Corporate Debt Maturity Matters For Monetary Policy*

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Abstract

We provide novel empirical evidence that firms' investment is more responsive to 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 have larger roll-over needs and are therefore more exposed to fluctuations in the real interest rate (*roll-over risk*). (2.) These firms also have higher default risk and therefore react more strongly to changes in the real burden of outstanding nominal debt (*debt overhang*). Unconventional monetary policy, which operates through long-term interest rates, has larger effects on debt maturity but smaller effects on output and inflation than conventional monetary policy.

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

Debt is the main source of external firm financing and plays a key role for investment. But not all debt is created equal. While a part of debt comes due in the short run, a large share is issued with long maturities and need not be repaid until years in the future. Figure 1 shows the distribution of debt maturity across listed U.S. firms. While for many firms only a small fraction of debt matures within the next year, in almost a fifth of firm-quarters this fraction amounts to ninety percent or more. In this paper, we show that this heterogeneity matters for the real effects of monetary policy.

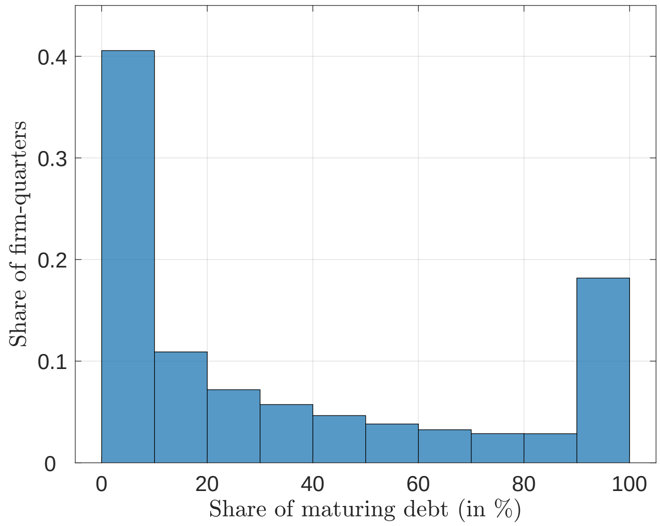
We begin by providing novel empirical evidence that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. After a tightening of monetary policy, firms with higher shares of maturing debt experience a larger fall in investment, borrowing, sales, and employment, and a larger increase in their credit spreads. These results are robust to a wide set of controls and specifications.

To understand the macroeconomic implications of these results, we develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. Debt maturity matters for monetary policy because of *roll-over risk* and *debt overhang*. Roll-over needs make firms with higher shares of maturing debt more sensitive to changes in interest rates. Long-term debt insures firms against roll-over risk but creates debt overhang. When tighter monetary policy increases the real burden of outstanding nominal long-term debt, this leads to higher default risk and lower investment.

The model generates the rich heterogeneity in firm financing choices found in the data, including the heterogeneity in debt maturity. Importantly, the model rationalizes the empirical evidence that firms with higher shares of maturing debt respond more strongly to monetary policy shocks. Given this ability to replicate key targeted and non-targeted micro moments, we use the model to study the macroeconomic implications of debt maturity for the transmission of conventional and unconventional monetary policy. We consider an expansionary unconventional monetary policy shock which lowers long-term interest rates but leaves the short-term rate unchanged. While in the short run unconventional monetary policy stimulates aggregate demand and lowers default rates, the reduction in long-term interest rates induces a large build-up of corporate long-term debt which subsequently drives up default rates and dampens investment. The overall effects on output and inflation are therefore smaller compared to conventional monetary policy.

In our empirical analysis, we combine balance sheet and credit spread data of listed U.S. firms with detailed bond-level information about outstanding debt and its maturity. This allows us to construct the precise distribution of bond maturity across firms and time.

Figure 1: Share of debt maturing within the next year



Note: The figure shows the distribution of the share of debt which matures within the next twelve months across all firm-quarters of listed U.S. non-financial firms for 1995Q1–2017Q4 from Compustat.

We complement this data with high-frequency identified monetary policy shocks and estimate their effect on firm-level outcomes using panel local projections. The main result of our empirical analysis is that firms' investment is more responsive to monetary policy if a larger fraction of their debt matures at the time of a shock. This result is statistically and economically significant. After a typical contractionary monetary policy shock, firms with a one-standard deviation higher maturing bond share experience a persistent additional reduction of their capital stock which peaks at 0.2% eight quarters after the shock. Assuming an annual investment-to-capital ratio of 10%, this corresponds to a reduction of investment of 1%. A higher maturing bond share is also associated with amplified responses of credit spreads, debt, sales, and employment. These results are robust to controlling for permanent differences across firms as well as various time-varying firm characteristics such as size, age, leverage, and liquidity.

To rationalize the empirical evidence and to study the implications for the aggregate effects 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 default risk.

We calibrate the model to empirical moments which characterize investment and financing choices of listed U.S. firms. Because the effects of debt overhang are more distortive for firms with higher default risk, these firms choose to borrow at shorter maturities. Through this mechanism, the model generates the empirical fact that smaller firms pay higher credit spreads and have higher maturing debt shares.

Importantly, the model explains our main empirical finding: a higher share of maturing debt at the time of a monetary policy shock is associated with a stronger response of firm capital. Both roll-over risk and debt overhang contribute to this result: (1.) Firms with more maturing debt roll over more debt and therefore experience a higher pass-through of interest rate changes to cash flow. This influences their need to access costly outside financing and thereby affects default risk and the firm-specific cost of capital. (2.) Firms with more maturing debt tend to have higher default risk and therefore react more strongly to fluctuations in the real burden of outstanding nominal debt. For these firms, default risk and investment respond more strongly to surprise changes in interest rates and inflation. The model generates 90% of the peak empirical differential capital response associated with the maturing bond share. Roll-over risk and debt overhang both contribute about equally to this result. In addition, the model rationalizes the empirical role of the maturing bond share for the firm-level responses of credit spreads, debt, sales, and employment.

Finally, we use the model to study the implications of corporate debt maturity for the macroeconomic effects of monetary policy. We compare conventional monetary policy, which sets short-term nominal interest rates, and unconventional monetary policy (e.g., quantitative easing, forward guidance), which targets long-term interest rates. Our model provides a unique framework for comparing the effects of these policies because it accounts for the fact that different firms borrow at different maturities. We find that unconventional monetary policy shocks have smaller effects on output and inflation than conventional monetary policy shocks of comparable size. One important reason for this difference is that expansionary unconventional monetary policy flattens the yield curve and thereby induces firms to borrow at longer maturities. While default rates fall on impact due to the expansionary effect of unconventional monetary policy, the subsequent build-up of long-term debt eventually leads to increased debt overhang and default risk, which dampens the increase in investment and results in a weaker stimulus of aggregate demand. In contrast, conventional monetary policy hardly affects firms' debt maturity choices. We conclude that debt maturity is key for understanding the transmission of monetary policy.

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 how debt maturity shapes firms' investment response to aggregate shocks. 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. Similarly, higher shares of maturing debt are associated with stronger investment declines during the Great Depression 1929–1933 (Benmelech et al., 2019) and during the 2010–2012 European sovereign debt crisis (Buera and Karmakar, 2022; Kalemli-Özcan et al., 2022). We complement these event studies of financial crises by providing evidence on how debt maturity shapes the investment response to monetary policy shocks.

A second related group of empirical papers studies the role of firm financing in explaining heterogeneous effects of monetary policy across firms. Important empirical covariates of firms' response to monetary policy shocks are size (Gertler and Gilchrist, 1994), leverage (Ottonello and Winberry, 2020; Anderson and Cesa-Bianchi, 2024), age (Cloyne et al., 2023), liquidity (Jeenas, 2019), the share of floating-rate debt (Ippolito et al., 2018; Gürkaynak et al., 2022), and the share of bond financing (Darmouni et al., 2021). To this literature, we contribute the result that not only the *level* of debt (or leverage) is important, but also the precise *timing* of when this debt comes due.[1]

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 do not account for differences in debt maturity across firms. Gomes et al. (2016) study the role of nominal long-term debt for monetary policy using a representative firm setup with exogenous debt maturity. Our heterogeneous firm model accounts for the distribution of debt maturity across firms. In a short-term debt model without equity issuance, Ottonello and Winberry (2020) show that firms with low net worth and high leverage react less to monetary policy shocks. By allowing firms to choose the maturity of their debt, our model studies an additional dimension of firm heterogeneity and demonstrates its quantitative importance for monetary policy.

Starting with Bernanke et al. (1999), the theoretical literature on the role of financial frictions in generating cross-sectional differences in firm-level responses to aggregate shocks includes important contributions by 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), and 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.[2]

2 Empirical Evidence

In this section, we show that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. After a tightening of monetary policy, firms with higher shares of maturing debt experience a larger fall in investment, borrowing, sales, and employment, and a larger increase in their credit spreads.

[1] Fabiani et al. (2022) show that monetary policy shocks affect the maturity structure of firms' new borrowing. Deng and Fang (2022) use Compustat data and find that firms with a higher share of long-term debt are less responsive to contractionary monetary policy. While qualitatively consistent with our findings, we show that Compustat data on debt maturity is generally not precise enough to yield robust and statistically significant results. Detailed bond-level information is crucial for precisely estimating the role of debt maturity for monetary policy.

[2] Net worth is the only financial 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), Perla et al. (2020), Gomes and Schmid (2021), Jungherr and Schott (2021), Karabarbounis and Macnamara (2021), Jungherr and Schott (2022), Jermann and Xiang (2023), Poeschl (2023), Reiter and Zessner-Spitzenberg (2023), and Xiang (2024). None of these models studies the role of debt maturity for monetary policy. Bhamra et al. (2011) examine monetary policy in an endowment economy with debt of infinite maturity. Deng and Fang (2022) study exogenous changes in the real interest rate in a partial equilibrium model with debt maturity. For continuous-time approaches to modeling debt maturity in corporate finance, see He and Xiong (2012), Admati et al. (2018), Crouzet and Tourre (2021), Dangl and Zechner (2021), DeMarzo and He (2021), or Friewald et al. (2022). Also related is the sovereign debt literature on risky long-term debt (e.g., Arellano and Ramanarayanan, 2012; Chatterjee and Eyigungor, 2012; Hatchondo et al., 2016; Aguiar et al., 2019; Bocola and Dovis, 2019; Aguiar and Amador, 2020).

2.1 Data

Our empirical analysis uses detailed bond-level information in combination with firm-level balance sheet data and high-frequency identified monetary policy shocks.

Bond maturity data. We obtain comprehensive bond-level information from the Mergent Fixed Income Securities Database (FISD). This database contains key characteristics of publicly-offered U.S. corporate bonds such as their issue date, maturity date, amount issued, principal, and coupon. It also records reductions in the amount of outstanding bonds between issuance and maturity, as well as the reason for the reduction, e.g., a call, reorganization, or default. Our empirical analysis focuses on fixed-coupon non-callable bonds, which account for the majority of the value of maturing bonds.[3] Appendix A.1 provides details on the bond-level data.

Credit spread data. We complement the FISD data with monthly bond-level credit spread data from Refinitiv. The credit spread of a bond is the difference between the bond yield and the interest rate of a U.S. treasury bond of comparable maturity. Appendix A.3 provides more details. Average credit spreads in our sample closely track the behavior of credit spreads over time documented by Gilchrist and Zakrajšek (2012), as Figure A.1 in the Appendix shows.

Firm balance sheet data. We merge the bond-level information on maturity and credit spreads with quarterly firm-level balance sheet data from Compustat. This is not a straightforward task. First, firm identifiers frequently change over time (e.g., after changes in the company name). Second, the bond debtor may change due to mergers and acquisitions. To map bonds to firms, we use information from CRSP and the Thomson Reuters M&A database. Appendix A.2 provides details on the linking of bonds and firms. We exclude firms in highly regulated sectors (public administration, finance, insurance, real estate, and utilities). We further exclude firm-quarters in which no bond is outstanding. This means that we are focusing on the subset of listed U.S. firms that issue corporate bonds. Even though this is a relatively small subset of firms, it contains the largest U.S. companies. Bond-issuing Compustat firms account for 66% of total sales in Compustat and 67% of total fixed assets.

A key variable in our empirical analysis is the maturing bond share

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

where $(\text{maturing bonds})_{it}$ is the value of bonds of firm i that mature in quarter t, and debt_{it-1} is the average total debt of firm i over the preceding four quarters from $t-1$ to $t-4$.[4]

Monetary policy shocks. We use high-frequency changes in the price of federal funds futures around FOMC meetings to identify monetary policy shocks. Our baseline shocks are

[3] We discuss the sensitivity of our results to callable and variable-coupon bonds in Section 2.5.

[4] The backward-looking moving average in the denominator helps smooth out firm-specific seasonal factors and other transitory fluctuations. See Section 2.5 for a sensitivity analysis using alternative denominators.

Table 1: Descriptive statistics

	Mean	Sd	Min	Max	Obs
Capital growth *(in log points)*	0.77	3.95	-40.52	72.81	35,545
Maturing bond share $\mathcal{M}_{it}$ *(in % of debt)*	0.19	1.77	0.00	67.18	35,545
Credit spread *(in basis points)*	222.07	222.41	5.00	3,239.30	8,425
Leverage *(debt/assets in %)*	34.02	18.52	0.00	152.04	35,545
Liquidity *(cash/assets in %)*	7.62	8.46	0.00	72.77	35,544
Total assets *(in bln. 2005 USD)*	13.50	26.35	0.03	188.97	35,545
Age *(in years)*	42.06	31.52	2.25	188.50	35,545
Sales growth *(in %)*	0.75	17.79	-90.92	95.72	35,489
Average bond maturity *(in years)*	9.00	6.19	0.08	99.83	35,502
Monetary policy shocks *(in basis points)*	-0.52	3.47	-15.27	7.87	94

Note: This table provides descriptive statistics for bond-issuing firms from 1995Q2 through 2018Q3. For details on the definition of variables, see Appendix A.3.

changes in the three-months ahead federal funds future for 30-minute event windows, as in Gertler and Karadi (2015). We exclude unscheduled FOMC meetings and conference calls. This helps to mitigate the problem that monetary surprises may convey private central bank information about the state of the economy (Meier and Reinelt, 2024). To further mitigate the central bank information problem, we follow Jarociński and Karadi (2020) and discard monetary policy shocks if the associated high-frequency change in the S&P500 moves in the same direction as the federal funds future. Finally, we aggregate the daily shocks to quarterly frequency. Daily shocks are fully assigned 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 as in Gorodnichenko and Weber (2016). The monetary policy shock series covers 1995Q2 through 2018Q3. The full time series of monetary policy shocks is shown in Figure A.1.[5]

Descriptive statistics. Table 1 reports descriptive statistics of key observables used in our empirical analysis. Our sample consists of 35,545 firm-quarter observations from 1995Q2 through 2018Q3. The primary outcome variable in our analysis is capital. We construct firm-level capital stock series by applying a perpetual inventory method to fixed assets in the balance sheet data.[6] Our empirical analysis emphasizes the role of the maturing bond share $\mathcal{M}_{it}$. Corporate bonds have long maturities with an average remaining time to maturity of 9 years, and they constitute more than 60% of total firm debt in our sample. The average value of $\mathcal{M}_{it}$ is 0.19% and the standard deviation is 1.77%. For firm-quarters in which bonds mature, the average of $\mathcal{M}_{it}$ is 7.64% and the standard deviation is 8.37%. Table 1 also documents the distribution of firm-level credit spreads and various firm-level control variables used in our analysis: leverage, liquidity, assets, sales growth, average bond

[5] We consider various alternative monetary policy shock series in Section 2.5.

[6] For details on the perpetual inventory method, see Appendix A.3. Our results are robust to using deflated fixed assets instead of using the perpetual inventory method.

maturity, and age based on WorldScope data.[7] Finally, Table 1 documents the distribution of the (baseline) monetary policy shock time series. The mean is approximately zero and the standard deviation 3.47 basis points. A one standard deviation monetary policy shock leads to a 30 basis point increase in the federal funds rate (Meier and Reinelt, 2024).

2.2 Investment response to monetary policy shocks

We use panel local projections to investigate the role of the maturing bond share for firms' investment response to monetary policy shocks.

Average response. We first estimate the average capital growth response using

$$\Delta^{h+1} \log k_{it+h} = \alpha_1^h \varepsilon_t^{\text{mp}} + \gamma_1^h \Delta\text{gdp}_{t-1} + \delta_i^h + \delta_{sq}^h + \nu_{it+h}^h, \tag{2.2}$$

for $h = 0, \ldots, 12$ 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, $\varepsilon_t^{\text{mp}}$ is the monetary policy shock, Δgdp_{t-1} is lagged GDP growth, and δ_i^h and δ_{st}^h are firm- and sector-fiscal quarter fixed effects.

Figure 2 (a) presents the estimated average investment response to a monetary policy shock. The estimated coefficients α_1^h are standardized to reflect the effect of a one standard deviation contractionary monetary policy shock. Eight quarters after the shock, the estimate $\alpha_1^8 = -1.5$ means the shock reduces capital growth on average by 1.5 percentage points. The shaded area is a 95% confidence band based on standard errors that are two-way clustered by firms and quarters.[8]

Differential response. We next present the main empirical result of the paper. We estimate the differential investment response associated with a higher maturing bond share. First, we consider the parsimonious baseline specification

$$\Delta^{h+1} \log k_{it+h} = \beta_0^h \mathcal{M}_{it} + \beta_1^h \mathcal{M}_{it} \varepsilon_t^{\text{mp}} + \beta_2^h \mathcal{M}_{it} \Delta\text{gdp}_{t-1} + \delta_i^h + \delta_{st}^h + \nu_{it+h}^h, \tag{2.3}$$

where δ_{st}^h denotes sector-quarter fixed effects. The coefficients of interest are β_1^h, which capture the differential response of capital growth for firms with a higher maturing bond share $\mathcal{M}_{it}$ at the time of a monetary policy shock.[9]

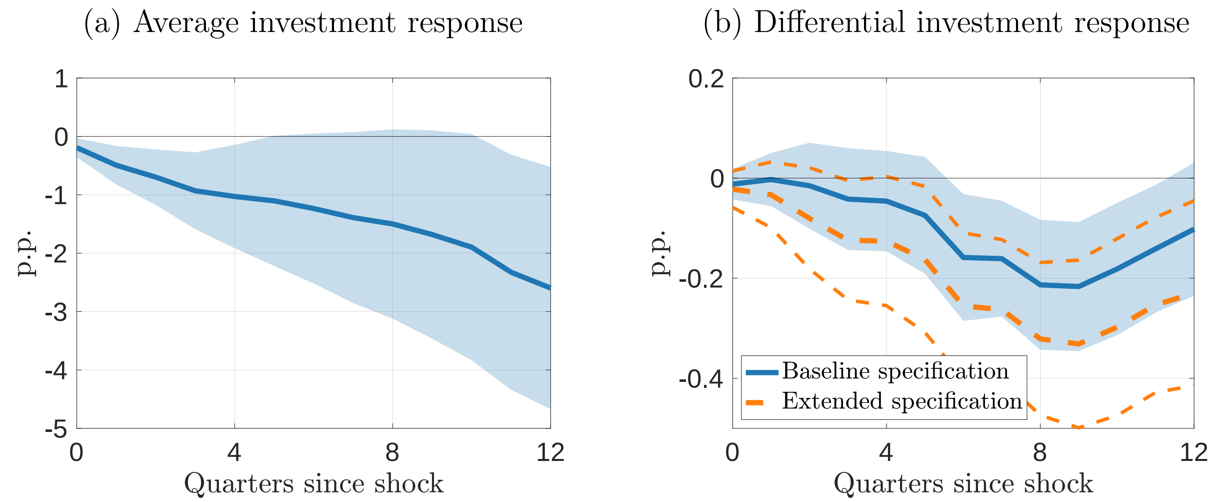
The solid line in Figure 2 (b) shows the estimated β_1^h coefficients based on (2.3). The figure shows that capital growth falls relatively more for firms that have a larger maturing bond share in the quarter of the shock. The differential response is statistically different

[7] A comparison of bond-issuing and non-issuing firms is provided in Table A.1. Bond-issuing firms are, on average, larger and older but have similar leverage as non-bond-issuing firms.

[8] Our main results are robust to using Driscoll and Kraay (1998) standard errors.

[9] The sector-quarter fixed effects δ_{st}^h *inter alia* absorb the average response to monetary policy shocks. Including firm- and sector-quarter fixed effects is not critically important for the estimated differential investment response, see Figure F.1 (a) in the Online Appendix. In addition to sector-quarter fixed effects, we include the interaction between $\mathcal{M}_{it}$ and Δgdp_{t-1} to control for differences in capital growth cyclicality across firms and time. For our main findings, including this interaction marginally lowers the standard errors of β_1^h but is not important for our conclusions.

Figure 2: Investment response to a contractionary monetary policy shock



Note: Panel (a) shows the estimated α_1^h coefficients using the local projection in equation (2.2). The estimates are standardized to show the response of capital growth to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$. Panel (b) shows the estimated β_1^h coefficients using the baseline specification in equation (2.3) and the extended specification in equation (2.4). The estimates are standardized to show the differential response of capital growth to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

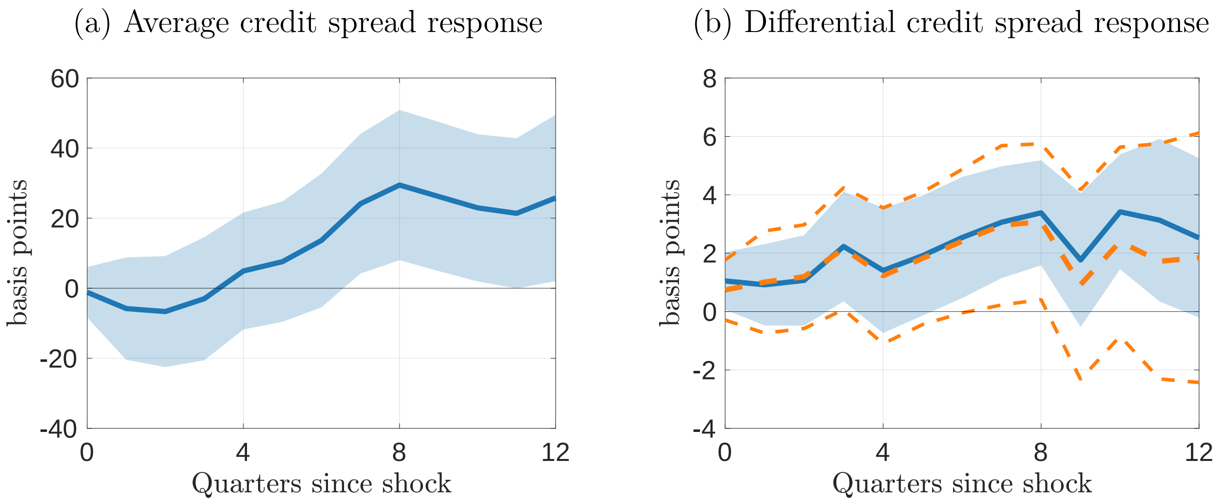
from zero at the 5% significance level at horizons between six and eleven quarters after the shock. The estimated coefficients β_1^h are standardized to reflect the differential response of firms that have a one standard deviation higher $\mathcal{M}_{it}$ at the time of a one standard deviation contractionary monetary policy shock. Eight quarters after the shock, the estimate $\beta_1^8 = -0.21$ means an additional reduction of capital growth by 0.21 percentage points. Given an annual investment-capital ratio of 10%, and thus an investment-capital ratio of 22.5% over 9 quarters, the decline in capital growth by 0.21 percentage points translates into roughly 1% lower investment between quarter $t-1$ and quarter $t+8$.

In principle, the results from the baseline specification (2.3) may be related to permanent firm characteristics or other time-varying observables beyond the maturing bond share. The extended specification in (2.4) below addresses this point. We find that the results are highly robust to focusing only on within-firm variation in $\mathcal{M}_{it}$ over time, and to including a large set of time-varying firm-level control variables. Formally, we estimate:

$$\begin{aligned}\Delta^{h+1}\log k_{it+h} = {}& \beta_0^h\left(\mathcal{M}_{it}-\overline{\mathcal{M}}_i\right)+\beta_1^h\left(\mathcal{M}_{it}-\overline{\mathcal{M}}_i\right)\varepsilon_t^{\mathrm{mp}}+\beta_2^h\left(\mathcal{M}_{it}-\overline{\mathcal{M}}_i\right)\Delta\mathrm{gdp}_{t-1}\\ &+\Gamma_0^h Z_{it-1}+\Gamma_1^h Z_{it-1}\varepsilon_t^{\mathrm{mp}}+\Gamma_2^h Z_{it-1}\Delta\mathrm{gdp}_{t-1}+\delta_i^h+\delta_{st}^h+\nu_{it+h}^h, \qquad (2.4)\end{aligned}$$

where $\mathcal{M}_{it}-\overline{\mathcal{M}}_i$ is the deviation of $\mathcal{M}_{it}$ from its firm-specific sample average $\overline{\mathcal{M}}_i$, and Z_{it-1} is a vector of control variables. Z_{it-1} includes leverage, liquidity, log real total assets, firm age, real sales growth, and the average maturity of outstanding bonds (all in deviation from their respective firm-specific averages).

Figure 3: Credit spread response to a contractionary monetary policy shock



Note: Panels (a) and (b) are analogous to panels (a) and (b) of Figure 2 when the left-hand side of equations (2.2), (2.3), and (2.4) is replaced by changes in credit spreads, respectively.

The dashed line in Figure 2 (b) shows the estimated β_1^h coefficients based on the extended specification in (2.4). The estimates broadly conform with the estimates in the baseline specification. The response of capital growth is more negative for firms that have a larger share of maturing bonds relative to their firm-level average maturing bond share, and conditional on other control variables. Compared to the baseline, the extended specification yields estimates that tend to be larger (e.g., $\beta_1^8 = -0.32$) and more precisely estimated.[10] Given the average capital response at $h = 8$ in panel (a), a one standard deviation higher maturing bond share is thus associated with a capital response that is amplified by 13–20% (depending on whether one uses the estimates from the baseline or the extended specification).

2.3 Credit spread response to monetary policy shocks

Given that credit spreads are an important component of firms' cost of financing investment, we now study whether the maturing bond share is also associated with differences in firms' credit spread response to monetary policy shocks. We replace the left-hand side of equations (2.2)–(2.4) by the change in the firm-specific credit spread between period $t-1$ and $t+h$. To control for the large spike in credit spreads during the Great Recession (Figure A.1), we include a dummy variable for the four quarters 2008Q3–2009Q2, which is interacted with $\varepsilon_t^{\mathrm{mp}}$ and $\Delta \mathrm{gdp}_{t-1}$, respectively.[11]

Figure 3 (a) presents the estimated average credit spread response to a one standard deviation contractionary monetary policy shock. At horizons around eight quarters after the

[10] For a full list of coefficient estimates for the baseline and the extended specification, see Online Appendix Tables F.1 and F.2.

[11] Whereas including sector-quarter fixed effects is not crucial, the firm fixed effects are important for detecting differences in credit spread responses across firms, see Figure F.1 (b) in the Online Appendix.

shock, the response is significant at the 5% level. We estimate $\alpha_1^8 = 29$ which means that eight quarters after the shock credit spreads have increased on average by 29 basis points. Figure 3 (b) shows the differential credit spread response associated with the maturing bond share. In both the baseline and the extended specification, we find that credit spreads increase by more for firms with a larger maturing bond share. At a two-year horizon, the differential increase in the credit spread is about 3 basis points. The two-year differential response is statistically different from zero at a five percent significance level.

2.4 Response of debt, sales, and other inputs

We further explore whether the maturing bond share also predicts differences in the responses of other firm observables besides investment and credit spreads. Specifically, we estimate the differential responses of firm-level debt, sales, employment, and cost of goods sold using the local projection in equation (2.4).[12]

Figure 4 (a) shows the differential debt response. After a contractionary monetary policy shock, debt grows by less for firms with a larger maturing bond share at the time of the shock. At a two-year horizon, the differential decline in debt growth is 0.40 p.p. This difference is statistically different from zero at significance levels between five and ten percent at horizons between three and eight quarters after the shock. The finding suggests that in periods of tighter monetary policy firms with maturing bonds refinance a smaller fraction of their maturing bonds.

