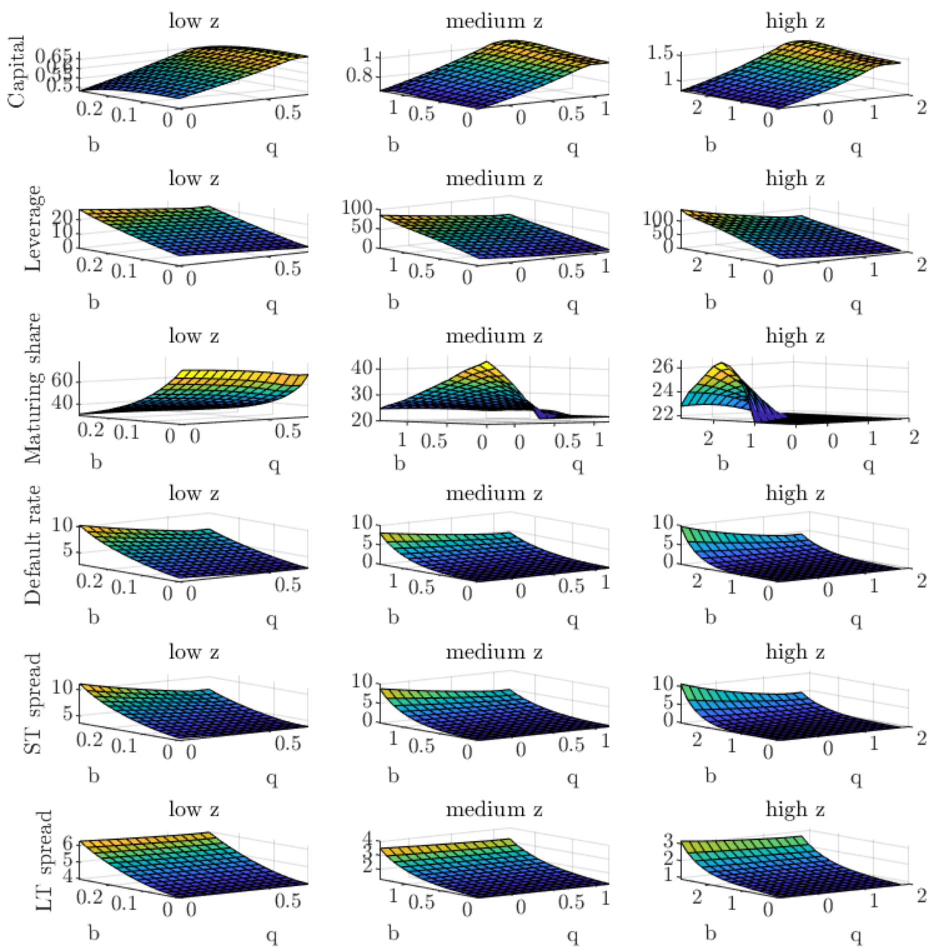
$$\ln(k_{it}) - \ln(k_{it-1}) \tag{A.37}$$

Given the aggregate states S and S', the total exit rate per quarter (exogenous and endogenous through default) is

$$\int_0^{\infty}\int_0^{\infty}\int_{-\infty}^{\infty}\Phi\Big(\bar{\varepsilon}(q,b,z,S,S')\Big)\mu(q,b,z)\,dq\,db\,dz \;+\; \kappa \tag{A.38}$$

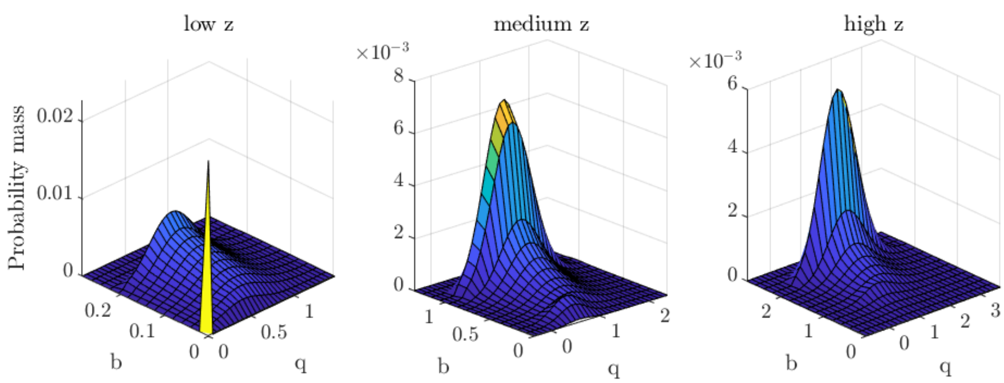
Appendix D Quantitative results

Figure 24: Steady state policy functions



Note: Steady state policy functions are plotted for different levels of firm productivity z against existing debt b and assets in place q. Existing debt b is normalized by average steady state firm debt; assets in place q are normalized by average firm capital. The policy function for *Capital* $k(q, b, z)$ is normalized by average steady state firm capital as well. All remaining firm policies are in %. *Leverage* is total firm debt over assets; *Maturing share* is the share of firm debt with remaining maturity of less than one year; *Default rate* is the annualized probability of default; *ST spread* is the annualized credit spread of short-term debt; *LT spread* is the annualized credit spread on long-term debt.

Figure 25: Steady state - Firm distribution $\mu(q, b, z)$



Note: The steady state firm distribution $\mu(q, b, z)$ is plotted for different levels of firm productivity z against existing debt b and assets in place q. Existing debt b is normalized by average steady state firm debt; assets in place q are normalized by average firm capital.