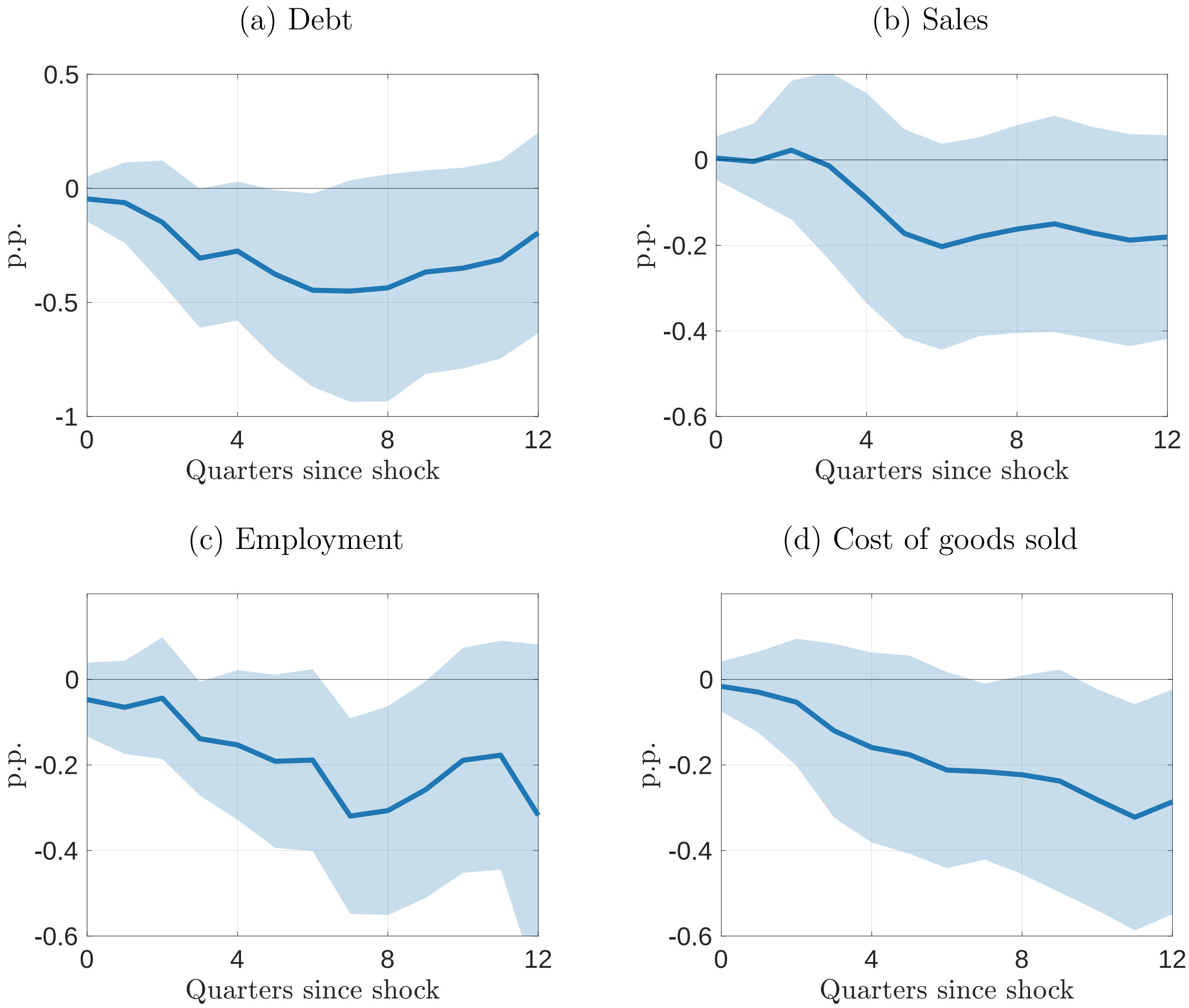
Panel (b) shows that sales growth declines by more for firms with a larger maturing bond share. A caveat here is that the differential sales response is estimated relatively imprecisely. Panels (c) and (d) show the differential responses of employment and cost of goods sold, where the latter measures total expenses for materials, intermediate inputs, labor, and energy. Both employment and cost of goods sold decline by more if $\mathcal{M}_{it}$ is larger at the time of the monetary policy shock. These estimates are statistically different from zero at significance levels between five and ten percent around eight quarters after the shock. Overall, the evidence in Figure 4 shows that a high maturing bond share not only correlates with differences in the investment and credit spread responses, but also with the responses of other firm-level outcomes.

2.5 Additional results

Monetary policy shocks. Our main findings are robust to a variety of alternative monetary policy shock series. Our baseline shock series is based on changes in the three-months-ahead federal funds future around regular FOMC meetings with sign restrictions following Jarociński and Karadi (2020). In addition, we consider the shocks in Miranda-Agrippino and Ricco (2021) that control for Greenbook forecasts, i.e., partially private central bank information, and the shocks in Bauer and Swanson (2023) that control for public information preceding FOMC meetings, see Figure B.2.

[12] Debt, sales, and cost of goods sold are backward-looking four-quarter moving averages to smooth out firm-specific seasonal factors and other transitory fluctuations. Annual employment data is imputed at quarterly frequency using quarterly data on cost of goods sold. For further details, see Appendix A.3. Figure B.1 in the Appendix provides the corresponding estimates for the baseline specification in (2.3).

Figure 4: Differential response associated with higher maturing bond share



Note: The figure shows the estimated β_1^h coefficients using the extended specification in equation (2.4), with the left-hand side being log changes in debt, sales, employment, and cost of goods sold, respectively. The β_1^h estimates are standardized to show the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Great Recession and ZLB. We study the sensitivity of our results with respect to different time periods. Panels (a) and (b) of Figure B.3 show results for investment and credit spreads over a shortened time sample which only includes observations before 2008Q2. These results show that our main findings are robust to excluding the time period after the Great Recession, largely characterized by a binding zero lower bound. Panel (c) of Figure B.3 excludes only the Great Recession period 2008Q3–2009Q2. Overall, these results show that our findings are robust to varying the time sample of the analysis. With respect to the estimated differential credit spread response, panel (d) highlights the importance of the Great Recession dummy in the four quarters 2008Q3–2009Q2.

Firms without bonds. Our empirical analysis focuses on bonds rather than loans because bonds and loans differ in several important aspects. In Appendix Figure B.4 we show that non-bond-issuing firms are more responsive to monetary policy shocks than bond-issuing firms without maturing bonds. This is consistent with the fact that firms without access to the bond market rely on bank loans that often feature floating interest rates (Ippolito et al., 2018) and are subject to frequent adjustments of other loan characteristics (Roberts and Sufi, 2009) allowing a quick response to changes in the macroeconomic environment and providing less insurance against monetary policy shocks. A caveat is that the investment response of firms without bonds is rather imprecisely estimated. This may reflect highly heterogeneous responses within the broad segment of firms without bonds.

Callable and variable-coupon bonds. Our main results are based on a maturing bond share which is computed using non-callable fixed-coupon bonds. Panel (a) of Figure B.5 shows differential investment responses when we include the maturing amount of both callable and non-callable bonds in the construction of the maturing bond share. Bonds which are called before their stated maturity do not enter $\mathcal{M}_{it}$. The estimates are highly similar to our main results. Panel (b) presents estimates when $\mathcal{M}_{it}$ is constructed using only callable bonds. The estimates become insignificant. One potential explanation are selection effects due to firms' decision whether to call a bond before the stated maturity. We also consider variable-coupon bonds. Panel (c) of Figure B.5 shows results when considering the maturing amounts of both variable-coupon and fixed-coupon bonds. Again, our main results remain robust. Panel (d) displays estimates using a maturing bond share which considers only variable-coupon bonds. The results are insignificant. This is consistent with the idea that non-maturing variable-coupon bonds provide less insurance against changes in interest rates than non-maturing fixed coupon bonds. Another potential explanation is a lack of statistical power; we observe four times fewer variable-coupon bonds than fixed-coupon bonds in our sample. Figure B.6 repeats the corresponding exercises with credit spreads as left-hand side variable. As in the case of investment, our main results on the differential response of credit spreads change considerably if we restrict the bond sample to callable or variable-coupon bonds.

Measurement of maturing debt. Our empirical analysis uses detailed FISD bond-level information which allows us to measure the amount of maturing bonds in a given quarter. To highlight the importance of using precise maturity data, we construct the shares of bonds maturing in the next *year*, i.e., between quarters t and $t+3$. Figure B.7 shows that the resulting point estimates are similar to the baseline, but smaller in magnitude and less precisely estimated. The correlation of the credit spread response with this alternative maturing bond share is statistically insignificant. We further study the capital growth and credit spread responses when replacing $\mathcal{M}_{it}$ by $\mathcal{M}_{it-1}$, the maturing bond share in the quarter preceding the monetary policy shock. Figure B.8 shows that the associated differential responses are small and insignificant. Finally, we repeat our empirical analysis using maturity data from Compustat. In contrast to FISD data, Compustat only provides information on maturing debt over a twelve-month window and does not distinguish between bonds and bank loans. In Figure B.9, we show that the differential investment and credit spread responses associated with the Compustat share of total maturing debt within the next twelve months are very imprecisely estimated. Taken together, these findings show the benefit of using FISD data to precisely measure bond maturity.[13] Our baseline measure of the maturing bond share in equation (2.1) defines $\mathcal{M}_{it}$ as the ratio of maturing bonds over the backward-looking four-quarter average of total debt. We consider three alternative measures, for which we replace total debt in the denominator with capital, sales, or assets. Panels (a)–(c) of Figures B.10 and B.11, respectively, show the associated β_1^h estimates for investment and credit spreads. In panel (d), we show the β_1^h estimates when using as denominator the simple lagged level of debt, capital, sales, and assets, respectively. Our main finding is robust to these alternative definitions of $\mathcal{M}_{it}$.

Dummy specifications. Our baseline specification includes a linear interaction between monetary policy shocks and the maturing bond share. Alternatively, we consider a modification of (2.3), in which monetary policy shocks are interacted with a dummy variable that is one if the maturing bond share is above a certain threshold. As thresholds, we consider 0% and 15%. Figure B.12 shows that this leads to significant differential responses. We further estimate the average responses of observations below and above the threshold. Figure B.13 confirms our main finding. A maturing bond share above either threshold is associated with a negative investment response to a contractionary monetary policy shock, while a maturing bond share below the thresholds is not associated with a significant change in capital. Differences in the average credit spread response are substantial when using 15% as threshold for the maturing bond share, but barely present for the 0%-threshold.[14]

Conditioning on firm size and age. Our extended specification (2.4) controls for firm size and age (among other covariates) in a linear way. In addition, we estimate the differential investment and credit spread responses when allowing for size- or age-specific differences in the association with the maturing bond share. Figure B.14 and B.15 show that even within age and size groups, a higher maturing bond share is associated with a stronger investment response to monetary policy shocks. While the estimates are more precise within the samples of older and larger firms and only marginally significant for younger and smaller firms, the point estimates across groups align with our baseline results.

3 Model

The previous section established empirically that firms' investment response to monetary policy shocks is larger when a higher fraction of their debt matures. To understand the

[13] Deng and Fang (2022) estimate the differential investment response associated with long-term debt shares using Compustat data. Their empirical specification differs from ours along various dimensions including the measure of investment, the monetary policy shock, the choice of fixed effects, and the set of control variables. While their results are qualitatively in line with our findings, our empirical exercise using the Compustat share of total maturing debt suggests that detailed bond-level information is crucial for precisely estimating the role of debt maturity for monetary policy.

[14] Note that in Figure B.12 (b) we estimate significant differences in the credit spread response associated with the 0%-threshold. This suggests an important role of the sector-time fixed effect which is absent from the specification in Figure B.13.

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.

At the heart of the model is a continuum of heterogeneous production 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 future leverage and default risk.

In addition, the economy consists of retail firms, capital producers, a representative household, and a government. Retail firms buy undifferentiated goods from production firms, turn them into differentiated retail goods and sell them to a final goods sector. 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

A production firm i enters period t with productivity z_{it} and capital k_{it}. It chooses labor l_{it} to produce an amount y_{it} of undifferentiated output:

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

Earnings before interest and taxes are

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

where p_t is the price of undifferentiated output, w_t is the wage rate, δ is the depreciation rate, Q_t is the price of capital goods, and f is a fixed cost of production. All prices (p_t, w_t, Q_t) are expressed in terms of time t final goods. The firm-specific capital quality shock ε_{it} is i.i.d. with mean zero and continuous probability distribution $\varphi(\varepsilon_{it}|z_{it})$. The shock is realized 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.

After the realization of ε_{it}, firms decide whether to pay current debt obligations. There are two types of debt instruments.

Definition. Short-term debt. A short-term bond is a promise to pay one unit of currency in period t together with a nominal coupon c. The quantity of nominal short-term bonds outstanding at the beginning of period t is B_{it}^{S}.

Definition. Long-term debt. A long-term bond is a promise to pay a fraction $\gamma \in (0,1)$ of the principal in period t together with a nominal coupon c. In period $t+1$, a fraction $1-\gamma$ of the bond remains outstanding. Firms pay the fraction γ of the remaining principal together with a coupon $(1-\gamma)c$, and so on. The quantity of nominal long-term bonds outstanding at the beginning of period t is B_{it}^{L}.

This computationally tractable specification of long-term debt goes back to Leland (1994). Long-term debt payments decay geometrically over time. The maturity parameter γ controls the speed of decay. In the following, we use the real face value of short-term debt and long-term debt: $b_{it}^S \equiv B_{it}^S/P_{t-1}$ and $b_{it}^L \equiv B_{it}^L/P_{t-1}$, where P_{t-1} denotes the price of final goods in period $t-1$.

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

$$q_{it} = Q_t k_{it} - \frac{b_{it}^S}{\pi_t} - \frac{\gamma b_{it}^L}{\pi_t} + (1-\tau)\left[A_{it}k_{it}^{\alpha} + (\varepsilon_{it} - \delta)Q_t k_{it} - f - \frac{c(b_{it}^S + b_{it}^L)}{\pi_t}\right], \tag{3.3}$$

where the real face value of nominal short-term and long-term debt depends on (gross) inflation $\pi_t \equiv P_t/P_{t-1}$. Revenue net of wage payments is $A_{it}k_{it}^{\alpha} = \max_{l_{it}}\{p_t y_{it} - w_t l_{it}\}$, with $A_{it} = A(z_{it}, p_t, w_t)$ and $\alpha \in (0,1)$ (see Appendix C for details). The fact that coupon payments are tax deductible lowers total tax payments by the amount $\tau c(b_{it}^S + b_{it}^L)/\pi_t$. This is the benefit of debt. The downside is that firms cannot commit to paying their debt obligations.

Definition. Default. 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 only recover a fraction $1-\xi$ of firm assets.

A defaulting firm exits the economy. In addition, there is exogenous exit with probability κ. In this case, the firm repurchases any outstanding long-term debt at market value and pays out all remaining firm assets to shareholders. Continuing firms draw next period's productivity level z_{it+1} from the probability distribution $\Pi(z_{it+1}|z_{it})$.

At the end of period t, next period's capital stock k_{it+1} is financed through retained earnings, outside equity, and by selling new short- and long-term bonds. A firm that sells new short-term bonds of (real) face value b_{it+1}^S at price p_{it}^S raises $b_{it+1}^S p_{it}^S$ on the bond market. Selling new long-term bonds of real value $b_{it+1}^L - (1-\gamma)b_{it}^L/\pi_t$ at price p_{it}^L raises $(b_{it+1}^L - (1-\gamma)b_{it}^L/\pi_t)p_{it}^L$. Accordingly, the market value of next period's capital is given by the cash flow constraint

$$Q_t k_{it+1} = q_{it} + e_{it} + b_{it+1}^S p_{it}^S + \left(b_{it+1}^L - \frac{(1-\gamma)b_{it}^L}{\pi_t}\right)p_{it}^L, \tag{3.4}$$

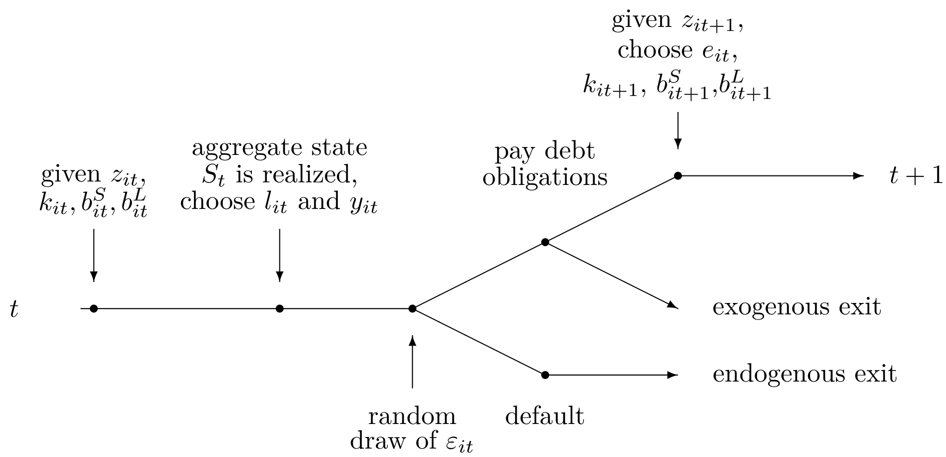
where e_{it} denotes net issuance of outside equity. A negative value of e_{it} indicates dividend payments to a firm's shareholders. Whereas dividend payouts are costless, issuing equity and debt is costly.[15]

Definition. Equity issuance cost. Firms pay a quadratic issuance cost whenever they raise outside equity. Net dividend payouts ($e_{it} < 0$) are costless. Equity issuance costs $G(e_{it})$ are given by

$$G(e_{it}) = \nu \cdot (\max\{e_{it}, 0\})^2. \tag{3.5}$$

[15]Equity and debt issuance costs capture underwriting fees charged by investment banks to firms. Equity issuance costs may also capture costs from adverse selection on the stock market (*cf.* Myers and Majluf, 1984). Altınkılıç and Hansen (2000) provide empirical evidence of increasing marginal issuance costs of equity and debt.

Figure 5: Timing



Definition. Debt issuance cost. Firms pay a quadratic issuance cost for selling new short- and long-term debt. Repurchasing outstanding long-term debt (by choosing $b^L_{it+1} < (1-\gamma)b^L_{it}/\pi_t$) is costless. Total debt issuance costs $H(b^S_{it+1}, b^L_{it+1}, b^L_{it}/\pi_t)$ are therefore

$$H\left(b^S_{it+1}, b^L_{it+1}, \frac{b^L_{it}}{\pi_t}\right) = \eta \cdot \left(b^S_{it+1} + \max\left\{b^L_{it+1} - \frac{(1-\gamma)b^L_{it}}{\pi_t}, 0\right\}\right)^2. \tag{3.6}$$

Short-term debt needs to be constantly rolled over which implies high issuance costs. 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. This saves debt issuance costs.

Value functions. The timing of the firm problem is summarized in Figure 5. A firm enters period t with an idiosyncratic state $x_{it} \equiv (z_{it}, k_{it}, b^S_{it}, b^L_{it})$. Given the aggregate state S_t (defined below), it chooses labor demand l_{it} and produces output y_{it}. After the idiosyncratic capital quality shock ε_{it} is realized, the firm decides whether to default. Negative realizations of ε_{it} can generate losses that absent default must be borne by shareholders through lower dividends or higher equity injections. Limited liability creates an upper bound on the losses that shareholders are willing to bear. Let $W_t(x_{it}, \varepsilon_{it}; S_t)$ denote shareholder value conditional on servicing all current debt obligations. Default is optimal if and only if $W_t(x_{it}, \varepsilon_{it}; S_t) < 0$. After the realization of ε_{it}, shareholder value is therefore given by

$$V_t(x_{it}, \varepsilon_{it}; S_t) = \max\Big\{0, W_t(x_{it}, \varepsilon_{it}; S_t)\Big\}. \tag{3.7}$$

The value of servicing current debt obligations $W_t(x_{it}, \varepsilon_{it}; S_t)$ includes the possibility of exogenous exit:

$$W_t(x_{it}, \varepsilon_{it}; S_t) = (1-\kappa)\mathbb{E}_{z_{it+1}|z_{it}} W^C_t(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) + \kappa\left(q_{it} - \frac{(1-\gamma)b^L_{it}}{\pi_t}\mathbb{E}_{z_{it+1}|z_{it}} p^L_{it}\right) \tag{3.8}$$

With probability κ, a non-defaulting firm exits exogenously. In this case, it repurchases all outstanding long-term debt and pays out remaining firm assets $q_{it} - ((1-\gamma)b^L_{it}/\pi_t)p^L_{it}$ to shareholders. With probability $1-\kappa$, the firm stays active and chooses e_{it}, k_{it+1}, b^S_{it+1}, b^L_{it+1} with associated continuation value $W^C_t(x_{it}, \varepsilon_{it}, z_{it+1}; S_t)$:

$$W^C_t(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) = \max_{\substack{e_{it} \geq \underline{e}, k_{it+1}, \\ b^S_{it+1} \geq 0, b^L_{it+1} \geq 0}} -e_{it} - G(e_{it}) - H\left(b^S_{it+1}, b^L_{it+1}, \frac{b^L_{it}}{\pi_t}\right) + \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \int_{\varepsilon_{it+1}} V_{t+1}(x_{it+1}, \varepsilon_{it+1}; S_{t+1}) \varphi(\varepsilon_{it+1}|z_{it+1}) d\varepsilon_{it+1} \quad (3.9)$$

Because all firms are owned by the representative household, firms optimize using the household's stochastic discount factor $\Lambda_{t,t+1}$. In (3.9), equity issuance e_{it} is pinned down through the cash flow constraint (3.4): $e_{it} = Q_t k_{it+1} - q_{it} - b^S_{it+1} p^S_{it} - (b^L_{it+1} - (1-\gamma) b^L_{it}/\pi_t) p^L_{it}$. A firm's choice of e_{it} is bounded from below: $e_{it} \geq \underline{e}$, where $\underline{e} < 0$ sets an upper limit for dividend payments.[16]

3.2 Creditors

A firm's choice of capital k_{it+1}, short-term debt b^S_{it+1}, and long-term debt b^L_{it+1} crucially depends on the two bond prices p^S_{it} and p^L_{it} set by creditors. Low bond prices imply high credit spreads which increase a firm's cost of capital. If a firm does not default in period $t+1$, short-term creditors receive a real amount $(1+c)b^S_{it+1}/\pi_{t+1}$, and long-term creditors are paid $(\gamma + c)b^L_{it+1}/\pi_{t+1}$. In case of default, the value of firm assets left for creditors is

$$\underline{q}_{it+1} \equiv \max\{0, Q_{t+1}k_{it+1} + (1-\tau)\left[p_{t+1}y_{it+1} - w_{t+1}l_{it+1} + (\varepsilon_{it+1} - \delta)Q_{t+1}k_{it+1} - f\right]\}. \quad (3.10)$$

At this point, creditors liquidate the defaulting firm's assets and receive $(1-\xi)\underline{q}_{it+1}$.

Creditors are perfectly competitive. Because ultimately all debt is held by the representative household, bonds are priced using the stochastic discount factor $\Lambda_{t,t+1}$. Short- and long-term debt have equal seniority. The break-even price of nominal short-term debt is therefore

$$p^S_{it} = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \int_{\varepsilon_{it+1}} \left[(1 - \mathcal{D}_{it+1})\frac{1+c}{\pi_{t+1}} + \mathcal{D}_{it+1}\frac{(1-\xi)\underline{q}_{it+1}}{b^S_{it+1} + b^L_{it+1}}\right] \varphi(\varepsilon_{it+1}|z_{it+1}) d\varepsilon_{it+1}, \quad (3.11)$$

where the indicator function $\mathcal{D}_{it+1}$ is one if and only if the firm defaults in period $t+1$, i.e., if $W_{t+1}(x_{it+1}, \varepsilon_{it+1}; S_{t+1}) < 0$. The probability of default in $t+1$ depends on the firm's future state $x_{it+1} = (z_{it+1}, k_{it+1}, b^S_{it+1}, b^L_{it+1})$. Low values of capital k_{it+1} and high values of short-term debt b^S_{it+1} and long-term debt b^L_{it+1} tend to increase the risk of default. Whereas the price of short-term debt p^S_{it} only depends on the probability distribution of variables in

[16] If the stock of previously issued outstanding debt $(1-\gamma)b^L_{it}/\pi_t$ is sufficiently large, a 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. Firm debt cannot be negative ($b^S_{it+1} \geq 0$, $b^L_{it+1} \geq 0$), i.e., we do not allow firms to accumulate financial savings.

$t+1$, today's price of long-term debt p^L_{it} also depends on the future price of long-term debt:

$$p^L_{it} = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\int_{\varepsilon_{it+1}}\Bigg[(1-\mathcal{D}_{it+1})\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z_{it+2}|z_{it+1}}g_{t+1}(x_{it+1},\varepsilon_{it+1},z_{it+2};S_{t+1})}{\pi_{t+1}} + \mathcal{D}_{it+1}\frac{(1-\xi)\underline{q}_{it+1}}{b^S_{it+1}+b^L_{it+1}}\Bigg]\varphi(\varepsilon_{it+1}|z_{it+1})d\varepsilon_{it+1}. \tag{3.12}$$

If the firm does not default in period $t+1$, it repays a fraction γ of outstanding long-term debt plus the coupon c. A fraction $1-\gamma$ of debt remains outstanding at price $p^L_{it+1} = g_{t+1}(x_{it+1},\varepsilon_{it+1},z_{it+2};S_{t+1})$. Because this price depends on future firm behavior, it is a function of the future state of the firm.

Creditors price riskless debt analogously. The price P^S_{rt} of riskless nominal short-term debt and the associated nominal interest rate i_t are

$$P^S_{rt} = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\frac{1+c}{\pi_{t+1}} \qquad \text{and} \qquad i_t = \frac{1+c}{P^S_{rt}} - 1. \tag{3.13}$$

The price P^L_{rt} of riskless long-term debt and the nominal long-term interest rate i^L_t are

$$P^L_{rt} = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\frac{\gamma + c + (1-\gamma)P^L_{rt+1}}{\pi_{t+1}} \qquad \text{and} \qquad i^L_t = \frac{\gamma + c + (1-\gamma)P^L_{rt}}{P^L_{rt}} - 1. \tag{3.14}$$

3.3 Retail firms

The remainder of the model setup closely follows Bernanke et al. (1999) and Ottonello and Winberry (2020). Nominal rigidities are introduced through a unit mass of retail firms which buy undifferentiated goods from production firms and sell them as differentiated varieties to the final goods sector. Retail firms are subject to Rotemberg-style quadratic costs of price adjustment. The resulting New Keynesian Phillips Curve is

$$1 - \rho\,(1-p_t) - \lambda\pi_t(\pi_t - 1) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{Y_t}\pi_{t+1}(\pi_{t+1}-1) = 0, \tag{3.15}$$

where $\rho > 1$ is the elasticity of substitution over differentiated varieties, and λ is a price adjustment cost parameter (see Appendix C for a detailed derivation). Equation (3.15) 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 (3.15). A higher value of the price adjustment cost parameter λ dampens the contemporary response of inflation.

3.4 Capital producers

There is a representative capital good producer who adjusts the aggregate stock of capital using an amount I_t of final goods with decreasing returns (determined by $\phi > 1$):

$$K_{t+1} = \Phi\left(\frac{I_t}{K_t}\right)K_t + (1-\delta)K_t, \quad \text{where} \quad \Phi\left(\frac{I_t}{K_t}\right) = \frac{\delta^{\frac{1}{\phi}}}{1-\frac{1}{\phi}}\left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\phi}} - \frac{\delta}{\phi - 1}. \tag{3.16}$$

Profit maximization pins down the price of capital goods:

$$Q_t = \left(\frac{\frac{I_t}{K_t}}{\delta} \right)^{\frac{1}{\phi}} \tag{3.17}$$

3.5 Government and monetary policy

The government levies 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 i_t according to the Taylor rule:

$$1 + i_t = \frac{1}{\beta} \pi_t^{\varphi^{\mathrm{mp}}} e^{\eta_t^{\mathrm{mp}}}, \tag{3.18}$$

where $\beta \in (0, 1)$ is the representative households' discount rate. The parameter φ^{mp} is the inflation weight of the reaction function, and the stochastic component η_t^{mp} is driven by monetary shocks $\varepsilon_t^{\mathrm{mp}}$ following

$$\eta_t^{\mathrm{mp}} = \rho^{\mathrm{mp}} \eta_{t-1}^{\mathrm{mp}} + \varepsilon_t^{\mathrm{mp}}, \quad \text{with} \quad \varepsilon_t^{\mathrm{mp}} \sim N(0, \sigma_{\mathrm{mp}}^2). \tag{3.19}$$

3.6 Households

We close the model by introducing a representative household that owns all equity and debt claims issued by production 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. It 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

$$\log(C_t) - \frac{L_t^{1+\theta}}{1+\theta}, \quad \text{with} \quad \theta > 0. \tag{3.20}$$

The stochastic discount factor of the representative household is

$$\Lambda_{t,t+1} = \beta \frac{C_t}{C_{t+1}}. \tag{3.21}$$

3.7 General equilibrium

A firm maximizes shareholder value (3.9) subject to the firm's cash flow constraint (3.4) and creditors' bond pricing equations (3.11) and (3.12). Because we assume that firms cannot commit to future actions, they must take their own future behavior as given and choose today's policy as a best response. In other words, firms play a game against their future selves. As in Klein et al. (2008), we restrict attention to the Markov perfect equilibrium, i.e., we consider policy rules which are functions of the payoff-relevant state variables. The time-consistent policy is a fixed point in which future firm policies coincide with today's firm policies.

The value function $W_t^C(x_{it}, \varepsilon_{it}, z_{it+1}; S_t)$ can be computed recursively, where W_t^C depends on the firm's idiosyncratic state $x_{it} = (z_{it}, k_{it}, b_{it}^S, b_{it}^L)$, the realization of the firm's capital quality shock ε_{it}, next period's firm productivity z_{it+1}, and the aggregate state S_t. Time subscripts are dropped in the recursive formulation. At the end of each period, the firm chooses a policy vector $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$ which solves

$$W^C(x, \varepsilon, z'; S) = \max_{\phi(x,\varepsilon,z';S)=\left\{\substack{e \geq \underline{e}, k', \\ b^{S'} \geq 0, \\ b^{L'} \geq 0}\right\}} -e - G(e) - H\left(b^{S'}, b^{L'}, \frac{b^L}{\pi}\right) + \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} V(x', \varepsilon'; S')\varphi(\varepsilon'|z')d\varepsilon' \tag{3.22}$$

subject to:

$$e = Qk' - q(x, \varepsilon; S) - b^{S'}p^S - \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)p^L$$

$$q(x, \varepsilon; S) = Qk - \frac{b^S}{\pi} - \frac{\gamma b^L}{\pi} + (1-\tau)\left[Ak^\alpha + (\varepsilon - \delta)Qk - f - \frac{c(b^S + b^L)}{\pi}\right]$$

$$V(x', \varepsilon'; S') = \max\left\{0, W(x', \varepsilon'; S')\right\}$$

$$W(x', \varepsilon'; S') = (1-\kappa)\mathbb{E}_{z''|z'}W^C(x', \varepsilon', z''; S') + \kappa\left(q(x', \varepsilon'; S') - \frac{(1-\gamma)b^{L'}}{\pi'}\mathbb{E}_{z''|z'}p^{L'}\right),$$

where bond prices p^S and p^L are determined by (3.11) and (3.12). Given a firm policy $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$, the continuum of production firms is characterized by the distribution $\mu(x)$ with law of motion

$$\mu(x') = \int_x \int_\varepsilon \mathcal{I}(k', b^{S'}, b^{L'}, x, \varepsilon, z'; S)\left[1 - \mathcal{D}(x, \varepsilon; S)\right]\varphi(\varepsilon|z)d\varepsilon(1-\kappa)\Pi(z'|z)\mu(x)dx + \mathcal{E}(x'; S), \tag{3.23}$$

where the indicator function $\mathcal{I}(k', b^{S'}, b^{L'}, x, \varepsilon, z'; S) = 1$ if $\{k', b^{S'}, b^{L'}\}$ corresponds to the firm's choice $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$. Firms exit the economy endogenously because of default, $\mathcal{D}(x, \varepsilon; S) = 1$, and exogenously at rate κ. The function $\mathcal{E}(x'; S)$ is equal to the mass of entrants starting in state x'. The total mass of firms is always equal to one because in each period the total mass of entrants equals the time-varying mass of exiting firms.

Definition. Given the aggregate state $S = (\mu(x), \eta^{\text{mp}})$, the equilibrium consists of *(i)* value functions $V(x, \varepsilon; S)$, $W(x, \varepsilon; S)$, and $W^C(x, \varepsilon, z'; S)$, *(ii)* a policy vector $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$, *(iii)* bond price functions p^S and p^L, *(iv)* household consumption C and aggregate labor supply L, *(v)* aggregate prices p, Q, w, *(vi)* a nominal interest rate i, inflation π, a real interest rate r, and a stochastic discount factor Λ, such that:

1. *Production firms:* The value functions $V(x, \varepsilon; S)$, $W(x, \varepsilon; S)$, $W^C(x, \varepsilon, z'; S)$, and policy functions $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$ solve the firm problem (3.22).

2. *Creditors:* p^S and p^L are given by (3.11) and (3.12).

3. *Retail firms:* p and π follow the New Keynesian Phillips curve (3.15).

4. *Capital producers:* The price of capital Q is given by (3.17).

5. *Households:* The representative household chooses C and L optimally: $(1+r)^{-1} = \mathbb{E}_{S'|S}\Lambda$, $(1+i)^{-1} = \mathbb{E}_{S'|S}\Lambda/\pi'$, and $w = L^\theta C$.

6. *Government:* The nominal interest rate i follows the Taylor rule (3.18).

7. *Firm distribution:* $\mu(x') = \Gamma(\mu(x); S)$ as in (3.23).

8. *Market clearing:* The labor market, the final goods market, and the market for capital goods clear (see Appendix C for details).

3.8 First-order conditions

The problem of a production firm (3.22) can be expressed in terms of three choice variables: the scale of production k' and the amounts of short-term debt $b^{S'}$ and long-term debt $b^{L'}$. We characterize the equilibrium behavior of firms in terms of the three associated first-order conditions. For simplicity, we discuss these optimality conditions assuming that there is no exogenous exit ($\kappa = 0$). See Online Appendix G for the general case and detailed derivations.

Capital. The first-order condition with respect to capital k' is

$$\begin{aligned}&\left[1+\frac{\partial G(e)}{\partial e}\right]\left[-Q+b^{S'}\frac{\partial p^S}{\partial k'}+\left(b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}\right]\\&+\mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}[1-\mathcal{D}(x',\varepsilon';S')]\frac{\partial q(x',\varepsilon';S')}{\partial k'}\mathbb{E}_{z''|z'}\left(1+\frac{\partial G(e')}{\partial e'}\right)\varphi(\varepsilon'|z')d\varepsilon'=0.\end{aligned} \tag{3.24}$$

This equation can be decomposed into the costs and benefits of capital. For given choices of $b^{S'}$ and $b^{L'}$, an increase in capital k' must be financed through an equity injection into the firm (see equation 3.4). The marginal cost of capital therefore depends on the price of capital Q and the marginal equity issuance cost $\partial G(e)/\partial e$, shown on the first line of (3.24). The marginal benefit of capital consists of two parts. The first one is direct: capital increases production and raises future assets $q(x', \varepsilon'; S')$, as shown on the second line of (3.24). If default is avoided, higher assets reduce the need for future equity issuance or increase future dividends. The second benefit is indirect. If capital reduces default risk, it increases bond prices and bond market revenue, $\partial p^S/\partial k' > 0$ and $\partial p^L/\partial k' > 0$ on the first line of (3.24).

A firm's past choices of debt issuance and debt maturity are important for this indirect benefit of capital. As shown on the first line of (3.24), the benefit is falling in the amount of previously issued long-term debt $(1-\gamma)b^L/\pi$. A higher long-term bond price p^L benefits shareholders only to the extent that it increases the firm's revenue from selling *new* long-term debt. The fact that a lower default risk also increases the market value of *existing* long-term debt is not internalized by the firm. In this way, a larger existing stock of debt can reduce firm investment. This is the classic *debt overhang* effect described in Myers (1977).

Short-term debt. The first-order condition for short-term debt $b^{S'}$ is

$$\left[1+\frac{\partial G(e)}{\partial e}\right]\left[p^S+b^{S'}\frac{\partial p^S}{\partial b^{S'}}+\left(b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{S'}}\right]-\frac{\partial H(b^{S'},b^{L'},\frac{b^L}{\pi})}{\partial b^{S'}}$$
$$+\mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}[1-\mathcal{D}(x',\varepsilon';S')]\frac{\partial q(x',\varepsilon';S')}{\partial b^{S'}}\mathbb{E}_{z''|z'}\left(1+\frac{\partial G(e')}{\partial e'}\right)\varphi(\varepsilon'|z')d\varepsilon'=0. \tag{3.25}$$

For given choices of k' and $b^{L'}$, selling additional short-term debt is beneficial because it reduces the need for costly equity issuance by $[1+\partial G(e)/\partial e]\cdot p^S$. This is shown on the first line of (3.25). The costs of short-term debt consist of debt issuance costs $H(\cdot)$ and higher default risk which reduces bond market revenue, i.e., $\partial p^S/\partial b^{S'}<0$ and $\partial p^L/\partial b^{S'}<0$. For each short-term bond sold, the firm promises a payment of $(1+c)/\pi'$ which reduces future assets, captured by $\partial q(x',\varepsilon';S')/\partial b^{S'}<0$ on the second line of (3.25). The bond price p^S fully reflects the coupon c promised to creditors, but because it is tax deductible it only reduces $q(x',\varepsilon';S')$ by $(1-\tau)c$. This is the tax benefit of debt.

A larger stock of previously issued long-term debt $(1-\gamma)b^L/\pi$ lowers bond market revenue. As can be seen from the first line of (3.25), this reduces the impact of changes in p^L caused by additional short-term debt $b^{S'}$. The firm disregards the fact that an increase in default risk lowers the market value of existing long-term debt. In this way, debt overhang increases firms' incentive to issue additional debt.[17]

Long-term debt. Finally, the first-order condition with respect to $b^{L'}$ is

$$\left[1+\frac{\partial G(e)}{\partial e}\right]\left[p^L+b^{S'}\frac{\partial p^S}{\partial b^{L'}}+\left(b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{L'}}\right]-\frac{\partial H(b^{S'},b^{L'},\frac{b^L}{\pi})}{\partial b^{L'}}$$
$$+\mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}[1-\mathcal{D}(x',\varepsilon';S')]$$
$$\mathbb{E}_{z''|z'}\left[\left(\frac{\partial q(x',\varepsilon';S')}{\partial b^{L'}}-\frac{1-\gamma}{\pi'}\cdot g(x',\varepsilon',z'';S')\right)\left(1+\frac{\partial G(e')}{\partial e'}\right)-\frac{\partial H(b^{S''},b^{L''},\frac{b^{L'}}{\pi'})}{\partial b^{L'}}\right]\varphi(\varepsilon'|z')d\varepsilon'=0. \tag{3.26}$$

Similar to short-term debt, selling additional long-term debt reduces the need for costly equity issuance by $[1+\partial G(e)/\partial e]\cdot p^L$. At the same time, it increases a firm's default risk and lowers bond market revenue, $\partial p^S/\partial b^{L'}<0$ and $\partial p^L/\partial b^{L'}<0$. In addition, the firm incurs the marginal debt issuance cost $\partial H(b^{S'},b^{L'},b^L/\pi)/\partial b^{L'}>0$. This is shown on the first line of (3.26). Different from short-term debt, a long-term bond only promises a payment of $(\gamma+c)/\pi'$ next period, a fraction γ of the principal plus a coupon. The associated reduction of future assets $q(x',\varepsilon';S')$ on the third line of (3.26) is therefore smaller. However, the fact that a fraction $1-\gamma$ of long-term debt remains outstanding lowers future bond market revenue by $(1-\gamma)/\pi'\cdot g(x',\varepsilon',z'';S')$.

[17] In the sovereign debt literature (e.g., Hatchondo et al., 2016) this incentive to increase indebtedness at the expense of existing creditors is known as *debt dilution*. In corporate finance, the term *debt dilution* is sometimes used to describe the specific situation that a larger number of creditors must share a given liquidation value of a bankrupt firm. The mechanism described above is at work even if the liquidation value is zero or if existing debt is fully prioritized (as in Bizer and DeMarzo, 1992).

The main benefit of issuing long-term debt is that it reduces future debt issuance costs, shown as $\partial H(b^{S''}, b^{L''}, b^{L'}/\pi')/\partial b^{L'} < 0$ on the third line of (3.26). The downside is that it creates debt overhang. Whereas an increase in $b^{S'}$ affects p^L only through next period's default risk, an increase in $b^{L'}$ also affects p^L through its effect on future choices of capital k'', short-term debt $b^{S''}$, and long-term debt $b^{L''}$. As discussed above, a higher future stock of outstanding long-term debt generates debt overhang which can lead to reduced investment and higher borrowing. This increases future leverage and default risk and thereby has an additional negative effect on today's bond price p^L.

Debt overhang is a commitment problem. When selling long-term debt, shareholders would like to promise low future values of leverage and default risk because this would increase today's bond price p^L. However, this promise is not credible. After long-term debt is sold, the firm continues to internalize the benefits of higher leverage. Yet a part of the associated costs is borne by existing creditors. As creditors have rational expectations, p^L correctly anticipates the effects of debt overhang on future firm behavior. Shareholders therefore face a commitment problem: leverage is higher ex-post than optimal ex-ante (see Jungherr and Schott, 2021).

4 Quantitative Analysis

In order to compare the model results to the empirical evidence, we now proceed with a quantitative analysis. Our calibrated model replicates several targeted and non-targeted moments that characterize financing choices of U.S. firms. The model also rationalizes the empirical result that firms with higher shares of maturing debt react more strongly to monetary policy shocks. At the aggregate level, we show that unconventional monetary policy, which operates through long-term interest rates, has larger effects on debt maturity but smaller effects on output and inflation than conventional monetary policy.

4.1 Solution method

We use value function iteration and interpolation to compute the Markov perfect equilibrium of our model. There are three key challenges. The first is the dimensionality of the state space. The variables (z, k, b^S, b^L) describe the firm's idiosyncratic state at the beginning of the period. Together with S and ε, they determine a firm's default decision. Firms decide about investment and financing at the end of the period after the realization of z'. The state in (3.22) is therefore given by $(z, k, b^S, b^L, \varepsilon, z'; S)$. To solve the model, we exploit the fact that this information can be summarized in the reduced state vector $(q, b, z'; S)$ which includes firm assets $q = q(z, k, b^S, b^L, \varepsilon; S)$ and outstanding long-term debt $b = (1-\gamma)b^L$.

The second difficulty is finding the equilibrium price of risky long-term debt, p^L, the key computational challenge for a precise solution of the model. 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 own future behavior and thereby today's bond price p^L. 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

Table 2: Externally set parameters.

Parameter	β	c	θ	ζ	ψ	δ	γ	τ	ρ	φ^{mp}	ρ^{mp}	λ	ϕ
Value	0.99	0.01	0.5	0.75	0.33	0.025	0.05	0.4	10	1.25	0.5	90	4

first-period equilibrium firm policy and bond prices as the equilibrium of the infinite-horizon problem.

The third challenge is that the aggregate state of our general equilibrium model includes the time-varying firm distribution. We follow Reiter (2009) in first computing a fully non-linear global solution of the steady state with idiosyncratic firm-level uncertainty but without aggregate shocks. We then use a numerical first-order perturbation method to approximate the dynamics of the model and its endogenous firm distribution around the steady state in response to aggregate shocks.[18]

4.2 Calibration

A number of parameters can be set externally using standard values from the literature on firm dynamics and New Keynesian business cycle models. The remaining parameters are internally calibrated.

Externally set parameters. The model period is one quarter. We set $\beta = 0.99$ which implies a quarterly steady-state real interest rate of $r^* = 1.01\%$. In the steady state of the model, inflation is zero and the nominal interest rate i is equal to the real rate. The debt coupon is fixed at $c = r^*$ which implies that the steady state equilibrium prices of riskless short-term and long-term bonds are both equal to one. The preference parameter θ is chosen to match 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 $\gamma = 0.05$.[19] The choice of γ implies a Macaulay duration of $(1 + r^*)/(\gamma + r^*) = 16.8$ quarters or 4.2 years. This is a conservative choice relative to the average duration of 6.5 years calculated by Gilchrist and Zakrajšek (2012) for a sample of U.S. corporate bonds with remaining term to maturity above one year. Figure D.3 shows that the calibrated model is successful in generating an empirically realistic maturity structure of debt at various time horizons.

As in Kaplan et al. (2018), we set the elasticity of substitution for retail good varieties to $\rho = 10$ (implying a steady state markup of 11 percent) and the Taylor rule parameters to $\varphi^{\text{mp}} = 1.25$ and $\rho^{\text{mp}} = 0.5$. The price adjustment cost parameter λ and the parameter of the capital goods technology ϕ are taken from Ottonello and Winberry (2020). The parameters

[18] Online Appendix H.1 contains more details about the solution algorithm and a discussion of computational challenges in the presence of long-term debt and default.

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

Table 3: Internally calibrated parameters

Parameter	Value	Target	Data	Model
ρ_z	0.988	Regression log(k) on age	0.022	0.024
$\bar{z}$	0.300	Std. of firm capital growth *(in %)*	16.8	15.0
$\sigma_{\varepsilon\|z\leq\mathbb{E}(z)}$	0.60	Average firm leverage *(in %)*	34.4	30.9
$\sigma_{\varepsilon\|z>\mathbb{E}(z)}$	0.88	Regression leverage on age	0.196	0.225
ξ	0.54	Average credit spread on long-term debt *(in %)*	3.1	2.73
η	0.0045	Average share of debt due within a year *(in %)*	30.5	30.6
ν	0.0005	Average equity issuance *(in %)*	11.4	15.0
κ	0.0151	Firm exit rate *(in %)*	2.2	2.1
f	0.2606	Steady state value of firm entry	–	0

Note: The data sample is 1995-2017. Firm-level data on capital, age (quarters since IPO), leverage (debt/assets), the share of debt due within a year, and equity issuance (relative to assets) is from Compustat. Firm-level credit spreads are computed using data from Compustat and FISD. The exit rate is from Ottonello and Winberry (2020). See Appendix D.1 and D.2 for details.

generate a slope of the Phillips Curve of $\rho/\lambda = 0.1$ as in Kaplan et al. (2018), and a response of aggregate investment to monetary policy shocks which is roughly twice as large as that of aggregate output (Christiano et al., 2005). All externally set parameters are summarized in Table 2.

Internally calibrated parameters. Firm-level productivity z follows a productivity ladder with discrete support $\{Z_1, ..., Z_j, ..., Z_J\}$, where $\log Z_1 = -\bar{z}$ and $\log Z_J = +\bar{z}$. Entrants start at the lowest productivity level $z^e = Z_1$ (with zero assets, $q = 0$, and zero debt, $b = 0$). For an incumbent firm with $z = Z_j$, the probability to become more productive next period is given by $1 - \rho_z$:

$$z' = \begin{cases} Z_j & \text{with probability } \rho_z \\ Z_{\min\{j+1,J\}} & \text{with probability } 1-\rho_z \end{cases} \tag{4.1}$$

Once a firm has reached the highest productivity level Z_J, it remains there until it defaults or exits the economy exogenously. This productivity process has two desirable features. First, it captures the positive skewness of empirical firm growth (Decker et al., 2014). Second, it facilitates the computation of the Markov perfect equilibrium.[20] The probability distribution of the firm-specific capital quality shock ε is normal with zero mean and standard deviation $\sigma_{\varepsilon|z}$. We allow $\sigma_{\varepsilon|z}$ to vary with firm productivity z.

We internally calibrate nine parameters: ρ_z, $\bar{z}$, $\sigma_{\varepsilon|z\leq\mathbb{E}(z)}$, $\sigma_{\varepsilon|z>\mathbb{E}(z)}$, ξ, η, ν, κ, and f. Their values are chosen to match key empirical moments which are informative about the financing and investment behavior of firms. To discipline firms' debt choices, we use Compustat

[20] If a firm's amount of outstanding long-term debt $(1-\gamma)b^L/\pi$ is sufficiently high, large negative shocks to z' would increase the incentive to pay out dividends at the expense of existing creditors, causing the dividend payout constraint $e \geq \underline{e}$ in (3.9) to bind for any value of $\underline{e}$. The productivity process described above avoids such counterfactual firm behavior.

information on leverage and on the share of total debt due within a year. While the FISD data used in Section 2 contains more precise information on maturity within a quarter, it is only available for a subset of Compustat firms. The model does not distinguish between different types of debt and therefore assumes all debt to consist of bonds. Firm-level data on capital, age (quarters since initial public offering), and equity issuance comes from Compustat as well. Credit spreads are calculated by combining firm-level credit ratings with rating-specific corporate bond spreads, following Arellano et al. (2019).

The internal calibration is summarized in Table 3. When comparing model moments to Compustat data, we account for the sample selection into Compustat by restricting the model sample to firms older than seven years which is the approximate median time before firms go public (Ottonello and Winberry, 2020). While the model is highly non-linear and all parameters are jointly identified, we provide some intuition for their identification. The stochastic process of firm-level productivity z is determined by the two parameters ρ_z and $\bar{z}$, which are pinned down through *i)* the relationship between firm size and firm age (captured through a linear regression) and *ii)* the within-firm standard deviation of capital growth. The two parameters $\sigma_{\varepsilon|z\leq\mathbb{E}(z)}$ and $\sigma_{\varepsilon|z>\mathbb{E}(z)}$ are key for matching both average leverage and its dispersion across firms. A higher standard deviation of the capital quality shock ε increases earnings volatility and default risk, which induces firms to reduce leverage. Allowing this parameter to vary with firm productivity is key for controlling how fast leverage increases with firm age in the model (captured through a linear regression). The average credit spread is directly affected by the default cost ξ. The average maturing debt share pins down the debt issuance cost parameter η because higher debt issuance costs make short-term debt less attractive. The equity issuance cost parameter ν targets equity issuance relative to firm assets. The probability of exogenous exit κ affects the total rate of exit (endogenous and exogenous). Finally, the fixed cost of production f is chosen such that the steady state value of firm entry is zero.

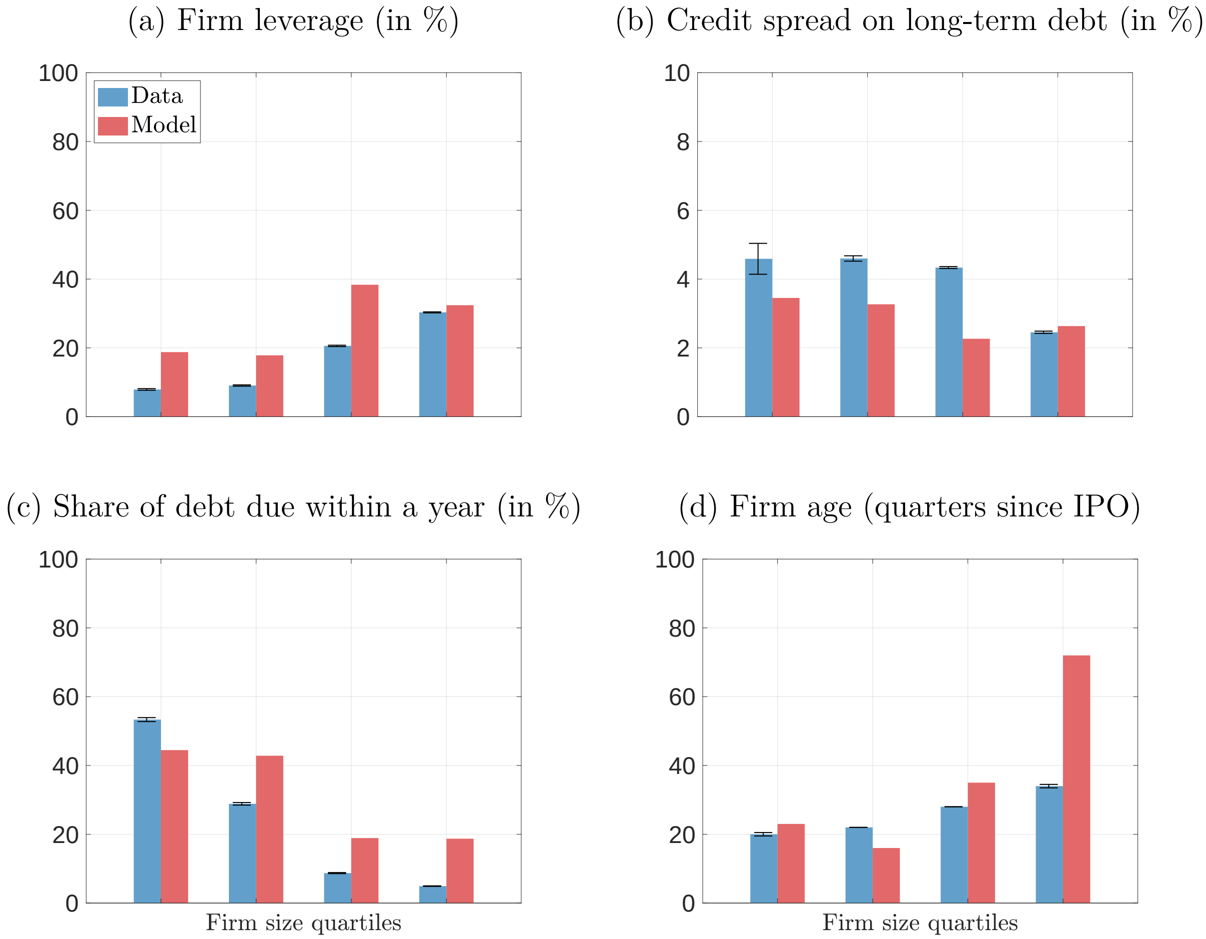
Table 3 shows that the model matches the data well. Average firm leverage and the maturing debt share are both about 30%. The average annual credit spread on long-term debt is close to 3 percent. Even though the value of the equity issuance cost parameter ν is smaller than the debt issuance cost parameter η, aggregate equity issuance costs exceed aggregate debt issuance costs (0.27% vs. 0.04% of GDP). The model generates a quarterly default rate of 0.7%. Although untargeted, the default rate is very close to the corresponding values of 0.8% in Bernanke et al. (1999) and the 1.0% in Moody's expected default frequency across rated and unrated Compustat firms reported by Hovakimian et al. (2011).

4.3 Steady state results

The steady state of the calibrated model replicates how empirical firm financing choices vary across the size distribution. One important fact in the data is that smaller firms pay higher credit spreads and have larger shares of maturing debt. The model generates this result through endogenous variation in firms' exposure to debt overhang.

Figure 6 shows leverage, credit spreads, and the maturing debt share across quartiles of the firm size distribution. Blue bars indicate empirical values (with 95% confidence intervals). Red bars show the corresponding moments in the model. In the data, leverage increases with firm size. Smaller firms pay higher credit spreads and have larger shares of maturing debt

Figure 6: Firm variables conditional on size



Note: For each variable, median values are shown by size quartile. The data sample is 1995–2017. Firm-level data on size (measured by capital), leverage, the share of debt due within a year, and age (quarters since IPO) is from Compustat. Firm-level credit spreads are computed using data from Compustat and FISD. Empirical median values are shown with 95% confidence intervals. Model moments are computed from the stationary distribution of the model using the 'post-IPO sample'. See Appendix D.1 and D.2 for details.

per period. The last panel shows that larger firms are older.

The model replicates these empirical patterns. Differences in firm productivity are key for this result. Low productivity firms choose a smaller scale of production. The fixed cost of production f implies that smaller firms are less profitable and therefore have higher default risk for given amounts of leverage. As a consequence, smaller firms pay higher credit spreads and choose lower amounts of leverage. The fact that average firm productivity increases with age generates the positive relationship between firm age and size in panel (d).

Panel (c) shows that the model also replicates the fact that the maturing debt share is higher for smaller firms. An advantage of long-term debt is that it reduces future debt issuance costs. However, issuing additional long-term debt decreases the long-term bond price because debt overhang will lead to higher future leverage and default risk (*cf.* Section 3.8). Note that this cost of long-term debt is increasing in default risk. In case of default, creditors receive the liquidation value of the firm. Because firms disregard the payoff to existing creditors, a higher default risk leads to a larger distortive effect of long-term debt on firm behavior. The costs of debt overhang are therefore higher for firms with higher default risk. Through this mechanism, the model can explain why smaller firms borrow at shorter maturities and therefore have higher shares of maturing debt.[21]

4.4 Aggregate effects of monetary policy shocks

The previous section showed that the model successfully replicates key cross-sectional facts about the financing choices of U.S. public firms. The model thus provides an appropriate quantitative framework for studying the role of debt maturity for the aggregate and heterogeneous effects of monetary policy. We begin by showing the model's aggregate implications.

Figure 7 shows the aggregate effects of an unexpected one standard deviation (30bp) increase in the nominal interest rate i_t caused by a monetary policy shock ($\varepsilon_t^{\text{mp}}$ in equation (3.19)). GDP, consumption, and investment all fall in response to the shock. The real interest rate r_t increases by more than the nominal rate because inflation π_t falls. The second panel also includes the nominal long-term interest rate i_t^L. It increases by less than the short-term rate i_t because it is a weighted average of present and future short-term rates.

The fall in aggregate demand causes a reduction in the price of undifferentiated output p_t. This reduces firms' demand for capital and labor and decreases the wage w_t and the price of capital goods Q_t. Lower inflation π_t increases the real burden of outstanding nominal long-term debt $(1-\gamma)b_t^L/\pi_t$. As a result, firms accept an increase in leverage and default risk. Short-term credit spreads respond more strongly than long-term spreads because the price of short-term debt only depends on next period's default risk while the long-term bond price depends on default risk in all future periods. Firms react by increasing the average maturity of their debt portfolio.

4.5 Heterogeneous effects of monetary policy shocks

Our empirical analysis showed that firms with a higher share of maturing debt are more responsive to monetary policy shocks. In this section, we show that our model replicates this result.

Local projection on simulated model data. To compare the model with the empirical evidence, we run the model counterpart of the baseline local projection (2.3) on simulated data generated by our model. We estimate:

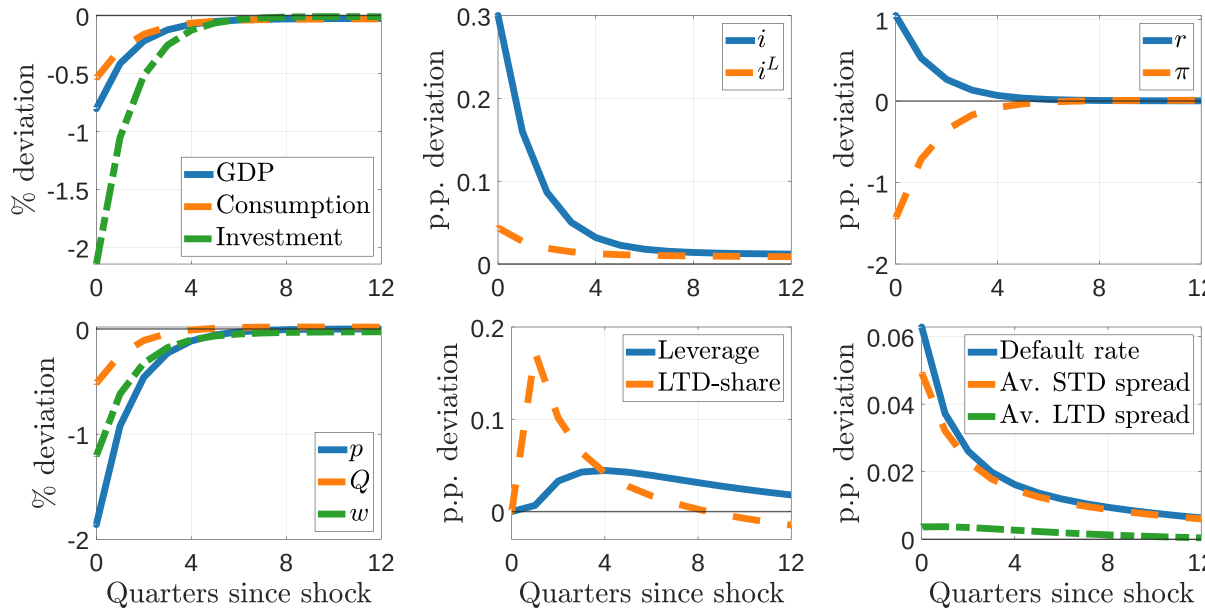
$$\Delta^{h+1} \log k_{it+h} = \beta_0^h \mathcal{M}_{it} + \beta_1^h \mathcal{M}_{it} \varepsilon_t^{\text{mp}} + \delta_i^h + \delta_t^h + \nu_{it+h}^h, \tag{4.2}$$

where δ_i^h and δ_t^h are firm- and time-fixed effects, and $\mathcal{M}_{it}$ is the maturing bond share:

$$\mathcal{M}_{it} = \frac{b_{it}^S + \gamma b_{it}^L}{b_{it}^S + b_{it}^L} \tag{4.3}$$

[21]Figure D.5 shows how this mechanism operates in the calibrated model. Firms whose long-term bond price is more sensitive to an increase in long-term debt tend to choose higher maturing debt shares (panel (a)). For these firms, an increase in long-term debt has a larger negative effect on future capital (panel (b)) and drives up future leverage and default risk by more (panels (c) and (d)).

Figure 7: Aggregate response to a contractionary monetary policy shock



Note: The nominal short-term rate i, the nominal long-term rate i^L, the real interest rate r, and inflation π are annualized. Leverage (debt over capital) and the long-term debt share (*LTD-share*) are cross-sectional averages. The default rate is annual. The short-term credit spread (*STD spread*) and the long-term credit spread (*LTD spread*) are cross-sectional averages. See Appendix D.1 for details.

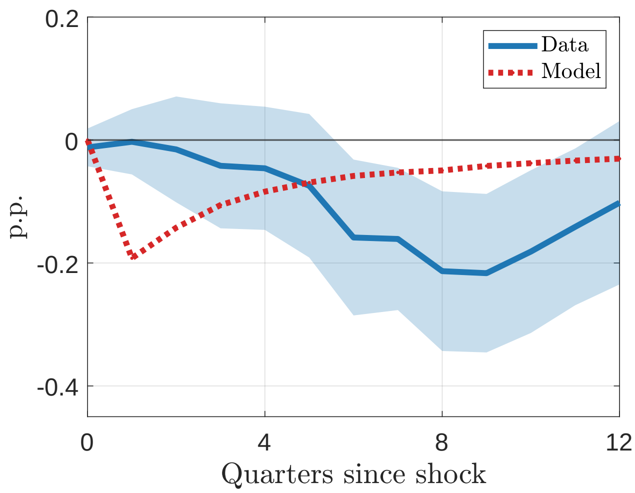
It measures the share of a firm's total debt that is due in the current period, i.e., short-term debt plus a fraction γ of outstanding long-term debt.[22] Figure 8 shows the estimated β_1^h coefficients in the model (red dotted line) and in the data (blue solid line, *cf.* Figure 2(b)). The estimates in Figure 8 are standardized to measure the differential capital growth response associated with a one standard deviation higher $\mathcal{M}_{it}$ at the time of an unexpected one standard deviation (30bp) increase in the nominal interest rate i.

As in the data, β_1^h is negative at all time horizons: A higher maturing bond share at the time of the monetary policy shock implies a larger negative capital response. The model's peak differential response is 19 bp, which is 90% of the peak differential response in the data (21 bp). While the model response displays substantial persistence, it reaches its peak in the period after the shock, as opposed to the slow build-up observed in the data. One potential reason for this difference is that our model does not feature firm-level capital adjustment costs.

The model also replicates the empirical role of the maturing bond share for the response of other important firm variables. Figure D.6 in the Appendix shows that a higher $\mathcal{M}_{it}$ at the time of the shock is associated with a larger increase of credit spreads and larger reductions in total debt, sales, and employment. These model results are in line with the empirical findings in Figures 3 and 4.

[22] Note that in the model b_{it}^S and b_{it}^L denote predetermined debt levels at the beginning of period t. This corresponds to debt_{it-1} in the empirical part of the paper. As in the empirical specification, we use average total debt over the preceding four quarters as the denominator for $\mathcal{M}_{it}$. All model results are virtually indistinguishable when using the current level of debt as denominator instead.

Figure 8: Differential investment response associated with $\mathcal{M}_{it}$



Note: The red dotted line shows the estimated β_1^h coefficients based on equation (4.2) using simulated model data. The β_1^h estimates are standardized to capture the differential cumulative capital growth response (in p.p.) to a one standard deviation (30bp) increase in the nominal interest rate i associated with a one standard deviation higher $\mathcal{M}_{it}$. The blue solid line shows the empirical baseline estimates from Figure 2(b) together with 95% confidence bands.

Monetary transmission and the maturing bond share. The model rationalizes the main empirical result of the paper: a higher share of maturing debt at the time of a monetary policy shock is associated with a stronger response of firm investment, credit spreads, debt, sales, and employment. But how does the model generate this key result? In the model, debt maturity matters for monetary policy because of two channels: (1.) Debt maturity determines *roll-over risk* and thereby affects investment through firms' cash flow response to changes in interest rates and inflation. (2.) Debt maturity determines *debt overhang* and thereby affects investment through changes in the real burden of existing debt.

Roll-over risk: The maturing bond share $\mathcal{M}$ measures the share of a firm's total amount of debt which is due in the current quarter. Firms with higher $\mathcal{M}$ borrow at shorter maturities (i.e., higher b^S and lower b^L). For them, a given amount of total debt requires more debt roll-over per period. In firms' cash flow constraint, this implies a smaller stock of outstanding long-term debt $(1-\gamma)b^L/\pi$ and larger bond market revenue per period:

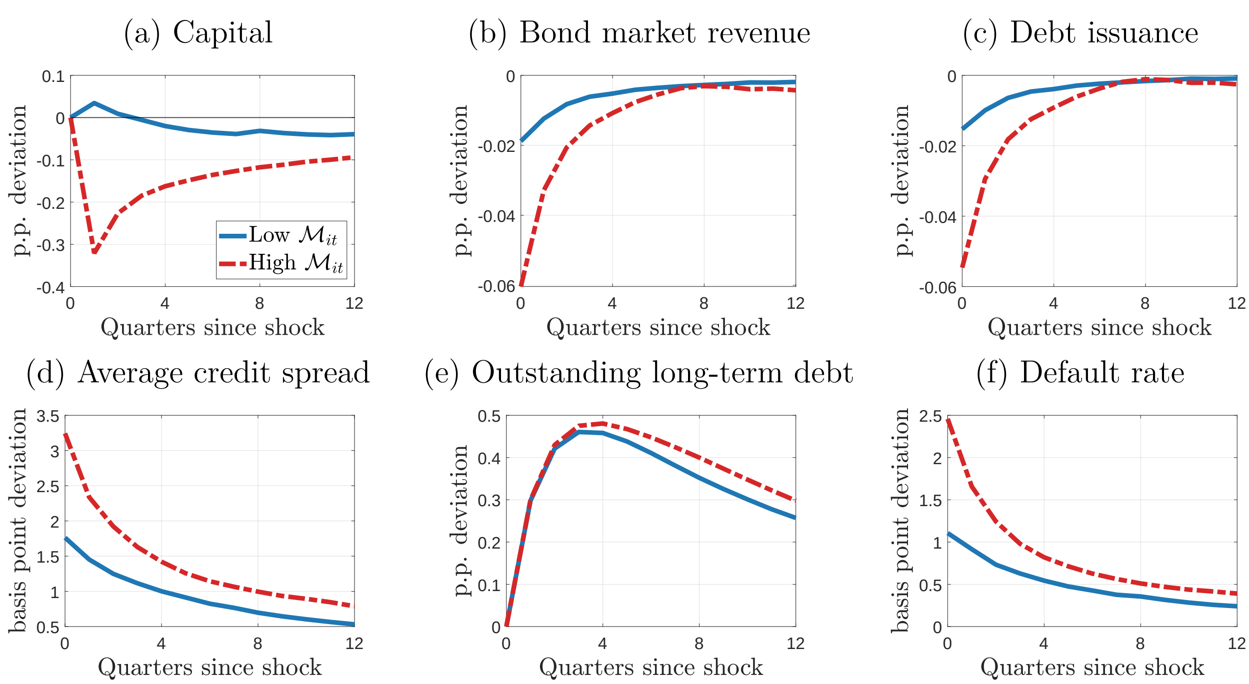
$$Qk' = q + e + \underbrace{\left(b^{S'}p^S + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)p^L\right)}_{\text{bond market revenue}} \tag{4.4}$$

Accordingly, if $\mathcal{M}$ is higher, any change in bond prices p^S and p^L caused by monetary policy generates a larger pass-through to firms' bond market revenue and therefore, ceteris paribus, to capital purchases Qk'.

Debt overhang: After a contractionary monetary policy shock, the real burden of outstanding nominal long-term debt $(1-\gamma)b^L/\pi$ increases as inflation π falls, an effect known as *Fisherian debt deflation*. As discussed in Section 4.3, an increase in the real burden of outstanding long-term debt has a larger negative effect on capital for firms with higher maturing bond shares (Figure D.5 (b)).

Figure 9 illustrates the role of the maturing bond share in the transmission of monetary policy. We split firms into two groups according to whether their maturing bond share is above or below the median. The panels show average firm responses of key model variables for both groups. Panel (a) shows that capital of high-$\mathcal{M}$ firms falls by about 30 bp after a contractionary monetary policy shock, whereas capital of low-$\mathcal{M}$ firms initially increases due to lower factor prices. Panel (b) shows that bond market revenue falls by more for high-$\mathcal{M}$ firms. This is driven by a larger fall in debt issuance (panel (c)) and a larger increase in credit spreads (panel (d)). This illustrates the roll-over risk associated with short-term debt: When interest rates change, this has larger effects on the bond market revenue of firms which borrow at shorter maturities. Long-term debt provides insurance against roll-over risk, but as panel (e) shows, the increase in the real burden of outstanding nominal long-term debt increases debt overhang. The associated rise of default risk, shown in panel (f), is larger for high-$\mathcal{M}$ firms (Figure D.5 (d)), explaining the larger increase in credit spreads.

Figure 9: Heterogeneous responses to a contractionary monetary policy shock



Note: The panels show the effect of an unexpected one standard deviation (30bp) increase in the nominal interest rate i for firms below and above the median maturing bond share $\mathcal{M}$ at the time of the shock. The panels show average firm-level changes in (a) capital, (b) bond market revenue (relative to pre-shock firm-level capital), (c) gross debt issuance, $b^{S'} + (b^{L'} - (1-\gamma)b^L/\pi)$ (relative to pre-shock firm-level capital), (d) the average of firms' short-term and long-term credit spread (weighted by the firm-level share of short-term and long-term debt), (e) the stock of outstanding long-term debt b, and (f) the annualized default rate.

Decomposing the transmission channels. We design two model experiments which are intended to isolate the two channels described above. Assessing the relative quantitative importance of roll-over risk and debt overhang is challenging because the two channels interact. The stronger cash flow response of high-$\mathcal{M}$ firms contributes to the increase in their default risk, amplifying debt overhang. Conversely, the stronger increase in default risk of high-$\mathcal{M}$ firms due to debt overhang contributes to the larger rise in their credit spreads, amplifying roll-over risk.

The first model experiment eliminates roll-over risk by compensating firms for the cash shortfall due to changes in interest rates and inflation. Formally, this experiment introduces a cash transfer $T(q, b, z', S)$ into the cash flow constraint (4.4), which now reads

$$Qk' = q + e + \left(b^{S'} p^S + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right) p^L\right) + \underbrace{T(q, b, z', S)}_{\text{cash transfer}}. \tag{4.5}$$

The cash transfer $T(q, b, z', S)$ is the sum of two components: (1) the difference between the steady-state bond market revenue of a firm in state (q, b, z', S_{ss}) and the bond market revenue of a firm in state (q, b, z', S) after a monetary policy shock in the benchmark model, and (2) the difference in the real market value of firm assets q induced by deviations of inflation π from its steady state value.[23] The transfer therefore compensates all cash flow effects of monetary policy associated with $\mathcal{M}$. In a model without financial frictions, this transfer would not have any effect on firms' capital choices.

Figure 10 compares the results of the local projection (4.2) from our benchmark model (red dotted line) with three model experiments. The solid orange line shows the β_1^h coefficients from the model with compensating cash transfers. The cash transfer reduces the peak differential capital response associated with $\mathcal{M}$ by eight basis points (or by 40%). The pass-through of cash transfers to capital is close to one for high-$\mathcal{M}$ firms and significantly smaller for low-$\mathcal{M}$ firms. The cash transfer affects firms' capital choice for two reasons. First, it reduces the current need to issue costly equity and thereby directly lowers the marginal cost of capital. Second, it lowers all firms' need to issue costly equity in the future and thereby increases shareholder value and reduces default risk. The upshot of this model experiment is that the cash flow effects of monetary policy shocks contribute significantly to the stronger response of high-$\mathcal{M}$ firms documented in Figure 8.

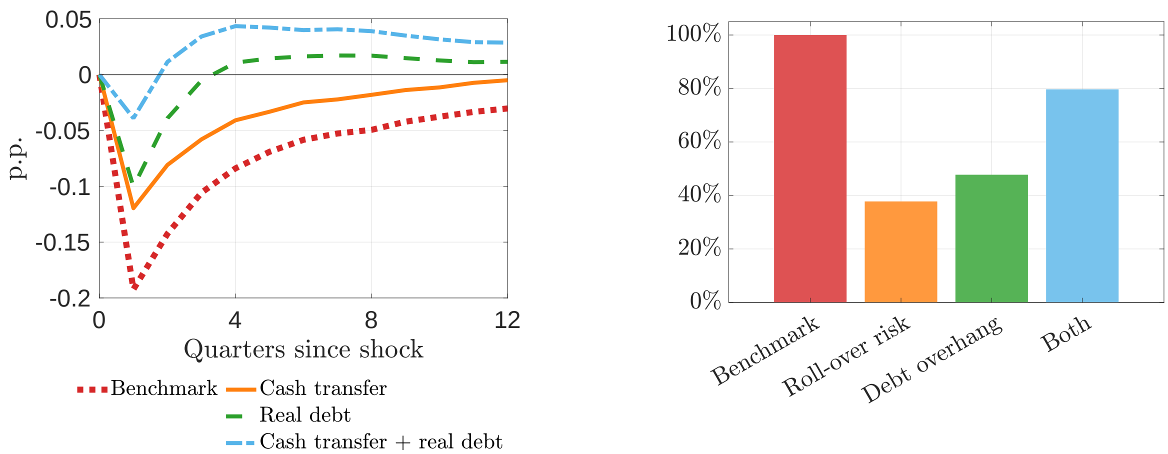
Our second experiment reduces the impact of monetary policy on debt overhang by introducing inflation-indexed debt.[24] This avoids the increase in debt overhang after a contractionary monetary policy shock due to *Fisherian debt deflation*. Formally, in this model experiment we replace all debt variables (e.g., b^S/π and b^L/π) by variables which do not respond to inflation (e.g., b^S and b^L). The green dashed line in Figure 10 shows the differential capital response associated with $\mathcal{M}$ in the model experiment with real debt. Eliminating the increase in debt overhang reduces the peak differential capital response associated with

[23] Changes in inflation affect the real value of nominal debt payments b^S/π and $\gamma b^L/\pi$ in (3.3). Figure H.2 in the Online Appendix shows that the majority of the cash flow effects of monetary policy are accounted for by changes in bond market revenue and only a small part by changes in the real value of nominal debt payments.

[24] It is important that the steady state of the model remains unaffected by these model experiments as otherwise differences in the stationary firm distribution would affect the comparison of the model response to monetary policy shocks. Debt covenants which eliminate debt overhang (as in Hatchondo et al., 2016 or in Jungherr and Schott, 2022) are therefore not an option.

Figure 10: Decomposition of differential investment response associated with $\mathcal{M}$

(a) Differential responses under experiments (b) Decomposition into channels



Note: In panel (a), the red dotted line shows the differential investment response to a contractionary monetary policy shock associated with a one standard deviation higher maturing bond share in the model (*cf.* Figure 8). The orange solid line shows the corresponding differential response in the *cash transfer* model experiment, which we use to offset *roll-over risk*. The green dashed line shows the corresponding differential response in the *real debt* model experiment, which we use to offset changes in *debt overhang*. The blue dash-dotted line shows the differential response in a model which combines both model experiments. In panel (b), we show the share of the peak impulse response function (at horizon $h = 1$) that can be attributed to *roll-over risk*, changes in *debt overhang*, or the combination of both. The shares are defined as relative reductions in the impulse responses under the model experiments compared to the benchmark.

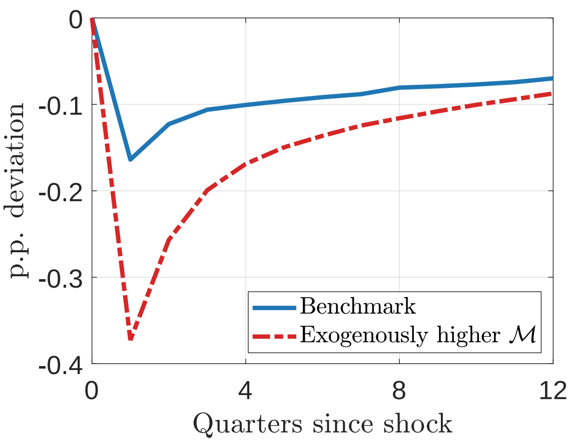
$\mathcal{M}$ by 10 basis points (or by about 50%). Real debt affects firms' capital choice mainly because it reduces the increase in leverage and default risk after the monetary policy shock. Because high-$\mathcal{M}$ firms are particularly sensitive to increases in the real burden of nominal long-term debt, they benefit most from eliminating debt deflation.

Finally, the blue dash-dotted line in Figure 10 shows the results of combining both model experiments. Once all cash flow effects of monetary policy shocks are compensated and the increase in the real value of outstanding nominal debt due to debt deflation is avoided, high-$\mathcal{M}$ and low-$\mathcal{M}$ firms respond very similarly. We conclude that the differential capital response associated with $\mathcal{M}$ in the benchmark model can to a large extent be explained by two channels: roll-over risk and changes in debt overhang. When both channels are switched off, the heterogeneity associated with $\mathcal{M}$ in firms' capital response is largely eliminated.

Exogenous variation in maturing bond share. To shed additional light on the role of debt maturity for the transmission of monetary policy, we conduct one final model experiment in which $\mathcal{M}$ is varied exogenously. While in the model debt maturity is endogenous and therefore systematically related to other firm characteristics (e.g., size, age, default risk), an exogenous variation in $\mathcal{M}$ isolates the role of debt maturity for firms' response to monetary policy shocks.

We draw a representative sample of firms of zero mass from our benchmark economy and

Figure 11: Average investment response with exogenous variation in maturing bond share



Note: The Figure shows the average capital growth response to a contractionary monetary policy shock for the selected firm sample. The blue solid line shows the average response in the benchmark model. The red dashed line shows the average response given an exogenously higher level of $\mathcal{M}$ in the initial period.

exogenously set $\mathcal{M}$ to a higher value by converting all of their long-term debt b^L to short-term debt b^S.[25] The red dash-dotted line in Figure 11 shows the average capital response to a contractionary monetary policy shock for firms in the selected sample. Compared to the response in the benchmark model (blue solid line), capital contracts by more if $\mathcal{M}$ is exogenously higher at the time of the shock. This confirms that firms' debt maturity structure has important effects on the investment response to monetary policy.

4.6 Unconventional monetary policy and corporate debt maturity

In this section, we use the model to gain new insights about the role of debt maturity for the aggregate effects of monetary policy. In particular, we compare the aggregate effects of conventional and unconventional monetary policy. While conventional monetary policy works by directly affecting short-term interest rates, unconventional monetary policy (e.g., quantitative easing, forward guidance) targets long-term interest rates. Our model provides a unique framework for comparing these policies because it accounts for the fact that different firms borrow at different maturities: Smaller firms borrow more short-term whereas larger firms rely more on long-term debt. We find that unconventional monetary policy has smaller effects on output and inflation than conventional monetary policy. An important reason for this result is a strong endogenous response of debt maturity to unconventional monetary policy.

Model extension. To study the effects of unconventional monetary policy, we introduce one small modification to the setup. Until now, the expected cash flows of all assets in the

[25]Because the sample of selected firms has zero mass, this experiment has no general equilibrium effects. Figure H.3 in the Online Appendix shows that in our model experiment the average share of debt due in one year increases from about 30% to 100% for the selected firm sample and subsequently slowly converges back to steady state.

economy were evaluated using the stochastic discount factor (SDF) $\Lambda_{t,t+1}$ of the representative household. We now generalize this assumption and allow that different assets are priced using different SDFs. In particular, we assume that the SDF $\Lambda^S_{t,t+1}$ which prices short-term assets (i.e., short-term corporate bonds in (3.11) and the short-term riskless nominal interest rate i in (3.13)) can differ from the SDF $\Lambda^L_{t,t+1}$ which prices long-term assets (i.e., expected dividends in (3.9), long-term corporate bonds in (3.12), and the long-term riskless nominal interest rate i^L in (3.14)):

$$\Lambda^L_{t,t+1} = (1+\eta^{\mathrm{ts}}_t)\Lambda^S_{t,t+1}\,, \tag{4.6}$$

where η^{ts}_t follows the AR(1)-process $\eta^{\mathrm{ts}}_t = \rho^{\mathrm{ts}}\eta^{\mathrm{ts}}_{t-1} + \varepsilon^{\mathrm{ts}}_t$ with $\rho^{\mathrm{ts}} \in (0,1)$ and $\varepsilon^{\mathrm{ts}}_t \sim N(0,\sigma^2_{\mathrm{ts}})$ is a term structure shock. When $\eta^{\mathrm{ts}}_t = 0$, arbitrage between short-term and long-term asset markets works without frictions. When $\eta^{\mathrm{ts}}_t \neq 0$, markets are temporarily segmented. A positive shock $\varepsilon^{\mathrm{ts}}_t$ increases the valuation of long-term assets relative to short-term assets. In this way, the model captures the effects of unconventional monetary policy on the term structure of interest rates.[26]

Effects of an expansionary unconventional monetary policy shock. We model an expansionary unconventional monetary policy shock as a positive realization of the term structure shock $\varepsilon^{\mathrm{ts}}_t$. To mimic the environment of the zero lower bound period, we accompany the term structure shock with period-t news about the future time path of the stochastic component of conventional monetary policy $\varepsilon^{\mathrm{mp}}_{t+h}$ in (3.19), for $h = 0,1,2,\ldots$. We choose the news about $\varepsilon^{\mathrm{mp}}_t$ in a way that ensures that at time t all market participants know that the short-term nominal interest rate i_t will not respond to the unconventional monetary policy shock and will always remain at its steady state value.[27] The term structure shock therefore causes a persistent decrease of the long-term nominal interest rate i^L_t and a persistent decrease of the term structure $i^L_t - i_t$. The size of the shock $\varepsilon^{\mathrm{ts}}_t$ is chosen to generate the same fall in the long-term interest rate i^L_t as a conventional expansionary monetary policy shock in the benchmark model studied above.[28]

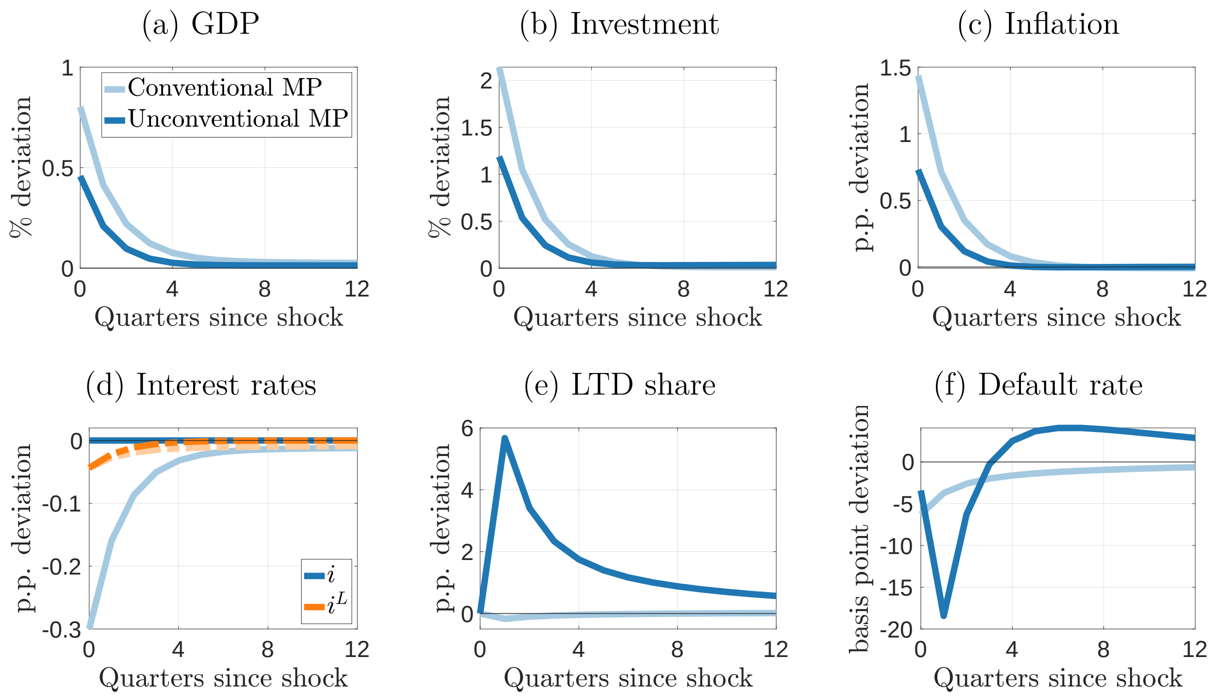
Figure 12 shows the aggregate response of the economy to this expansionary unconventional monetary policy shock and compares it to the effects of conventional monetary policy.

[26] A micro-founded approach to modeling segmented asset markets are preferred habitat models (Vayanos and Vila, 2021; Kekre et al., 2024). Risk-averse arbitrageurs can buy and sell both short- and long-term assets but require a time-varying term premium to engage in carry trades across the two markets. For studies of unconventional monetary policy in models without heterogeneity in corporate debt maturity, see Gertler and Karadi (2011); Carlstrom et al. (2017); Sims and Wu (2021). For empirical evidence on the effects of unconventional monetary policy, see Greenwood and Vayanos (2010); Gagnon et al. (2011); Swanson (2011); Krishnamurthy and Vissing-Jorgensen (2012); D'Amico and King (2013); Weale and Wieladek (2016); Droste et al. (2021).

[27] In the absence of these news about the time path of $\varepsilon^{\mathrm{mp}}_t$, the macroeconomic response to the term structure shock $\varepsilon^{\mathrm{ts}}_t$ would move inflation π_t and thereby trigger a response of the short-term nominal rate i_t through the Taylor rule (3.18). Because our model solution is linear with respect to aggregate fluctuations and the steady state of the model is identical to that of the benchmark model, we can apply results in McKay and Wolf (2023) to pin down the exact sequence of news shocks needed to be consistent with a constant short-term interest rate environment.

[28] The persistence ρ^{ts} is parameterized to be equal to the persistence ρ^{mp} of the conventional monetary policy shock studied above.

Figure 12: Aggregate effects of unconventional and conventional monetary policy



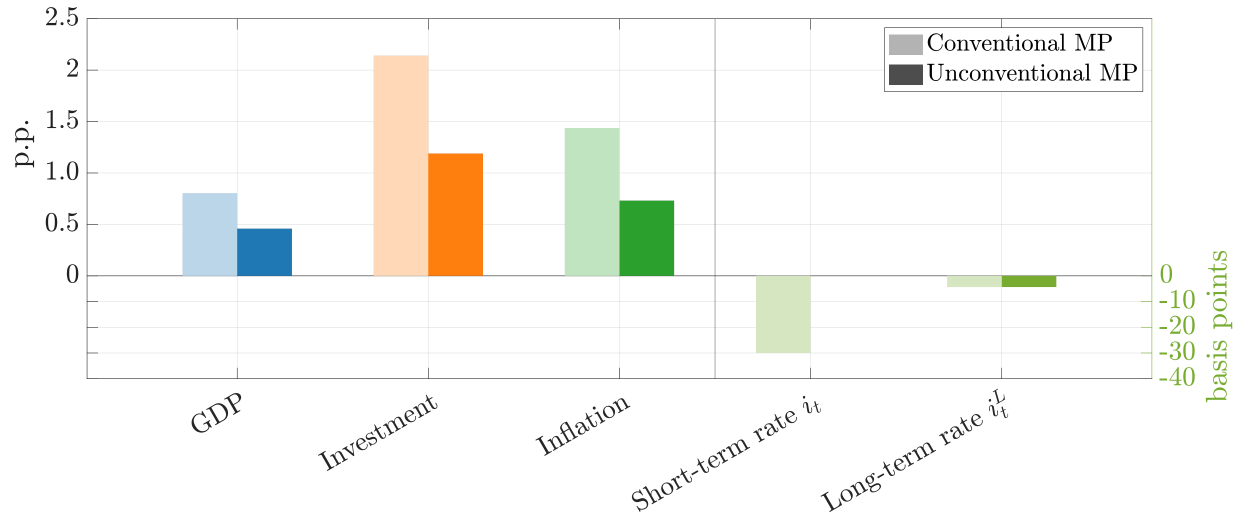
Note: This figure shows impulse responses to an expansionary unconventional monetary policy shock (dark lines) and compares it with impulse responses to an expansionary conventional monetary policy shock (light lines). The size of the unconventional monetary policy shock is chosen such that it generates the same fall in the long-term nominal interest rate i^L as a conventional expansionary monetary policy shock in the benchmark model studied above. The nominal short-term rate i, the nominal long-term rate i^L, and inflation are annualized. *LTD share* is the cross-sectional average of the long-term debt share. The default rate is annual. See Appendix D.1 for details.

The responses to an unconventional monetary policy shock are shown as the dark lines, those to an expansionary conventional monetary policy shock are shown as the light lines. On impact, the unconventional monetary policy shock lowers the long-term nominal rate i^L by 4 basis points (dark orange dash-dotted line), whereas the short-term nominal rate i remains unchanged (dark blue solid line). GDP jumps by 0.5% while inflation increases by 0.75 percentage points. In comparison, a conventional monetary policy shock which lowers the long-term nominal rate by the same amount (light orange dash-dotted line) but reduces the short-term rate by 30 basis points (light blue solid line), has larger effects on output and inflation. Figure 13 compares the peak responses of key model variables across the two policy experiments. The response of GDP, investment, and inflation to the unconventional monetary policy shock is dampened by 40–50% relative to conventional monetary policy.

One reason for the dampened response in Figure 13 is that unconventional monetary policy lowers the long-term nominal interest rate but the short-term nominal rate remains unchanged. A sizable part of firm investment is financed through short-term debt. A monetary policy shock with limited pass-through to short-term rates is therefore less effective than a conventional monetary policy shock which affects all interest rates in the economy.

A second important reason for the dampened dynamics is the strong endogenous response of debt maturity to the unconventional monetary policy shock. Panel (e) of Figure 12 shows

Figure 13: Comparison of unconventional and conventional monetary policy



Note: This figure shows peak impulse responses (at horizon $h = 0$) to an expansionary conventional monetary policy (MP) shock (light bars) and compares it with the impulse responses to an expansionary unconventional monetary policy shock (dark bars). See notes to Figure 12.

that the average share of long-term debt increases by almost 6 percentage points (compared to a *decrease* of less than 0.2 p.p. after an expansionary conventional monetary policy shock). Unconventional monetary policy flattens the yield curve and thereby induces firms to borrow at longer maturities. While default rates fall on impact due to the expansionary effect of unconventional monetary policy, the subsequent build-up of long-term debt eventually leads to a persistent increase in debt overhang and default rates which dampens investment and results in a weaker stimulus of aggregate demand.

This analysis highlights a key difference between conventional and unconventional monetary policy. After a conventional monetary policy shock the yield curve steepens, with small effects on firms' debt maturity choice. In contrast, unconventional monetary policy flattens the yield curve, with large effects on debt maturity. It is precisely this endogenous response of debt maturity which leads to a gradual build-up of debt overhang and thereby limits the overall stimulus of output and inflation.

5 Conclusion

More than two decades after the first seminal contributions introduced frictional firm financing into quantitative dynamic models of the macroeconomy (e.g., Bernanke et al., 1999), the contemporaneous literature offers new insights by focusing on debt heterogeneity.[29] As part of this broader research agenda, our paper documents the vast amount of heterogeneity in U.S. public firms' maturity choices. The maturity dimension of debt heterogeneity is

[29] For instance, recent contributions study differences between bonds and loans (Crouzet, 2018; Darmouni et al., 2021), between floating-rate debt and fixed-rate debt (Ippolito et al., 2018; Gürkaynak et al., 2022), or between credit lines and term loans (Greenwald et al., 2023).

typically absent from standard one-period-debt macro models.

We showed that heterogeneous debt maturity matters for monetary policy. We used micro data to show that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. We then developed a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. The model accounts for the maturity of debt and its distribution across firms. It replicates the empirical result that firms with higher shares of maturing debt react more strongly to monetary policy shocks. At the aggregate level, we showed that unconventional monetary policy has larger effects on debt maturity but smaller effects on output and inflation than conventional monetary policy.

These results raise new questions for the conduct of systematic monetary policy. How should central banks' policy response to shocks take debt maturity into account? When facing a trade-off between stabilizing output and inflation, the important role of debt overhang and debt deflation suggests that a given surprise increase in inflation can achieve a larger reduction in the output gap. The model developed in this paper provides a quantitative framework for studying this question.

Another possible extension of our model is to study the time-varying effectiveness of monetary policy. The partial equilibrium exercise shown in Figure 11 suggests that changes in firms' debt maturity structure can have important implications for the transmission of monetary policy shocks. In Compustat data, over the last 25 years the maturity of corporate debt has been trending upwards. Our model allows to assess the implications of this trend for the ability of central banks to stabilize the economy through monetary policy.

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Corporate Debt Maturity Matters for Monetary Policy

Appendix

Joachim Jungherr Matthias Meier Timo Reinelt Immo Schott

August 16, 2024

Appendix A Data Construction

A.1 Bond-level data

From Mergent FISD we obtain detailed bond-level data for bonds that mature between 1995Q2 and 2018Q3. The initial sample contains 304,868 bonds denominated in US$. In this sample, the total value of bonds at issue date amounts to 70.6 trillion (tn) US$ and the total value of bonds at maturity date is 57.7tn US$. The main reason why the value changes between issue date and maturity date is (partial) calls.

We construct a sample of comparable bonds by dropping the following types of bonds: convertible (number of bonds: 3,217; value at issue date: 698bn US$; value at maturity date: 292bn US$), convertible on call (322; 83bn; 37bn), exchangeable (32,105; 790bn; 752bn), (yankee) bonds issued by foreign entities (44,035; 8.8tn; 8.3tn), and bonds that mature less than one year after issuance (55,280; 22.3tn; 21.9tn). These bond types are not mutually exclusive and partially overlap. Dropping these type of bonds leaves us with a sample of 220,253 bonds with a value at issue date of 38.4tn US$ and a value at maturity date of 26.9tn US$. Of these bonds, we focus on fixed-coupon, non-callable bonds (61,642; 17.4tn; 17.1tn), which account for the majority of the value of bonds at maturity date. We further analyze bonds that are callable (140,598; 16.0tn; 4.9tn) or have a variable coupon (43,450; 7.1tn; 5.6tn).

We then create a monthly panel of bonds which tracks the outstanding amount – the par value computed as number of bonds issued times principal amount – over the lifetime of a bond. Mergent FISD further records the most recent action taken on a bond before maturity. An action can involve a reduction in the amount outstanding before maturity, e.g., due to calls, exchanges, reviews, defaults, or reorganizations. In this case, the data records the date, amount, and reason of reduction in the amount outstanding that occur before maturity. Among the total sample of bonds, about half record an action, while for only 5% of non-callable bonds an action is recorded. We use those records to track such changes to the outstanding amount over the life-cycle of each bond. When the bond matures at its scheduled maturity date, we use the remaining amount of the bond at maturity as maturing amount.

A.2 Linking bonds and firms

To match bonds to the debtor firm in every period over the bond's lifetime, we proceed in three steps. First, we construct a mapping from `gvkey`, the Compustat firm identifier, to the historical firm `cusip`. A firm `cusip` identifier is contained in the bond `cusip` identifier, which allows us to match bonds to firms. However, the bond `cusip` contains an identifier of a firm valid at the time of issuance. Because these firm `cusips` frequently change over time (for a given firm), we need to identify the historic firm `cusip` identifier valid in a given time period. To link `gvkey` and historical firm `cusip`, we combine the Compustat–CRSP link table (linking `gvkey` and `permno`, a firm identifier in CRSP) with CRSP, which links `permno` and historical firm `cusip`. The Compustat–CRSP link contains the start and end dates for which `gvkey-permno` links are valid. We only use links which are classified as reliable, coded "C" or "P" in the link table. We join this link table with the CRSP data and keep records that fall within link validity. For few `cusips` we have a link to more than one `gvkey`, which may arise due to the presence of subsidiary firms in CRSP. Among these ambiguous links, we drop links from `cusip` to `gvkey` with missing sales in Compustat. 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. We delete those bonds for which no link to `gvkey` is available in the Compustat—CRSP table and drop the bonds with remaining ambiguous links. 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. If the debtor firm of the bond does not change (e.g., because of M&A), this procedure correctly identifies the bond debtor over the lifetime of the bond.

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 firm. We prepare the SDC data as follows. 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 gvkeys 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 in 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 the 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. By accounting for M&A activities, we additionally map bonds issued by subsidiary firms before acquisition to the headquarter firms observed in Compustat.

A.3 Variables

Capital growth. We construct capital stock series using a perpetual inventory method (PIM) based on net property, plants, and equipment (PPE, `ppentq` in Compustat).[30] We exclude firm-

[30] We do not use data on capital expenditures (`capxy`) because it does not allow to precisely measure how the productive capital stock of a firm evolves over time. Compustat data on capital expenditures (`capxy`) is informative with respect to gross investment but it does not include information about capital retirements

quarters with negative values of net PPE. For the PIM, we first identify investment spells for which net PPE is observed without gaps. If the gap is only a single quarter, we impute net PPE via linear interpolation. We exclude a small number of one-quarter capital spikes. These are quarters 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. For the first period of every investment spell we initialize capital by (CPI-deflated) gross PPE (`ppegtq`). For all subsequent quarters of the same spell we compute capital by adding the first difference in (CPI-deflated) net PPE to capital of the previous quarter. We only consider firm-quarters of firms for which at least 40 quarters of capital are observed, similar to Ottonello and Winberry (2020). We trim the cumulative capital growth rates at the top and bottom 1% of the distribution.

Maturing bond share. We compute the maturing bond share $\mathcal{M}_{it}$ defined in (2.1) by dividing the total par value of maturing bonds of firm i in quarter t by average total debt of firm i over the preceding four quarters from $t-1$ to $t-4$. Total debt is based on debt in current liabilities and long-term debt (`dlcq+dlttq`). We smooth out firm-specific seasonal factors and other transitory fluctuations by using the backward-looking four-quarter moving average of debt. We trim the maturing bond share at 100%. Analogous to capital growth, we only consider firm-quarters for firms with at least 40 quarters of observed maturing bond shares. As alternative denominators for $\mathcal{M}_{it}$, we consider total debt at the end of period $t-1$, as well as capital, sales, and assets (both as backward-looking four-quarter moving averages and as simple lagged values), see Section 2.5.

Credit spreads. We obtain monthly credit spreads for corporate bonds, as identified by their ISIN, from Refinitiv. Credit spreads are defined as the difference between the corporate bond yield and the risk-free yield based on U.S. Treasury bonds of comparable maturity (data code `SP` in Refinitiv). Following Gilchrist and Zakrajšek (2012), we drop observations with spreads above 3500 basis points and below 5 basis points. Based on the methodology described above, bonds are matched to Compustat firms. To aggregate monthly spreads to firm-quarter average spreads, we first aggregate monthly bond-level credit spreads to the average bond-level spread per quarter. In a second step, we compute the volume-weighted average credit spread for each firm and quarter. Figure A.1 (b) plots the volume-weighted average credit spread over time, which closely tracks the spread series of Gilchrist and Zakrajšek (2012).

Control variables. The list of control variables includes leverage, liquidity, log assets, sales growth, average bond maturity, and age. Leverage is total debt (`dlcq+dlttq`) divided by assets (`atq`) and is trimmed at 1000%.[31] Liquidity is cash and short-term investments (`cheq`) divided by assets (`atq`). Log assets is the natural logarithm of deflated assets (`atq`). Sales growth is the growth rate of deflated sales (`saleq`). Average bond maturity is the average remaining maturity across outstanding bonds for firm i in quarter t, weighted by the par value of outstanding bonds. We measure firm age as the time since the firm's founding year, which we obtain from WorldScope (`WC18273` in Refinitiv). If there are Compustat observations prior to the founding year according to WorldScope, which is the case for 1% of observations, we define age as the time since the firm's first observation in the Compustat sample. All control variables except age are winsorized at the top and bottom 0.5% of the distribution.

and capital sales (Clementi and Palazzo, 2019).

[31] This treatment only affects the sample of non-bond-issuing firms. There are no observations with leverage above 1000% in the sample of bond-issuing firms.

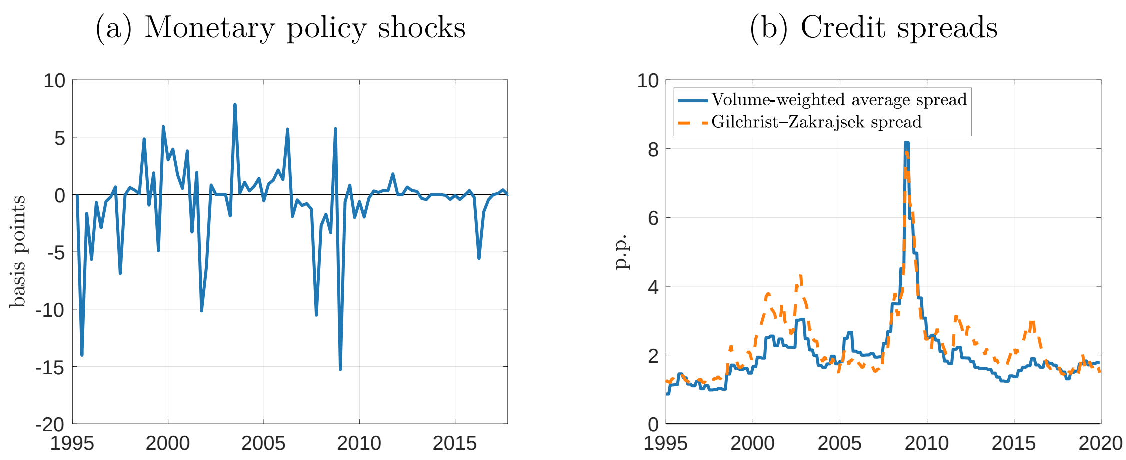
Other outcomes. In Figures 4 and B.1, we consider as outcomes growth in debt, sales, employment, and cost of goods sold. We use total debt (`dlcq`+`dlttq`), sales (`saleq`), and cost of goods sold (based on `cogsq`), all CPI-deflated. We smooth out firm-specific seasonal factors and other transitory fluctuations by using the backward-looking four-quarter moving average of debt, sales, and cost of goods sold. We then estimate local projections on the log differences of these smoothed variables. This yields similar results as Smooth Local Projections proposed by Barnichon and Brownlees (2019). Employment is recorded only annually in Compustat. We construct quarterly firm-level employment via the Chow and Lin (1971) method by combining annual employment and quarterly cost of goods sold. We use `cogsq` because it contains employment expenses, which means quarterly variation in `cogsq` should be informative about employment. We trim the cumulative growth rates of debt, sales, employment, and cost of goods sold at the top and bottom 1% of the distribution.

Table A.1: Descriptive statistics for bond-issuing and non-bond-issuing firms

	Bond-issuing firms			Non-bond-issuing firms		
	Mean	Sd	Obs	Mean	Sd	Obs
Capital growth *(in log points)*	0.77	4.74	35,545	1.47	8.73	415,409
Leverage *(debt/assets in %)*	34.02	18.67	35,545	31.96	58.67	395,536
Liquidity *(cash/assets in %)*	7.62	8.47	35,544	22.32	25.83	411,703
Total assets *(in bln. 2005 USD)*	13.50	14.30	35,545	0.90	3.72	411,899
Sales growth *(in %)*	0.75	19.63	35,489	1.82	40.25	370,079
Age *(in years)*	42.06	31.50	35,545	18.27	17.22	415,396

Note: This table provides descriptive statistics for bond-issuing firms (left panel) and non-bond-issuing firms (right panel) from 1995Q2 through 2018Q3. For details on the definition of variables, see Appendix A.3.

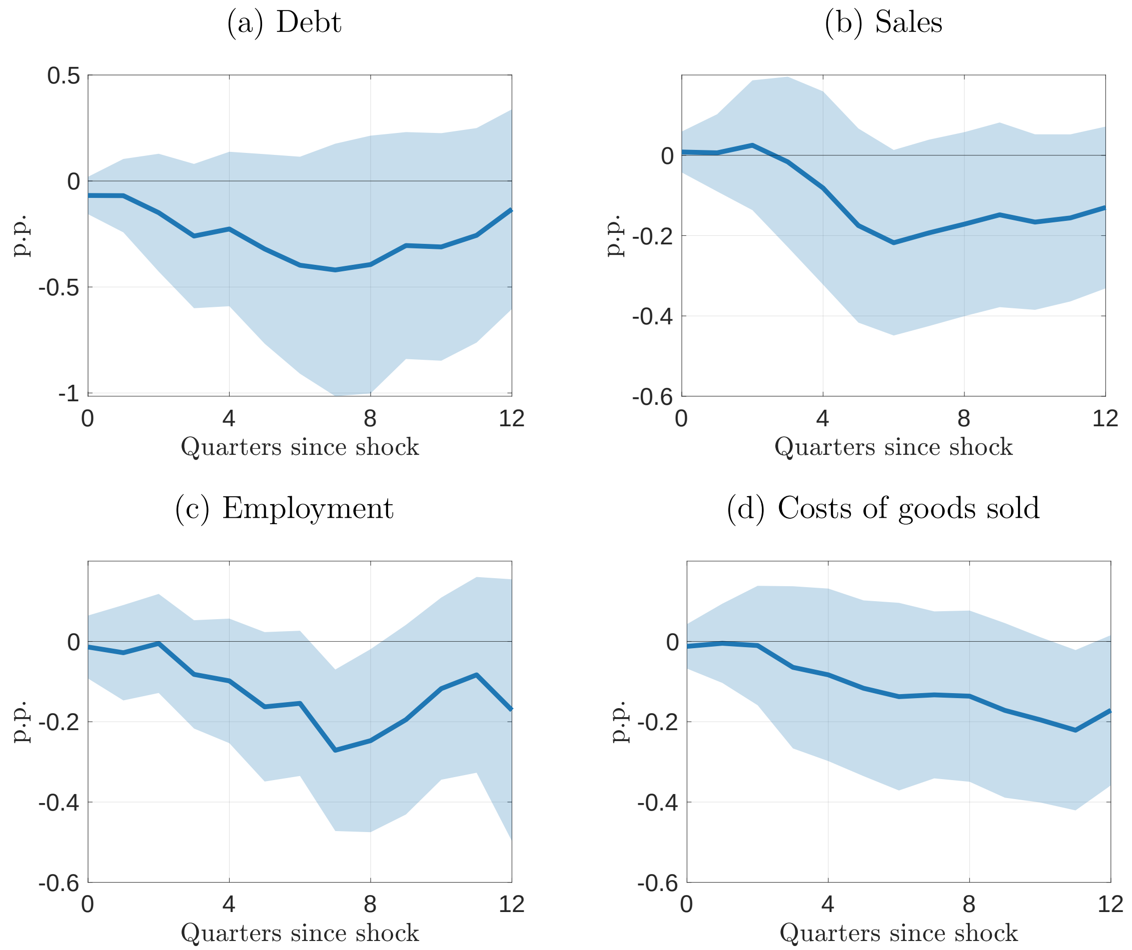
Figure A.1: Time series



Note: Panel (a) shows the baseline monetary policy shock series at quarterly frequency as described in Section 2.1. In panel (b), the solid line shows the volume-weighted cross-sectional average credit spread based on Refinitiv data as described above. The dashed line shows the Gilchrist and Zakrajšek (2012) series of credit spreads.

Appendix B Additional Empirical Results

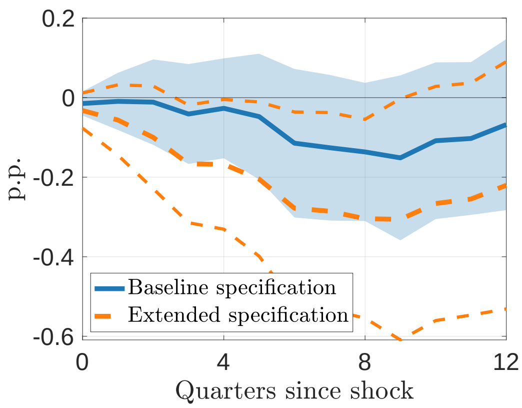
Figure B.1: Differential response of other variables associated with higher $\mathcal{M}_{it}$ using baseline local projection



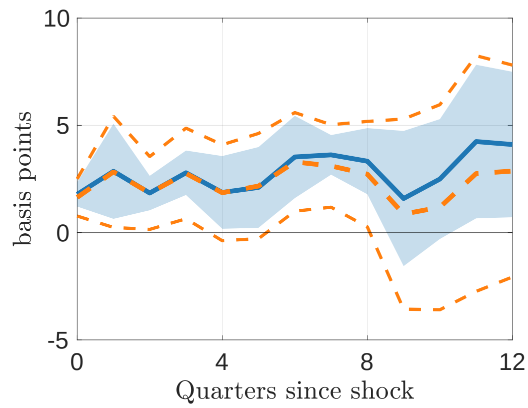
Note: The figure shows the estimated β_1^h coefficients based on equation (2.3), but where the left-hand side is $\Delta^{h+1}\log(\text{debt})_{it+h}$ in panel (a), $\Delta^{h+1}\log(\text{sales})_{it+h}$ in panel (b), $\Delta^{h+1}\log(\text{employment})_{it+h}$ in panel (c), and $\Delta^{h+1}\log(\text{cost of goods sold})_{it+h}$ in panel (d). The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.2: Differential investment and credit spread responses associated with maturing bond share for alternative monetary policy shocks accounting for public and central bank information effects

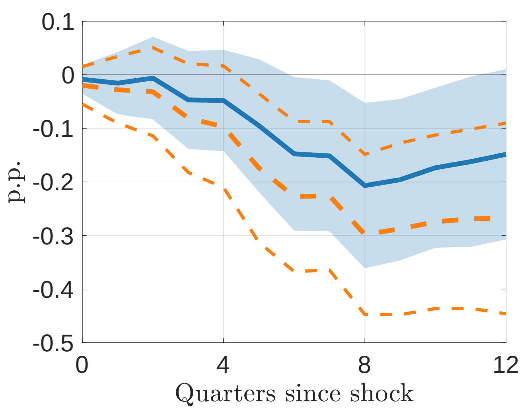
(a) Investment: Miranda-Agrippino and Ricco (2021)



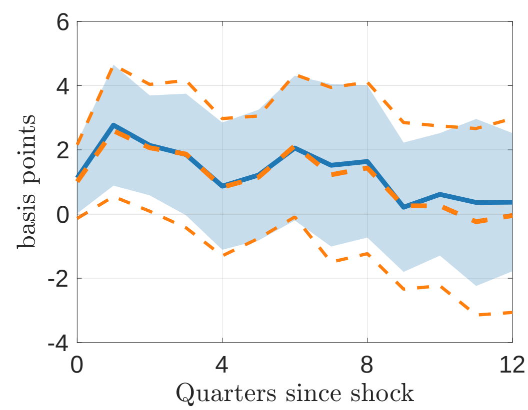
(c) Spread: Miranda-Agrippino and Ricco (2021)



(c) Investment: Bauer and Swanson (2023)

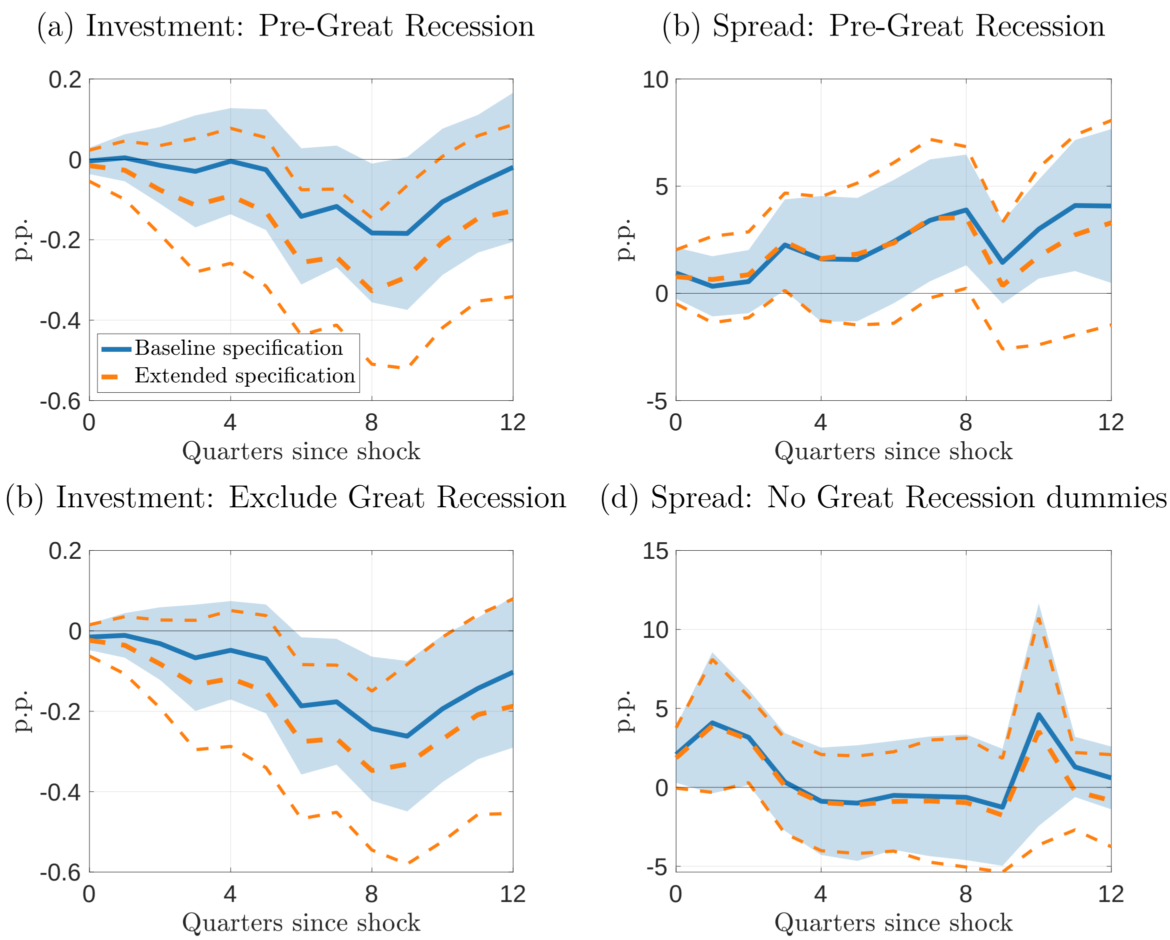


(d) Spread: Bauer and Swanson (2023)



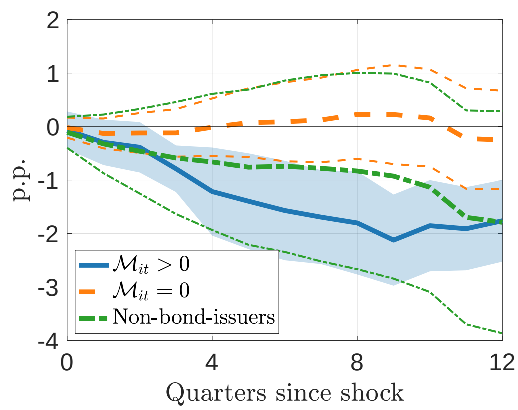
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) using various alternative monetary policy shocks $\varepsilon_t^{\text{mp}}$. In panels (a) and (b), we use the shocks of Miranda-Agrippino and Ricco (2021). In panels (c) and (d) we use the shocks of Bauer and Swanson (2023). The local projection for bond spreads interacts the regressors with a Great Recession (2008Q3-2009Q2) dummy and the figure plots the non-crisis coefficients. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.3: Differential investment and credit spread response associated with maturing bond share based on alternative samples



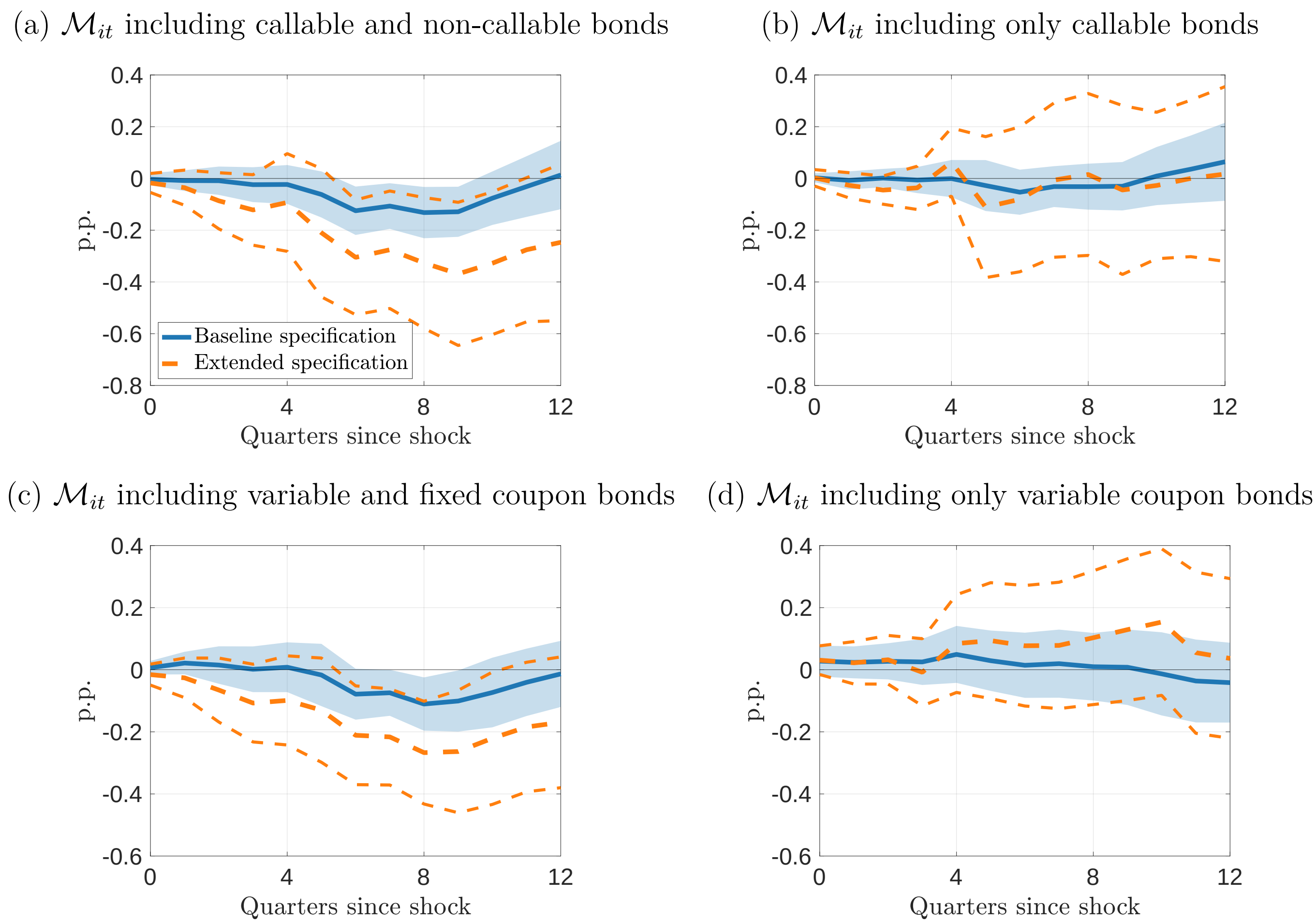
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), using alternative samples. Panels (a) and (c) use only observations until 2008Q2. Panel (b) excludes monetary policy shocks between 2008Q3 and 2009Q2. Panel (d) uses the full sample but does not include Great Recession dummies as in the specification in the main text. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.4: Differential investment response associated of firms with and without maturing bonds compared to non-bond-issuing firms



Note: The figure shows the estimated coefficients $\beta^h_{\cdot,1}$ based on the local projection $\Delta^{h+1} \log k_{it+h} = \beta^h_{\mathcal{M}>0,0} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{\mathcal{M}=0,0} \mathbb{1}\{\mathcal{M}_{it} = 0\} + \beta^h_{\mathcal{M}>0,1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\text{mp}}_t + \beta^h_{\mathcal{M}=0,1} \mathbb{1}\{\mathcal{M}_{it} = 0\} \varepsilon^{\text{mp}}_t + \beta^h_{\textit{non-issuer},1} \mathbb{1}\{\textit{Non-bond-issuer}_i\} \varepsilon^{\text{mp}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.5: Differential investment response associated with maturing bond share including callable bonds or bonds with variable coupon



(a) $\mathcal{M}_{it}$ including callable and non-callable bonds

(b) $\mathcal{M}_{it}$ including only callable bonds

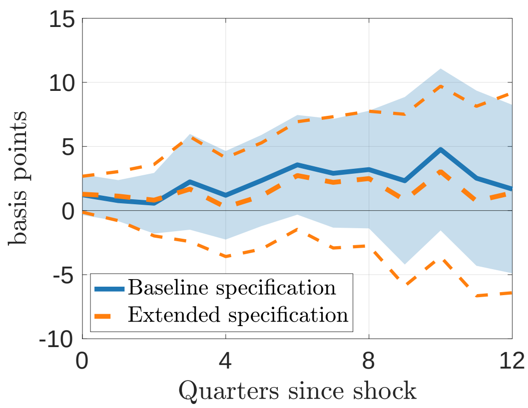
(c) $\mathcal{M}_{it}$ including variable and fixed coupon bonds

(d) $\mathcal{M}_{it}$ including only variable coupon bonds

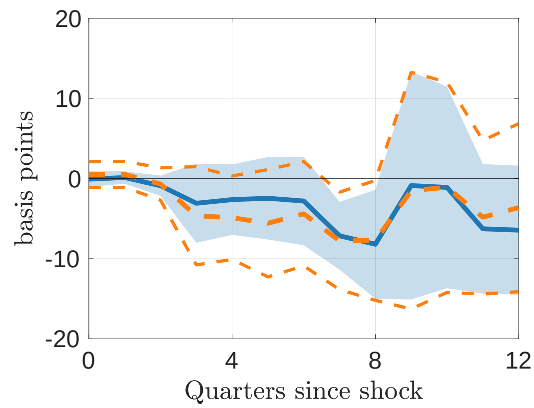
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), for various alternative definitions of the maturing bond share $\mathcal{M}_{it}$. In our main findings, $\mathcal{M}_{it}$ includes only non-callable fixed coupon bonds. In panel (a), we include both callable and non-callable (fixed coupon) bonds. In panel (b), we re-define $\mathcal{M}_{it}$ based only on callable (fixed coupon) bonds. In panel (c), we include both variable coupon and fixed coupon (non-callable) bonds. In panel (d), we re-define $\mathcal{M}_{it}$ based only on variable coupon (non-callable) bonds. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.6: Differential credit spread response associated with maturing bond share including callable bonds or bonds with variable coupon

(a) $\mathcal{M}_{it}$ including callable and non-callable bonds

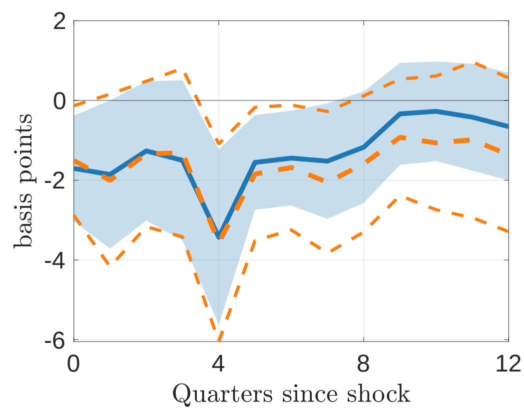


(b) $\mathcal{M}_{it}$ including only callable bonds



(c) $\mathcal{M}_{it}$ including variable and fixed coupon bonds

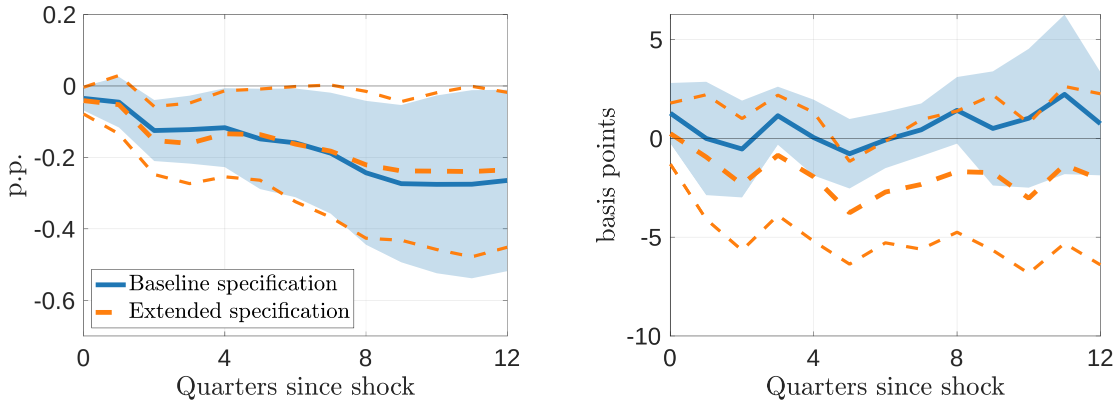
(d) $\mathcal{M}_{it}$ including only variable coupon bonds



Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), for various alternative definitions of the maturing bond share $\mathcal{M}_{it}$. In our main findings, $\mathcal{M}_{it}$ includes only non-callable fixed coupon bonds. In panel (a), we include both callable and non-callable (fixed coupon) bonds. In panel (b), we re-define $\mathcal{M}_{it}$ based only on callable (fixed coupon) bonds. In panel (c), we include both variable coupon and fixed coupon (non-callable) bonds. In panel (d), we re-define $\mathcal{M}_{it}$ based only on variable coupon (non-callable) bonds. The local projections additionally control for a Great Recession dummy variable interacted with the regressors. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.7: Differential investment response associated with one-year maturing bond share

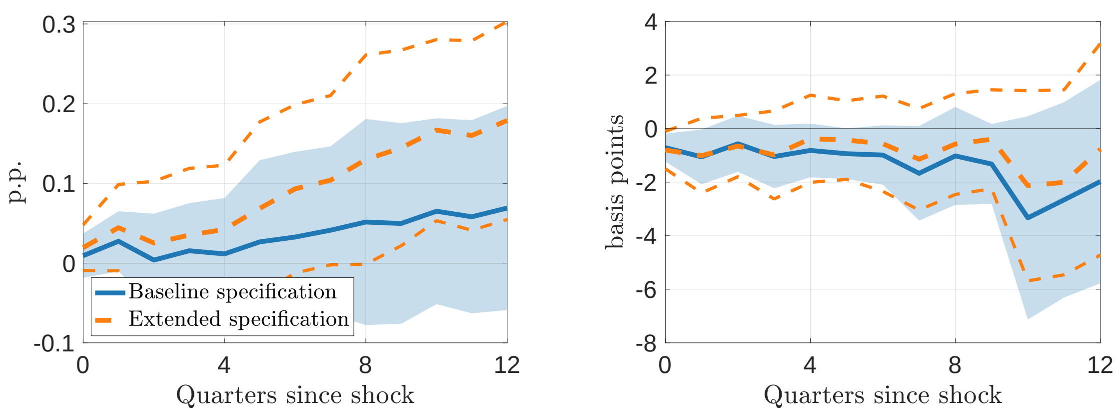
(a) Investment (b) Credit spreads



Note: This figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and the estimated β_1^h coefficients based on the extended local projection (2.4), using the maturing bond share $\mathcal{M}_{it}^{1y}$ defined over the next year (i.e., including maturing bonds in quarters t to including $t+3$). The local projections with credit spreads as left-hand side in panel (b) additionally control for a Great Recession dummy variable interacted with the regressors. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

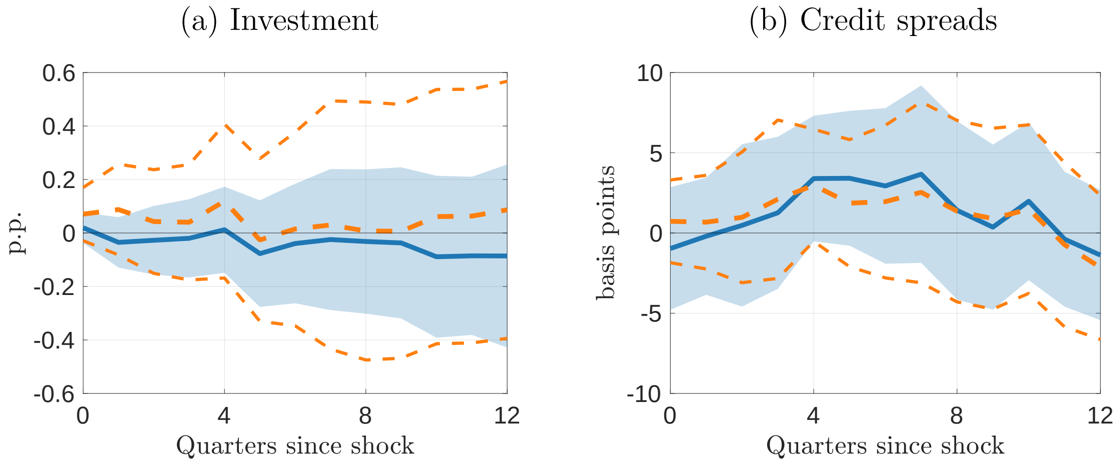
Figure B.8: Differential investment and credit spread responses associated with lagged maturing bond share

(a) Investment (b) Credit spreads



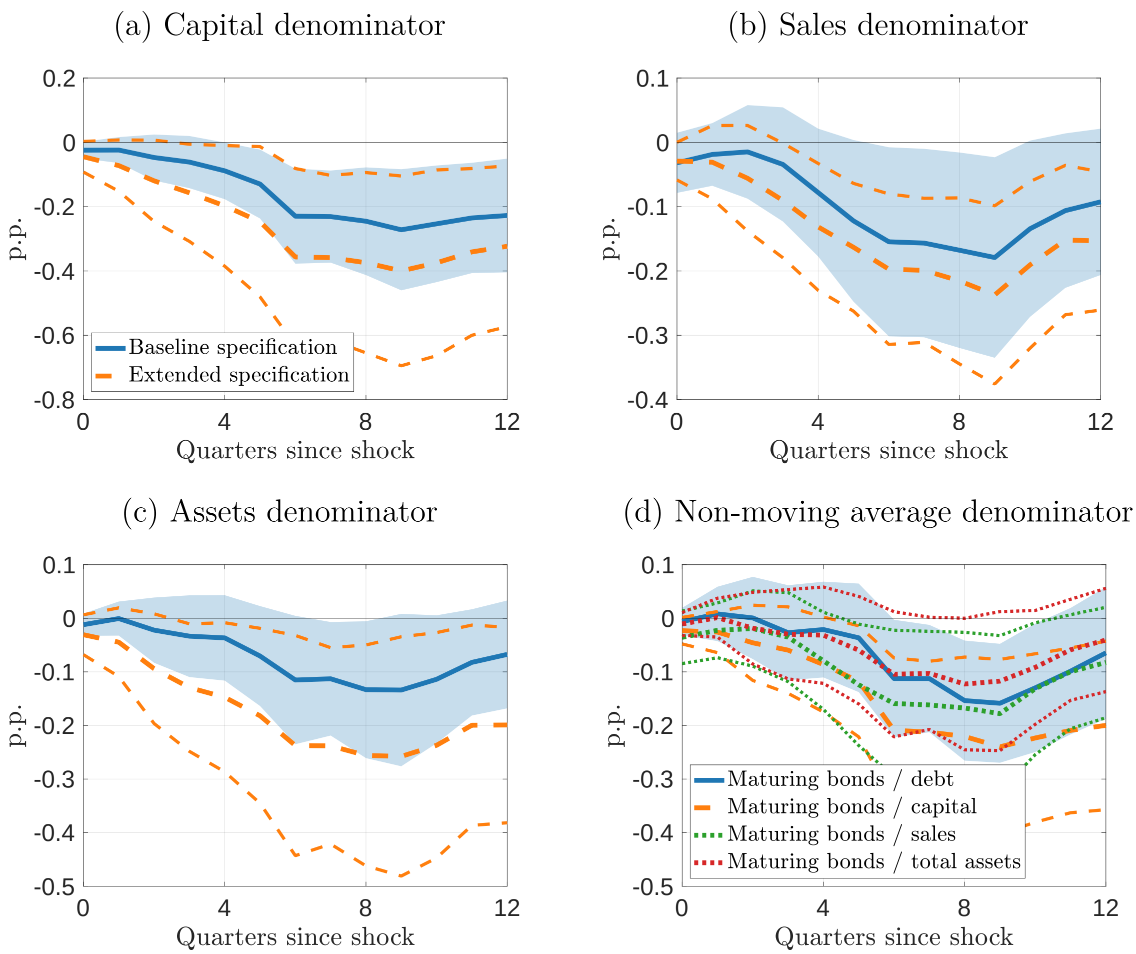
Note: This figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and the extended local projection (2.4), using $\mathcal{M}_{it-1}$ instead of $\mathcal{M}_{it}$. The local projections with credit spreads as left-hand side in panel (b) additionally control for a Great Recession dummy variable interacted with the regressors. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.9: Differential investment and credit spread response associated with Compustat maturing debt share



Note: This figure shows the estimated β_1^h coefficients based on the local projections (2.3) and (2.4), using $\widetilde{\mathcal{M}}_{it}$ instead of $\mathcal{M}_{it}$. $\widetilde{\mathcal{M}}_{it} = (\text{debt in current liabilities})_{it}/(\text{total debt})_{it-1}$ measures maturing debt based on Compustat data only. The local projections with credit spreads as left-hand side in panel (b) additionally control for a Great Recession dummy variable interacted with the regressors. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing debt share. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

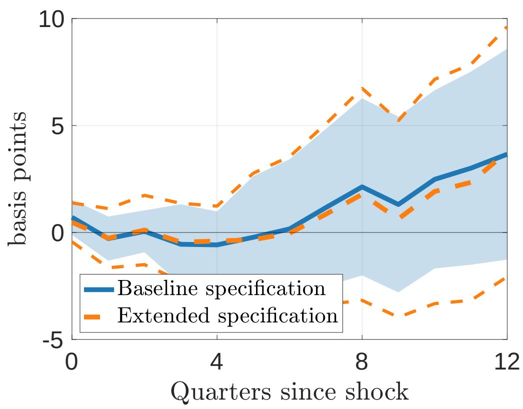
Figure B.10: Differential investment response associated with maturing bond share using alternative denominators



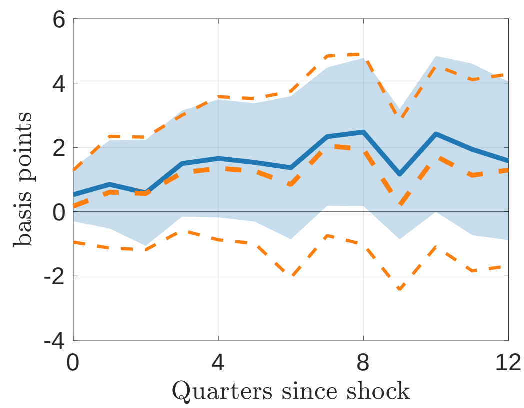
Note: In panels (a) to (c) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), for various alternative definitions of $\mathcal{M}_{it}$. In panel (a), we re-define $\mathcal{M}_{it}$ as the ratio of maturing bonds over the average capital stock in the preceding four quarters, in (b) the denominator is average sales, in (c) average assets. In panel (d) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) using as denominator debt, capital, sales, or assets in the preceding quarter, instead of constructing a moving average. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.11: Differential credit spread response associated with maturing bond share using alternative denominators

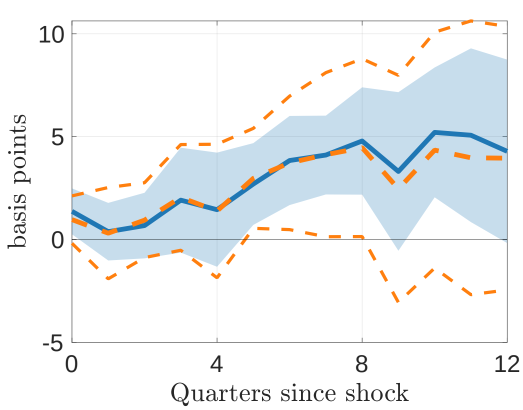
(a) Capital denominator



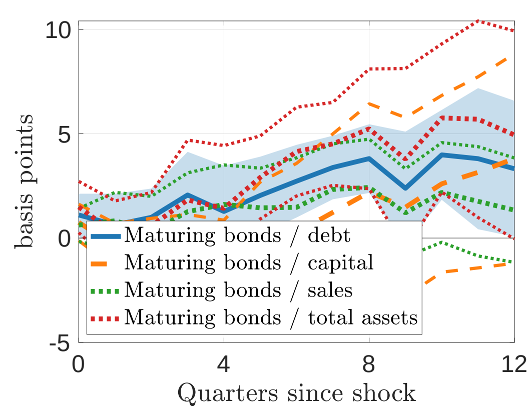
(b) Sales denominator



(c) Assets denominator

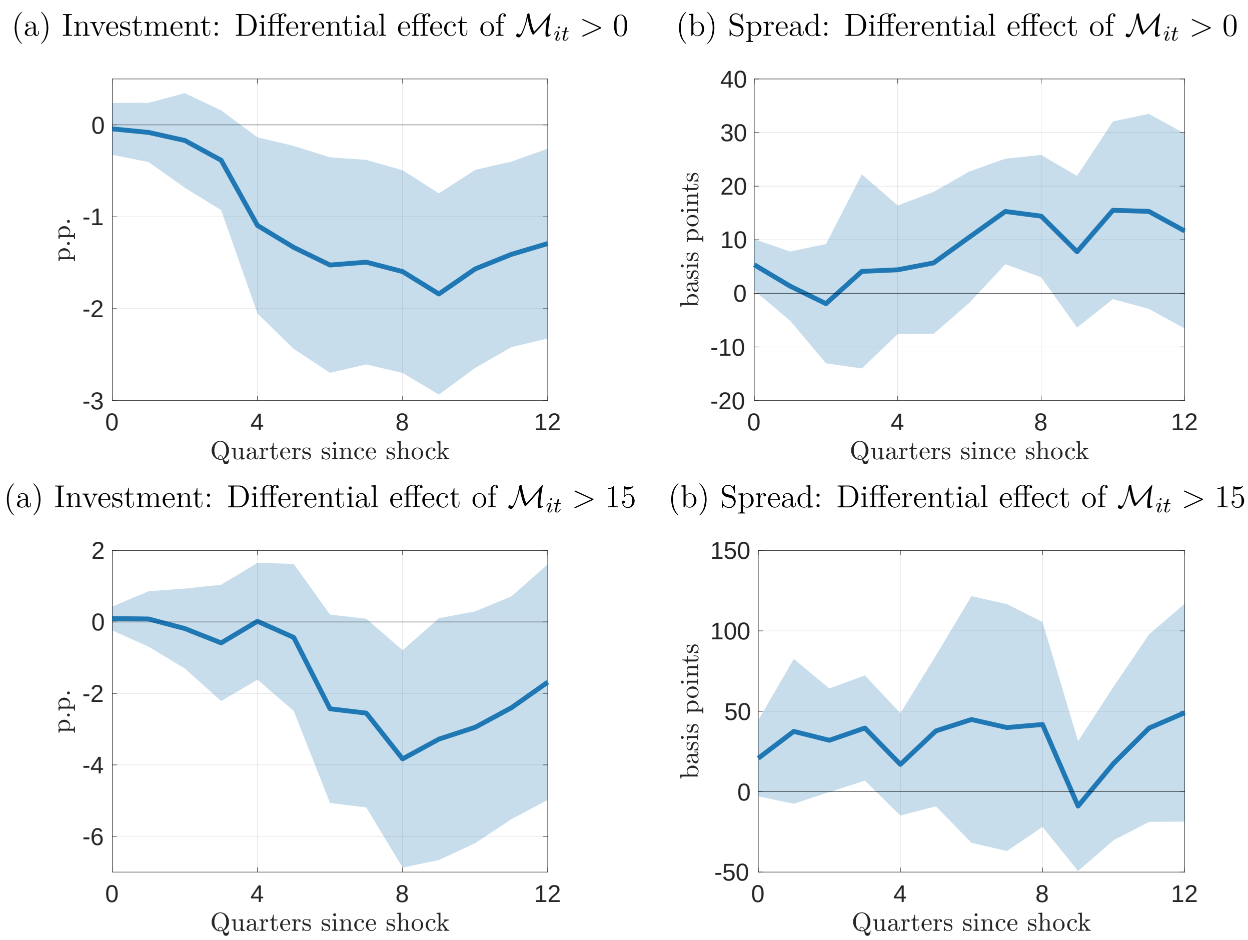


(d) Non-moving average denominator



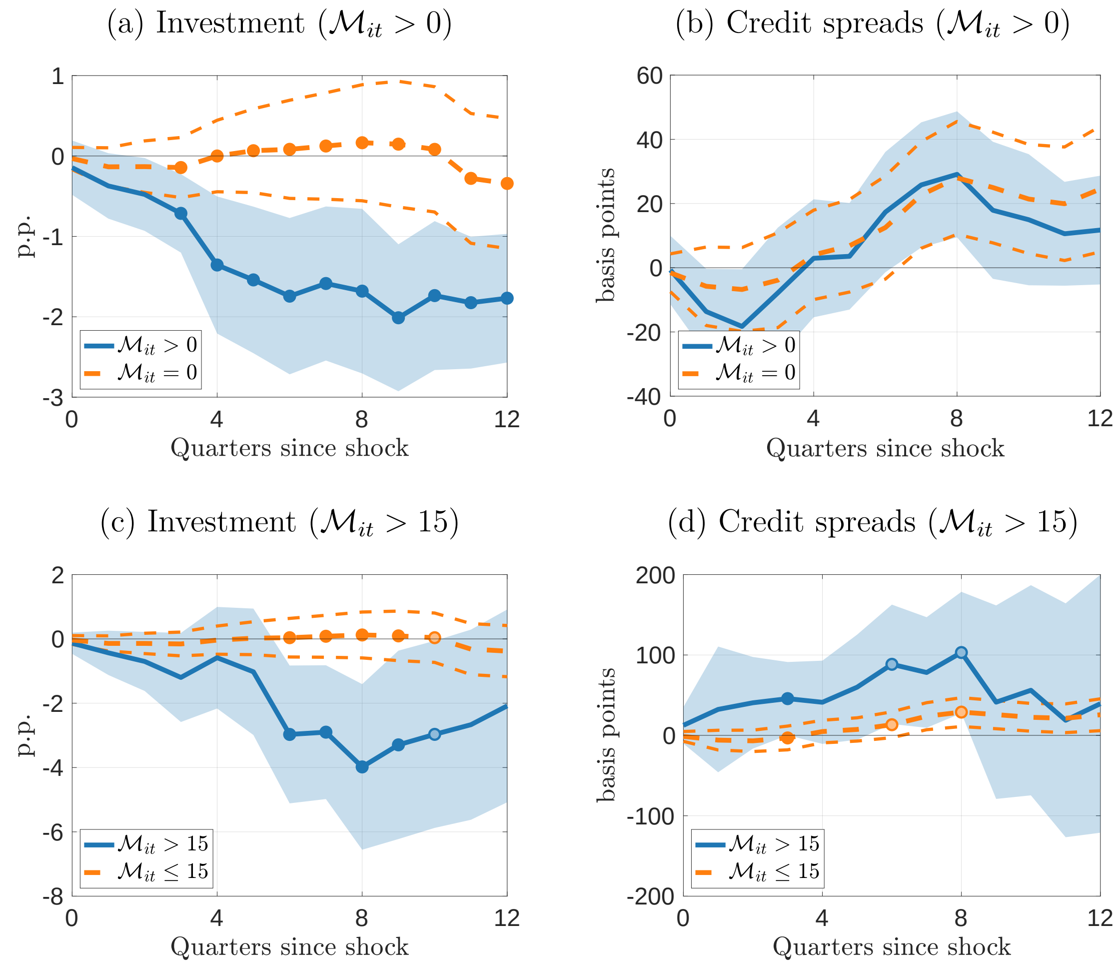
Note: In panels (a) to (c) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), for various alternative definitions of $\mathcal{M}_{it}$. In panel (a), we re-define $\mathcal{M}_{it}$ as the ratio of maturing bonds over the average capital stock in the preceding four quarters, in (b) the denominator is average sales, in (c) average assets. In panel (d) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) using as denominator debt, capital, sales, or assets in the preceding quarter, instead of constructing a moving average. The local projections additionally control for a Great Recession dummy variable interacted with the regressors. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.12: Differential investment and credit spread responses associated with maturing bond share using dummy specification of bond maturity



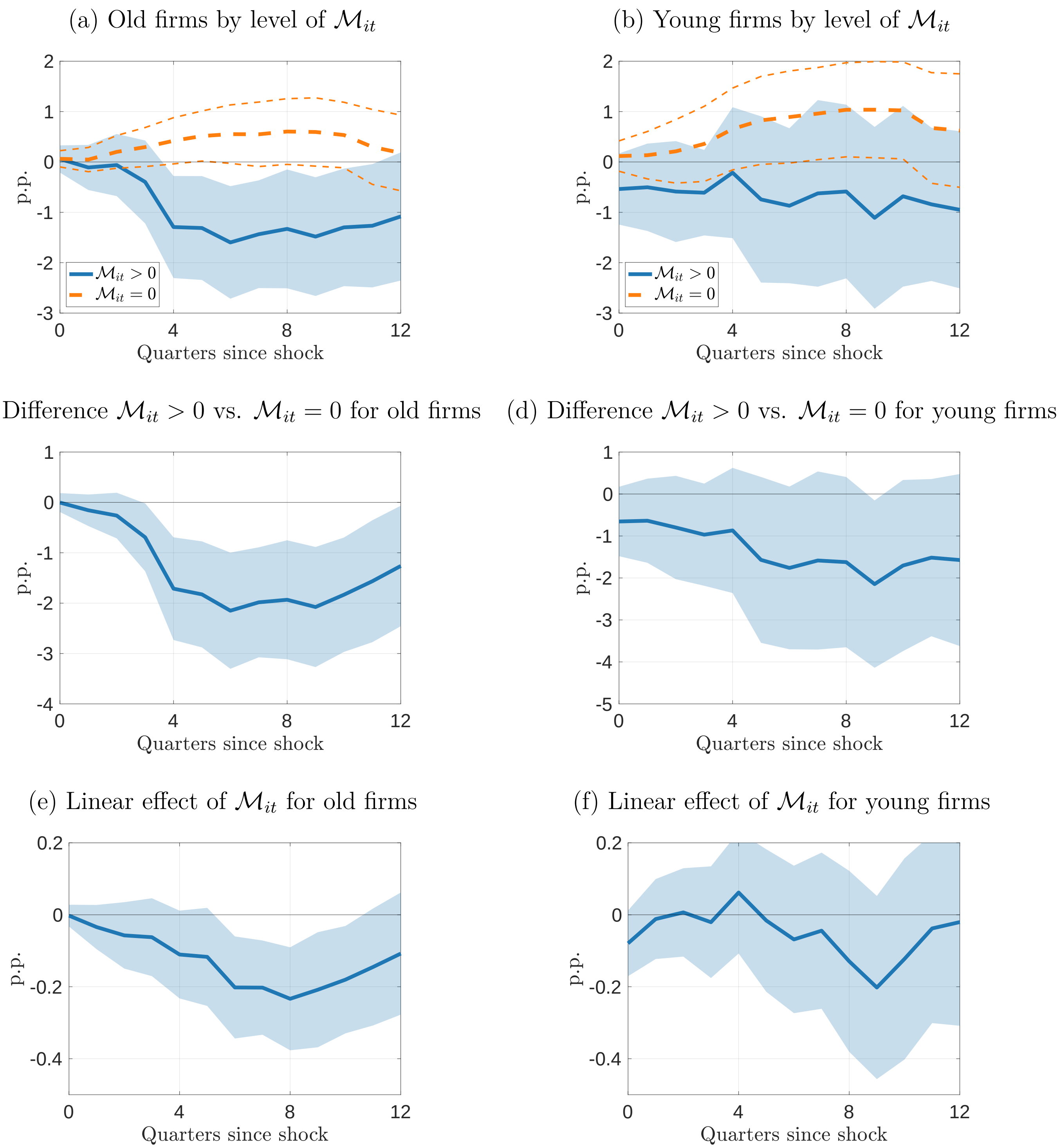
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3), using $\mathbb{1}\{\mathcal{M}_{it} > 0\}$ instead of $\mathcal{M}_{it}$ in panels (a) and (b), and $\mathbb{1}\{\mathcal{M}_{it} > 15\}$ instead of $\mathcal{M}_{it}$ in panels (c) and (d). The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with, respectively, $\mathcal{M}_{it} > 0$ and $\mathcal{M}_{it} > 15$ (i.e., 15 % of debt). The local projections with credit spreads as left-hand side in panel (b) additionally control for a Great Recession dummy variable interacted with the regressors. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.13: Grouping estimator for investment and credit spread responses



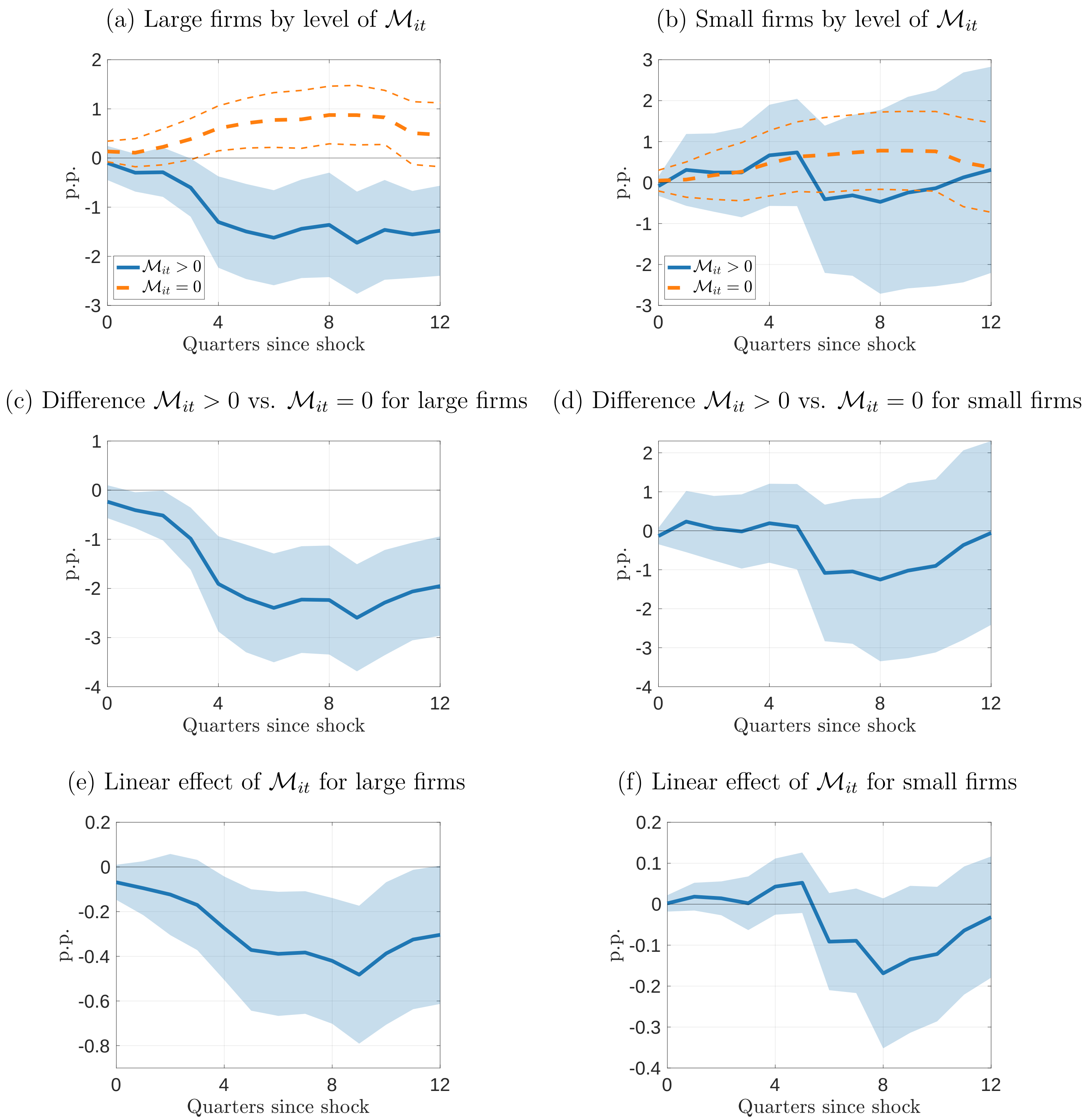
Note: The figure shows the estimated $\beta^h_{1,high}$ and $\beta^h_{1,low}$ coefficients based on the local projection $\Delta^{h+1} y_{it+h} = \beta^h_{0,high}\mathbb{1}\{\mathcal{M}_{it} > \widetilde{\mathcal{M}}\} + \beta^h_{1,low}\mathbb{1}\{\mathcal{M}_{it} \leq \widetilde{\mathcal{M}}\} \times \varepsilon^{\mathrm{mp}}_t + \beta^h_{1,high}\mathbb{1}\{\mathcal{M}_{it} > \widetilde{\mathcal{M}}\} \times \varepsilon^{\mathrm{mp}}_t + \beta^h_{2,low}\mathbb{1}\{\mathcal{M}_{it} \leq \widetilde{\mathcal{M}}\} \times \Delta\mathrm{gdp}_{t-1} + \beta^h_{2,high}\mathbb{1}\{\mathcal{M}_{it} > \widetilde{\mathcal{M}}\} \times \Delta\mathrm{gdp}_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$, where $\mathbb{1}\{\cdot\}$ denotes a dummy variable that equals one if the inequality is satisfied and zero else. In panels (a) and (c), we define $\Delta^{h+1} y_{it+h}$ as capital growth, in panels (b) and (d) as the change in credit spreads. In panels (a) and (b), the threshold maturing bond share is $\widetilde{\mathcal{M}} = 0$, in panels (c) and (d) we set $\widetilde{\mathcal{M}} = 15$. The local projection for bond spreads additionally interacts the regressors with a Great Recession (2008Q3-2009Q2) dummy and the figure plots the non-crisis coefficients. Shaded areas (and outer dashed lines) indicate 95% confidence bands based on standard errors clustered by firms and quarters. Filled (unfilled) dots indicate that the estimates of $\beta^h_{1,high}$ and $\beta^h_{1,low}$ are significantly different from each other at the 5% (10%) level.

Figure B.14: Differential investment responses due to maturing bond share conditional on firm age group



Note: Panels (a) and (b) show in the solid lines the estimated coefficients $\beta^h_{large,\mathcal{M}>0,1}$ and $\beta^h_{small,\mathcal{M}>0,1}$, and in the dashed lines the analogous coefficients for $\mathcal{M} = 0$, from the local projection $\Delta^{h+1} \log k_{it+h} = \beta^h_{young,\mathcal{M}>0,0} Young_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{old,\mathcal{M}>0,0} Old_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{young,\mathcal{M}>0,1} Young_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\text{mp}}_t + \beta^h_{old,\mathcal{M}>0,1} Old_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\text{mp}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$ where $Young_{it}$ and Old_{it} are dummy variables capturing if the firm's age is below or above the sector-quarter specific median age. The vector Z_{it} here contains the interactions for $\mathbb{1}\{\mathcal{M}_{it} = 0\}$ as written out for $\mathbb{1}\{\mathcal{M}_{it} > 0\}$, and all interactions of age and maturity dummies with lagged GDP growth Δgdp_{t-1}. In panels (c) and (d) we plot the difference between the respective estimators. Panels (e) and (f) show the estimated coefficients $\beta^h_{old,1}$ and $\beta^h_{young,1}$ from the local projection $\Delta^{h+1} \log k_{it+h} = \beta^h_{young,0} Young_{it-1} + \beta^h_{old,0} Old_{it-1} + \beta^h_{\mathcal{M},0} \mathcal{M}_{it} + \beta^h_{young,1} Young_{it-1} \mathcal{M}_{it} \varepsilon^{\text{MP}}_t + \beta^h_{old,1} Old_{it-1} \mathcal{M}_{it} \varepsilon^{\text{MP}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$. The vector Z_{it} contains all interactions of age dummies and maturity with lagged GDP growth Δgdp_{t-1}. 95% confidence bands based on standard errors clustered by firms and quarters.

Figure B.15: Differential investment responses due to maturing bond share conditional on firm size group



Note: Panels (a) and (b) show in the solid lines the estimated coefficients $\beta^h_{large,\mathcal{M}>0,1}$ and $\beta^h_{small,\mathcal{M}>0,1}$, and in the dashed lines the analogous coefficients for $\mathcal{M} = 0$, from the local projection $\Delta^{h+1} \log k_{it+h} = \beta^h_{small,\mathcal{M}>0,0} Small_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{large,\mathcal{M}>0,0} Large_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{small,\mathcal{M}>0,1} Small_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\mathrm{mp}}_t + \beta^h_{large,\mathcal{M}>0,1} Large_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\mathrm{mp}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$ where $Small_{it}$ and $Large_{it}$ are dummy variables capturing if the firm's size measured by total assets is below or above the sector-quarter specific median size. The vector Z_{it} here contains the interactions for $\mathbb{1}\{\mathcal{M}_{it} = 0\}$ as written out for $\mathbb{1}\{\mathcal{M}_{it} > 0\}$, and all interactions of interactions of size and maturity dummies with lagged GDP growth Δgdp_{t-1}. In panels (c) and (d) we plot the difference between the respective estimators. Panels (e) and (f) show the estimated coefficients $\beta^h_{large,1}$ and $\beta^h_{small,1}$ from the local projection $\Delta^{h+1} \log k_{it+h} = \beta^h_{small,0} Small_{it-1} + \beta^h_{large,0} Large_{it-1} + \beta^h_{\mathcal{M},0} \mathcal{M}_{it} + \beta^h_{small,1} Small_{it-1} \mathcal{M}_{it} \varepsilon^{\mathrm{MP}}_t + \beta^h_{large,1} Large_{it-1} \mathcal{M}_{it} \varepsilon^{\mathrm{MP}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$. The vector Z_{it} contains all interactions of size dummies and maturity with lagged GDP growth Δgdp_{t-1}. 95% confidence bands based on standard errors clustered by firms and quarters.

Appendix C Model

In this section we provide additional details of the model setup in Section 3.

Production firms' labor demand. A production firm i enters period t with productivity z_{it} and capital k_{it}. Given the price of undifferentiated output p_t and the wage rate w_t, optimal labor demand l_{it} solves a simple static maximization problem. The first-order condition with respect to l_{it} in (3.2) is:

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

This implies that firm revenue net of labor costs is

$$\max_{l_{it}} \quad p_t z_{it} \left(k_{it}^{\psi} l_{it}^{1-\psi} \right)^{\zeta} - w_t l_{it} = A_{it} k_{it}^{\alpha}, \tag{C.2}$$

where

$$A_{it} \equiv (p_t z_{it})^{\frac{1}{1-\zeta(1-\psi)}} \left[1 - \zeta(1-\psi) \right] \left(\frac{\zeta(1-\psi)}{w_{it}} \right)^{\frac{\zeta(1-\psi)}{1-\zeta(1-\psi)}} \quad \text{and} \quad \alpha \equiv \frac{\zeta\psi}{1-\zeta(1-\psi)}. \tag{C.3}$$

This is used in equation (3.3).

Retail firms. Retailer $j \in [0,1]$ buys y_{jt} units of undifferentiated goods from production firms at price p_t and converts them into a quantity $\tilde{y}_{jt}$ of differentiated retail goods which is sold to the final goods sector at price $\tilde{p}_{jt}$. Period profits are

$$\tilde{p}_{jt} \tilde{y}_{jt} - p_t y_{jt} - \frac{\lambda}{2} \left(\frac{\tilde{p}_{jt}}{\tilde{p}_{jt-1}} - 1 \right)^2 Y_t. \tag{C.4}$$

Rotemberg-style costs of price adjustment are parameterized by λ and 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:

$$Y_t = \left[\int_0^1 \tilde{y}_{jt}^{\frac{\rho-1}{\rho}} dj \right]^{\frac{\rho}{\rho-1}}, \tag{C.5}$$

where $\rho > 1$ is the elasticity of substitution over differentiated varieties. Profit maximization in the final goods sector yields a downward sloping demand curve for variety j:

$$\tilde{y}_{jt} = \left(\frac{P_t}{\tilde{p}_{jt}} \right)^{\rho} Y_t, \quad \text{with} \quad P_t = \left[\int_0^1 \tilde{p}_{jt}^{1-\rho} dj \right]^{\frac{1}{1-\rho}} \tag{C.6}$$

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 $\tilde{p}_{jt}$:

$$\tilde{y}_{jt} - \rho \left(\frac{\tilde{p}_{jt} - p_t}{\tilde{p}_{jt}} \right) \tilde{y}_{jt} - \lambda \frac{Y_t}{\tilde{p}_{jt-1}} \left(\frac{\tilde{p}_{jt}}{\tilde{p}_{jt-1}} - 1 \right) + \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \lambda \frac{Y_{t+1}}{\tilde{p}_{jt}} \left(\frac{\tilde{p}_{jt+1}}{\tilde{p}_{jt}} - 1 \right) \frac{\tilde{p}_{jt+1}}{\tilde{p}_{jt}} = 0 \tag{C.7}$$

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

$$1 - \rho\left(\frac{P_t - p_t}{P_t}\right) - \lambda\frac{1}{P_{t-1}}\left(\frac{P_t}{P_{t-1}} - 1\right) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{P_tY_t}\left(\frac{P_{t+1}}{P_t} - 1\right)\frac{P_{t+1}}{P_t} = 0. \tag{C.8}$$

The final good is the numéraire: $P_t = 1$. Using $\pi_t = P_t/P_{t-1}$ yields the New Keynesian Phillips Curve in (3.15):

$$1 - \rho\left(1 - p_t\right) - \lambda\pi_t(\pi_t - 1) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{Y_t}\pi_{t+1}(\pi_{t+1} - 1) = 0. \tag{C.9}$$

Market clearing. Labor market clearing implies

$$L = \int_x l(x;S)\mu(x)dx. \tag{C.10}$$

The aggregate amount of final goods Y is

$$Y = \int_x y(x;S)\mu(x)dx. \tag{C.11}$$

Output net of fixed costs of operation and default costs is

$$Y^{net} \equiv Y - \int_x \left[f + \xi\int_\varepsilon \mathcal{D}(x,\varepsilon;S)\underline{q}(x,\varepsilon;S)\varphi(\varepsilon|z)d\varepsilon\right]\mu(x)dx. \tag{C.12}$$

Final goods market clearing implies that

$$Y^{net} = C + \mathcal{G} + \mathcal{H} + I, \tag{C.13}$$

where C is aggregate consumption, and $\mathcal{G}$ and $\mathcal{H}$ are aggregate equity and debt issuance costs. Aggregate equity issuance costs are

$$\mathcal{G} = \int_x\int_\varepsilon\int_{z'} G\left(e(x,\varepsilon,z';S)\right)\Pi(z'|z)dz'(1-\kappa)[1-\mathcal{D}(x,\varepsilon;S)]\varphi(\varepsilon|z)d\varepsilon\mu(x)dx + \int_{x'}\tilde{G}(x';S)\mathcal{E}(x';S)dx', \tag{C.14}$$

where $\tilde{G}(x';S)$ is equity issuance costs of entrants starting in state x'. Aggregate debt issuance costs are

$$\begin{aligned}\mathcal{H} = &\int_x\int_\varepsilon\int_{z'} H\left(b^{S'}(x,\varepsilon,z';S), b^{L'}(x,\varepsilon,z';S), b^L(x)/\pi\right)\Pi(z'|z)dz'(1-\kappa)[1-\mathcal{D}(x,\varepsilon;S)]\varphi(\varepsilon|z)d\varepsilon\mu(x)dx\\ &+ \int_{x'}\tilde{H}(x';S)\mathcal{E}(x';S)dx',\end{aligned} \tag{C.15}$$

where $\tilde{H}(x';S)$ is debt issuance costs of entrants starting in state x'. Aggregate investment I follows from (3.16):

$$I = K\left[\frac{\phi-1}{\phi}\delta^{-\frac{1}{\phi}}\left(\frac{K'}{K} - 1 + \delta\frac{\phi}{\phi-1}\right)\right]^{\frac{\phi}{\phi-1}} \tag{C.16}$$

Capital goods market clearing implies:

$$K = \int_x k(x)\mu(x)dx, \quad \text{and} \quad K' = \int_{x'} k'(x')\mu(x')dx' \tag{C.17}$$

Finally, GDP is equal to $C + I$.

Appendix D Quantitative Analysis

This section of the appendix complements the quantitative analysis in Section 4. We define important model variables (Appendix D.1) and provide more details on the empirical moments used to calibrate the model (Appendix D.2). We present additional quantitative results on the steady state of the calibrated model (Appendix D.3) and on the heterogeneous effects of monetary policy (Appendix D.4).

D.1 Model variables

The total amount of firm debt is the sum of future principal payments:

$$\text{Firm debt} \equiv b_{it}^S + \gamma b_{it}^L + (1-\gamma)\gamma b_{it}^L + (1-\gamma)^2\gamma b_{it}^L + ... = b_{it}^S + \gamma b_{it}^L \sum_{j=0}^{\infty}(1-\gamma)^j = b_{it}^S + b_{it}^L \quad \text{(D.1)}$$

Firm leverage (debt over total assets) is:

$$\text{Firm leverage} \equiv \frac{b_{it}^S + b_{it}^L}{k_{it}} \quad \text{(D.2)}$$

In Table 3, we target the share of debt due within a year:

$$\text{Share of debt due within a year} \equiv \frac{b_{it}^S + \gamma b_{it}^L + (1-\gamma)\gamma b_{it}^L + (1-\gamma)^2\gamma b_{it}^L + (1-\gamma)^3\gamma b_{it}^L}{\frac{1}{4}\sum_{j=0}^{3}\left(b_{it-j}^S + b_{it-j}^L\right)} \quad \text{(D.3)}$$

As in the empirical part of the paper, we use a four-quarter moving average of debt in the denominator. Note that b_{it}^S and b_{it}^L denote debt levels chosen at the end of period $t-1$ and outstanding at the beginning of period t. For firms which are younger than four quarters, the denominator is average debt over the maximum number of past quarters available.

The maturing bond share $\mathcal{M}$ used in Section 4.5 measures the share of total debt which matures within one quarter:

$$\mathcal{M}_{it} = \frac{b_{it}^S + \gamma b_{it}^L}{b_{it}^S + b_{it}^L} \quad \text{(D.4)}$$

In Figures 8 and 10, we use average total debt over the preceding four quarters (just as in equation (D.3)) as denominator of $\mathcal{M}_{it}$ to be consistent with the empirical specification in Section 2. All model results are virtually indistinguishable when using the current level of debt as the denominator instead.

The Macaulay duration μ of long-term debt is the weighted average term to maturity of the cash flow from a riskless bond divided by its steady state market price:

$$\mu \equiv \frac{1}{P_r^L}\sum_{j=1}^{\infty} j(1-\gamma)^{j-1}\frac{c+\gamma}{(1+r^*)^j} = \frac{c+\gamma}{P_r^L}\frac{1+r^*}{(\gamma+r^*)^2}, \quad \text{(D.5)}$$

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

$$P_r^L = \mathbb{E}\sum_{j=1}^{\infty}(1-\gamma)^{j-1}\frac{c+\gamma}{(1+i)^j} \quad \text{(D.6)}$$

In steady state ($i = r^*$), this implies that $P_r^L = (c+\gamma)/(r^*+\gamma)$ with Macaulay duration

$$\mu = \frac{1+r^*}{\gamma+r^*} \tag{D.7}$$

The long-term debt share used in Figure 7 and Figure 12 is:

$$\text{Long-term debt share} \equiv \frac{b^L}{b^S+b^L} \tag{D.8}$$

The riskless nominal short-term and long-term interest rates i and i^L are given by (3.13) and (3.14). The real interest rate r is defined as:

$$\frac{1}{1+r} = \mathbb{E}_{S'|S}\Lambda \tag{D.9}$$

The credit spread on short-term debt compares the annualized gross return from buying a firm's nominal short-term debt (in the absence of default) to the annualized gross return from buying riskless nominal short-term debt:

$$spr^S \equiv \left(\frac{1+c}{p^S}\right)^4 - \left(\frac{1+c}{P_r^S}\right)^4, \tag{D.10}$$

where P_r^S is the price of a riskless short-term bond in (3.13).

The credit spread on long-term debt compares the annualized gross return from buying a firm's nominal long-term debt (in the absence of default and assuming constant p^L) to the annualized gross return from buying riskless nominal long-term debt:

$$spr^L \equiv \left(\frac{\gamma+c+(1-\gamma)p^L}{p^L}\right)^4 - \left(\frac{\gamma+c+(1-\gamma)P_r^L}{P_r^L}\right)^4 = \left(\frac{\gamma+c}{p^L}+1-\gamma\right)^4 - \left(\frac{\gamma+c}{P_r^L}+1-\gamma\right)^4, \tag{D.11}$$

where P_r^L is the price of a riskless long-term bond in (3.14).

The average credit spread used in Figure 9 is defined as

$$\text{Average credit spread} \equiv \frac{b^{S'}}{b^{S'}+b^{L'}} spr^S + \frac{b^{L'}}{b^{S'}+b^{L'}} spr^L \tag{D.12}$$

Equity issuance of firm i at time t is the average of quarterly equity issuance over the preceding four quarters relative to firm assets:

$$\text{Equity issuance} \equiv \frac{1}{4} \cdot \left(\max\{0, e_{it}\} + \max\{0, e_{it-1}\} + \max\{0, e_{it-2}\} + \max\{0, e_{it-3}\}\right) \cdot \frac{1}{k_{it}} \tag{D.13}$$

We use an average of quarterly equity issuance over four quarters to be consistent with the empirical moment used in Table 3.

Firm capital growth is $\log(k_{it}) - \log(k_{it-1})$. To compute the standard deviation of capital growth in Table 3, we compute firm-specific standard deviations of within-firm quarterly capital growth and take the average across firms.

When comparing the model to Compustat data on firm age (or quarters since IPO), in the model we assume that IPO occurs 28 quarters after entry (based on the empirical approximate median time to IPO, Ottonello and Winberry, 2020). For the regressions of $\log(k)$ and leverage on age reported in Table 3, we regress age-quartile specific median values of $\log(k)$ (or leverage, respectively) on median age (quarters since IPO) per age-quartile and report the OLS coefficient associated to age. The quarterly default rate is

$$\text{Default rate} \equiv \int_x \int_\varepsilon \mathcal{D}(x, \varepsilon; S)\varphi(\varepsilon) d\varepsilon \mu(x) dx \tag{D.14}$$

The total rate of firm exit is total exit (endogenous through default and exogenous) per quarter:

$$\text{Firm exit rate} \equiv \text{Default rate} + \kappa \cdot (1 - \text{Default rate}) \tag{D.15}$$

Finally, the value of firm entry is $W^C(x, \varepsilon, z'; S)$ for the firm state corresponding to $q = 0$, $b = 0$, and $z' = z^e$.

D.2 Empirical variables

In this section, we provide details on the empirical moments used in Table 3. As described in Section 2, we use quarterly firm-level balance sheet data from Compustat and FISD bond-level information. The time sample is 1995–2017. We exclude firms that are not incorporated in the U.S. and we delete firms in the highly regulated sectors public administration, finance, insurance, real estate, and utilities. Negative observations of total assets (`atq`), fixed assets (`ppegtq` and `ppentq`), and short-term and long-term debt (`dlcq`, `dlttq`) are set to missing.

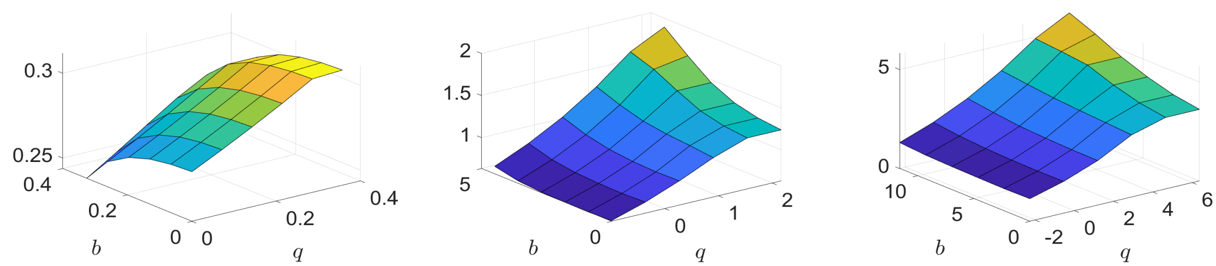
Firm leverage is total debt (`dlcq+dlttq`) divided by assets (`atq`). The share of debt due within one year is debt in current liabilities (`dlcq`) divided by the moving average of total firm debt (`dlcq+dlttq`) over the last four quarters. This procedure smoothes out seasonal factors and other transitory fluctuations. If less than four past quarters of total debt are available, we use average debt over the maximum number of past quarters available as denominator. The credit spread on long-term debt used in Table 3 is constructed using firm-level credit ratings combined with rating-specific corporate bond spreads, following Arellano et al. (2019). We use quarterly Standard & Poor's credit ratings from Compustat Monthly Updates. Based on this rating, each firm-quarter is assigned the time-varying median spread of the corresponding rating class from the FISD data. Because FISD data only includes bonds with maturity above one quarter, this data is informative with respect to long-term credit spreads in our model. See Jungherr and Schott (2021) for details on the construction of time-varying rating-specific credit spreads using FISD data. For leverage, the credit spread on long-term debt, and the share of debt due within a year we exclude observations below the 1st and above the 99th percentile. The share of debt due within a year is winsorized at 100%. Equity issuance is defined as the average of quarterly sale of common and preferred stock over the preceding four quarters divided by assets (`atq`). Quarterly sale of common and preferred stock is constructed from the yearly cumulative variable `sstky`, where missing entries are set to zero. We use an average of quarterly equity issuance over four quarters to reduce the skewness of equity issuance caused by rare but large positive spikes. Firm-level capital stocks are constructed using the perpetual inventory method described in Appendix A.3. To compute the standard deviation of capital growth in Table 3, we compute firm-specific standard deviations of within-firm quarterly capital growth and take the average across firms. For the regressions of $\log(k)$ and leverage on age (quarters since IPO based on Compustat) reported in Table 3, we regress age-quartile specific median values of capital (or leverage, respectively) on median age per age-quartile and report the OLS coefficient associated to age. The firm exit rate is the quarterly value of the yearly exit rate of 8.7% reported in Ottonello and Winberry (2020).

D.3 Steady state results

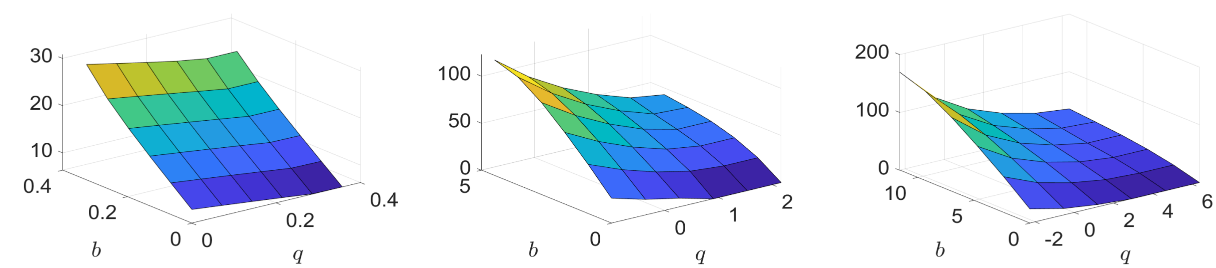
Steady state firm policy functions. Figure D.1 and Figure D.2 show firm policy functions in the calibrated model over three levels of firm productivity z'. As described in Section 4.1, we exploit the fact that the idiosyncratic state $(z, k, b^S, b^L, \varepsilon, z'; S)$ in the firm problem (3.22) can be summarized by the reduced state vector $(q, b, z'; S)$ which includes firm assets after production $q = q(z, k, b^S, b^L, \varepsilon; S)$ and outstanding long-term debt $b = (1-\gamma)b^L$. We create grids for the endogenous firm states q and b which are specific to the exogenous firm state z'.

Figure D.1: Steady state policy functions

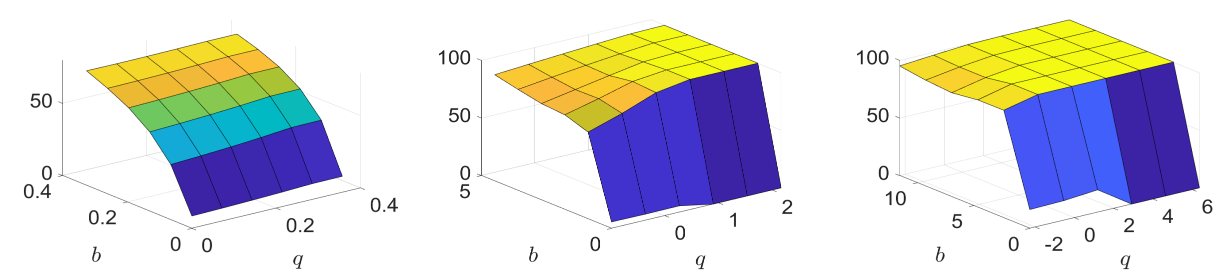
(a) Capital



(b) Leverage



(c) Long-term debt share

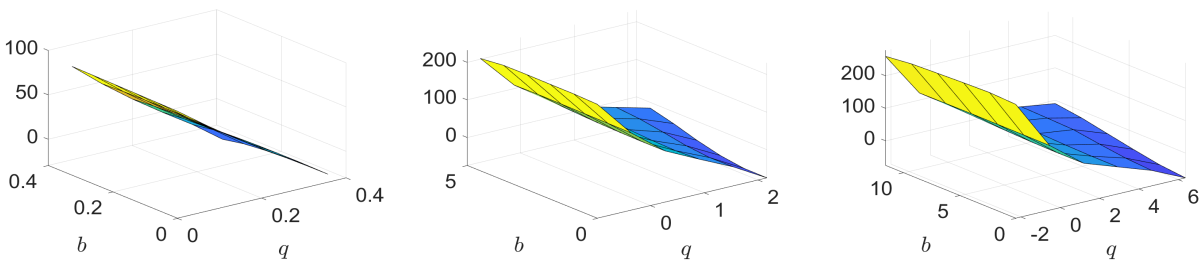


Low z' Medium z' High z'

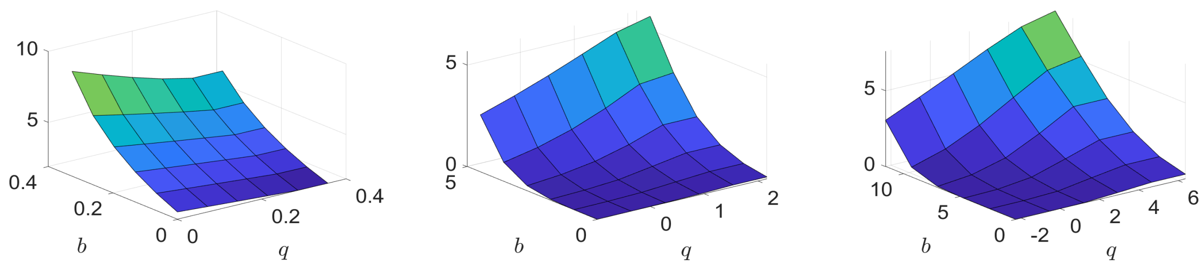
Note: On the x-axis are firm assets $q = q(z, k, b^S, b^L, \varepsilon; S)$ normalized by average firm capital. On the y-axis is outstanding long-term debt $b = (1-\gamma)b^L$ normalized by average firm debt. Policy functions for *Capital* (k') are normalized by average firm capital. The remaining firm policies are in %. *Leverage* is total firm debt over assets $((b^{S'} + b^{L'})/k')$; the *Long-term debt share* is $b^{L'}/(b^{S'} + b^{L'})$.

Figure D.2: Steady state policy functions (continued)

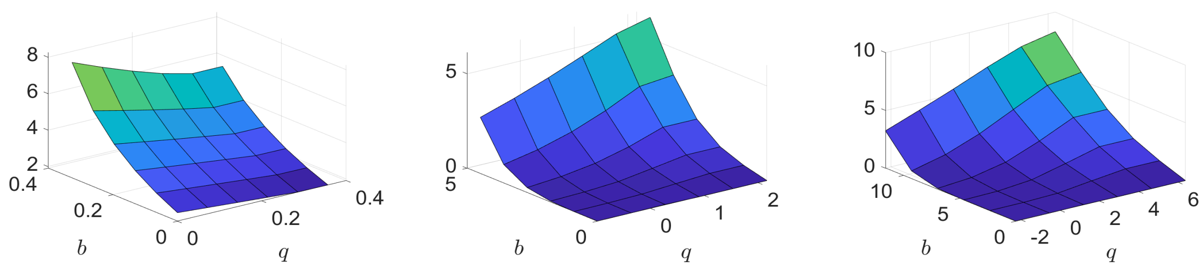
(a) Equity issuance



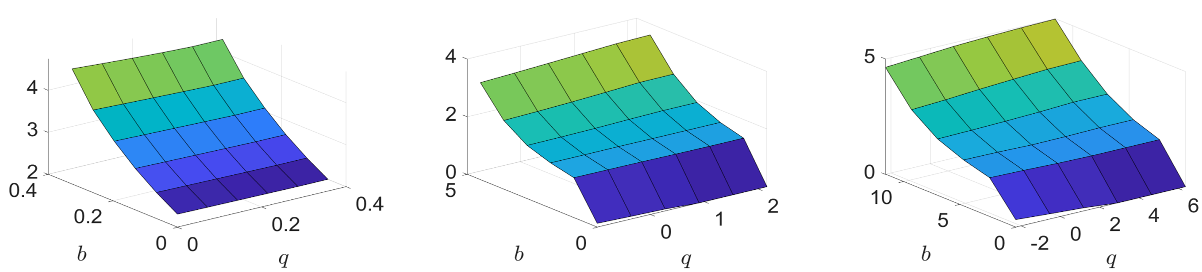
(b) Default risk



(c) Short-term credit spread



(d) Long-term credit spread

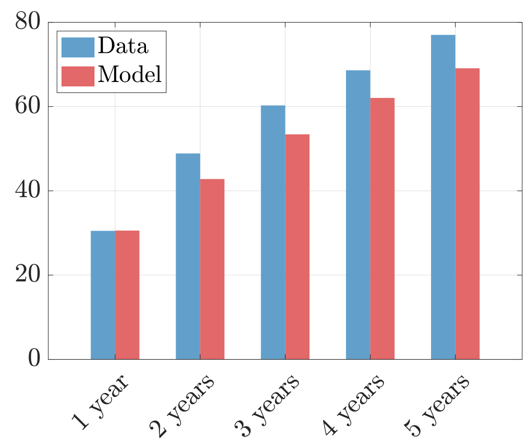


Low z' | Medium z' | High z'

Note: On the x-axis are firm assets $q = q(z, k, b^S, b^L, \varepsilon; S)$ normalized by average firm capital. On the y-axis is outstanding long-term debt $b = (1-\gamma)b^L$ normalized by average firm debt. Policy functions are in %. *Equity issuance* is relative to firm assets (e/k'). Default risk and credit spreads are annualized.

Share of maturing debt at longer time horizons. The calibrated model is successful in generating an empirically realistic maturity structure of debt at various time horizons. Figure D.3 uses Compustat data to calculate the cross-sectional average of firms' share of total maturing debt at various time horizons. The average share of debt due within a year is about 30% and steadily increases over longer time horizons. While the share of debt due within a year is a target in the calibration (Section 4.2), shares of maturing debt at longer time horizons are untargeted. The model tracks those shares very well.

Figure D.3: Share of maturing debt at longer time horizons (in %)



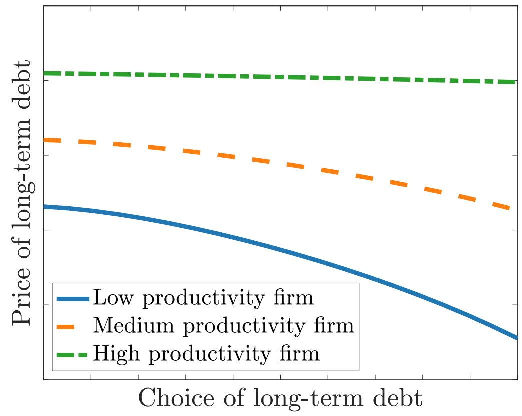
Note: The figure shows the cross-sectional average of firms' share of debt maturing within one year, within two years, within three years, within four years, and within five years. The data sample is 1995–2017. Firm-level data on maturing debt at time horizons of two to five years (`dd2, dd3, dd4, dd5`) is from Compustat.

Sensitivity of firm policies with respect to outstanding long-term debt. As discussed in Section 3.8, the price of long-term debt p^L in (3.12) is a key equilibrium object in the model. Issuing additional long-term debt $b^{L'}$ decreases the long-term bond price because debt overhang will lead to higher future leverage and default risk.

Figure D.4 shows that the long-term debt price p^L is more sensitive to the issuance of additional long-term debt $b^{L'}$ at lower levels of firm productivity z'. The derivative $\partial p^L/\partial b^{L'}$ in the first order condition for long-term debt (3.26) is therefore steeper for low-productivity firms. Section 4.3 shows that low-productivity firms tend to have higher default risk in the calibrated model. This increases the sensitivity of p^L with respect to $b^{L'}$. In case of default, creditors receive the liquidation value of the firm. Because firms disregard the payoff to existing creditors, a higher default risk leads to a larger distortive effect of long-term debt on future firm behavior.

Figure D.5 shows that firms whose bond price is more sensitive to outstanding long-term debt b tend to choose higher maturing bond shares $\mathcal{M}$, i.e., borrow at shorter maturities (panel (a)). For these firms, an increase in outstanding long-term debt b has a larger negative effect on future capital k_{t+1} (panel (b)) and drives up future leverage and default risk by more (panels (c) and (d)).

Figure D.4: Price of long-term debt p^L

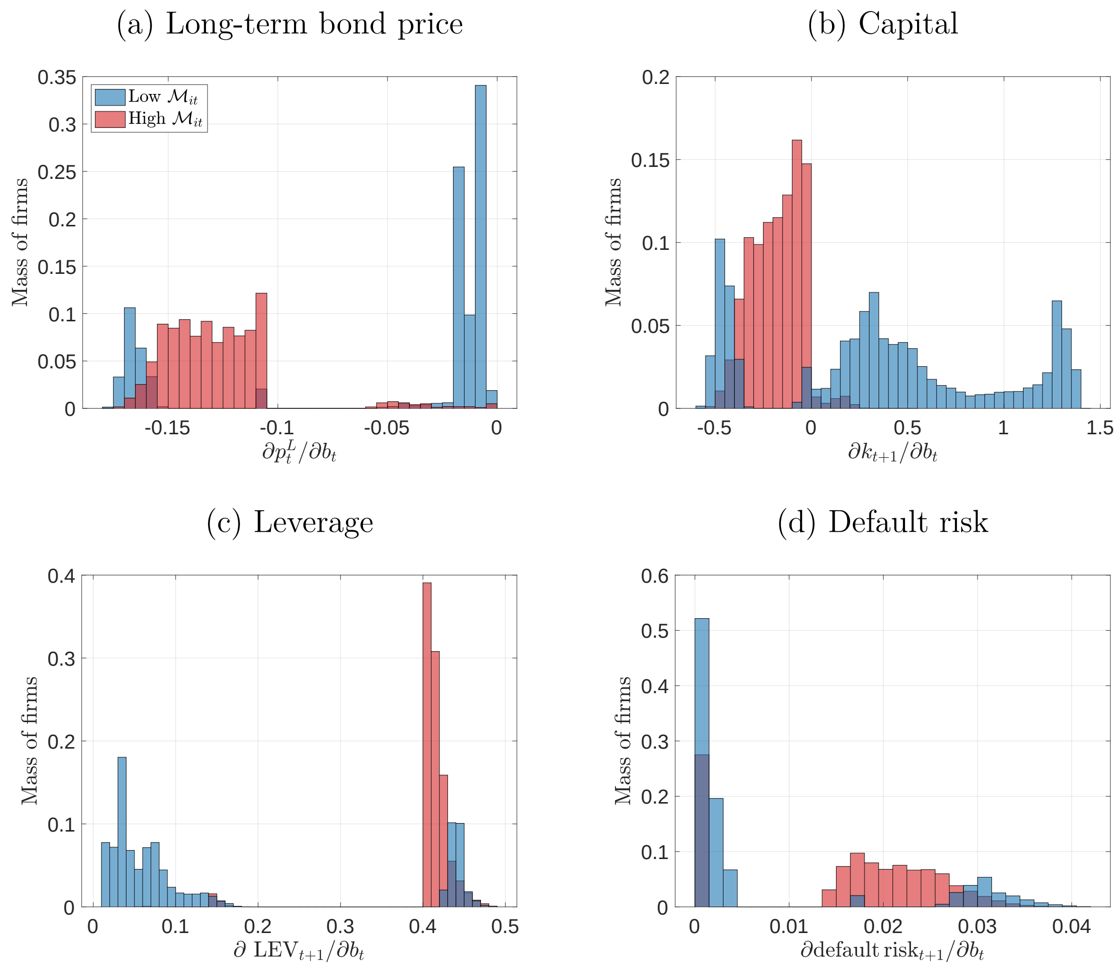


Note: The price of long-term debt p^L in (3.12) is shown as a function of the firm's choice of long-term debt $b^{L'}$ for a given state of firm assets q and outstanding long-term debt b, and three different productivity levels z'. All firm-level choices besides $b^{L'}$ (i.e., capital k' and short-term debt $b^{S'}$) are held at their steady-state values.

D.4 Heterogeneous effects of monetary policy shocks

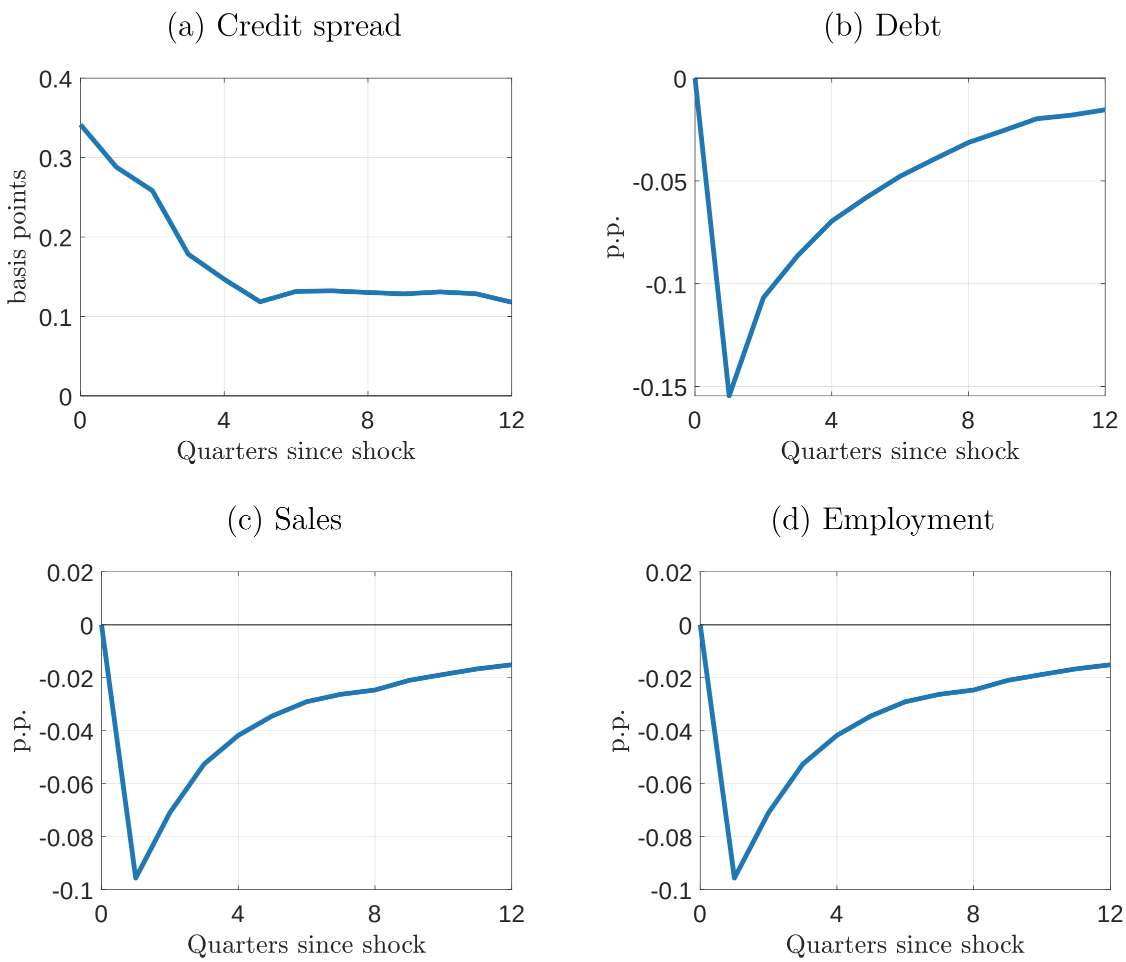
Figure 8 in Section 4.5 shows the estimated β_1^h coefficients from (4.2) using simulated model data. We construct these estimates as follows. Starting from the steady state of the model, we simulate two panels of a large number of firms for 50 time periods. In the first simulation firms are subject to idiosyncratic shocks in capital quality ε and productivity z', as well as exogenous exit, but there are no monetary policy shocks, i.e., the economy remains in steady state. In the second simulation, all idiosyncratic firm shocks are exactly identical to the first simulation. The only difference is a one-time innovation to $\varepsilon_t^{\text{mp}}$ which on impact induces a 30bp increase in the nominal interest rate i. By regressing the difference in firm-level capital growth between the two simulations at various time horizons h on the pre-shock maturing bond share, we obtain β_1^h in (4.2) displayed in Figure 8. The estimates are standardized to measure the differential response associated with a one standard deviation higher $\mathcal{M}_{it}$. The model estimates shown in Figure 10 as well as those in Figure D.6 (using credit spreads, debt, sales, and employment as additional firm outcomes) are constructed correspondingly.

Figure D.5: Derivative of firm policies with respect to outstanding long-term debt



Note: The figure shows the stationary distribution in the calibrated model of the derivative of different firm policies with respect to outstanding long-term debt b_t. Panel (a) shows the derivative of the long-term bond price p_t^L with respect to b_t, panel (b) the derivative of capital k_{t+1} with respect to b_t, panel (c) the derivative of leverage LEV$_{t+1}$ with respect to b_t, and panel (d) the derivative of default risk$_{t+1}$ with respect to b_t. *Low* $\mathcal{M}_{it}$ firms (blue) and *High* $\mathcal{M}_{it}$ firms (red) are firms with a maturing bond share below and above the median, respectively.

Figure D.6: Differential firm-level responses associated with $\mathcal{M}_{it}$



Note: The lines show the differential response of the average credit spread, debt growth, sales growth, and employment growth associated with $\mathcal{M}_{it}$ in simulated model data. All values are standardized to capture the differential response to a one standard deviation (30bp) increase in the nominal interest rate i_t associated with a one standard deviation higher $\mathcal{M}_{it}$. The average credit spread in panel (a) is the average of a firm's short-term and long-term credit spread weighted by firm-level shares of short-term and long-term debt. Debt in panel (b) is the sum of short-term and long-term debt. Sales in panel (c) is $p_{it}y_{it}$. Employment in panel (d) is l_{it}.

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Corporate Debt Maturity Matters for Monetary Policy

Online Appendix – Not intended for publication

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Appendix F Further Empirical Results

Table F.1: Full list of coefficients in baseline local projection for selected forecast horizons h

	$\Delta^{h+1} \log k_{it+h}$			
	$h = 0$	$h = 4$	$h = 8$	$h = 12$
$\mathcal{M}_{it}$	0.0143	0.000987	0.0726	0.239**
	(0.0237)	(0.0854)	(0.0952)	(0.0967)
$\mathcal{M}_{it}$ × MP shock	-0.0120	-0.0460	-0.213***	-0.102
	(0.0157)	(0.0511)	(0.0663)	(0.0678)
$\mathcal{M}_{it}$ × GDP growth	-0.0319	-0.0240	-0.00360	-0.237
	(0.0346)	(0.0966)	(0.160)	(0.154)
Firm FE	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes
R^2	.15	.26	.33	.38
N	35,512	35,125	33,589	31,691

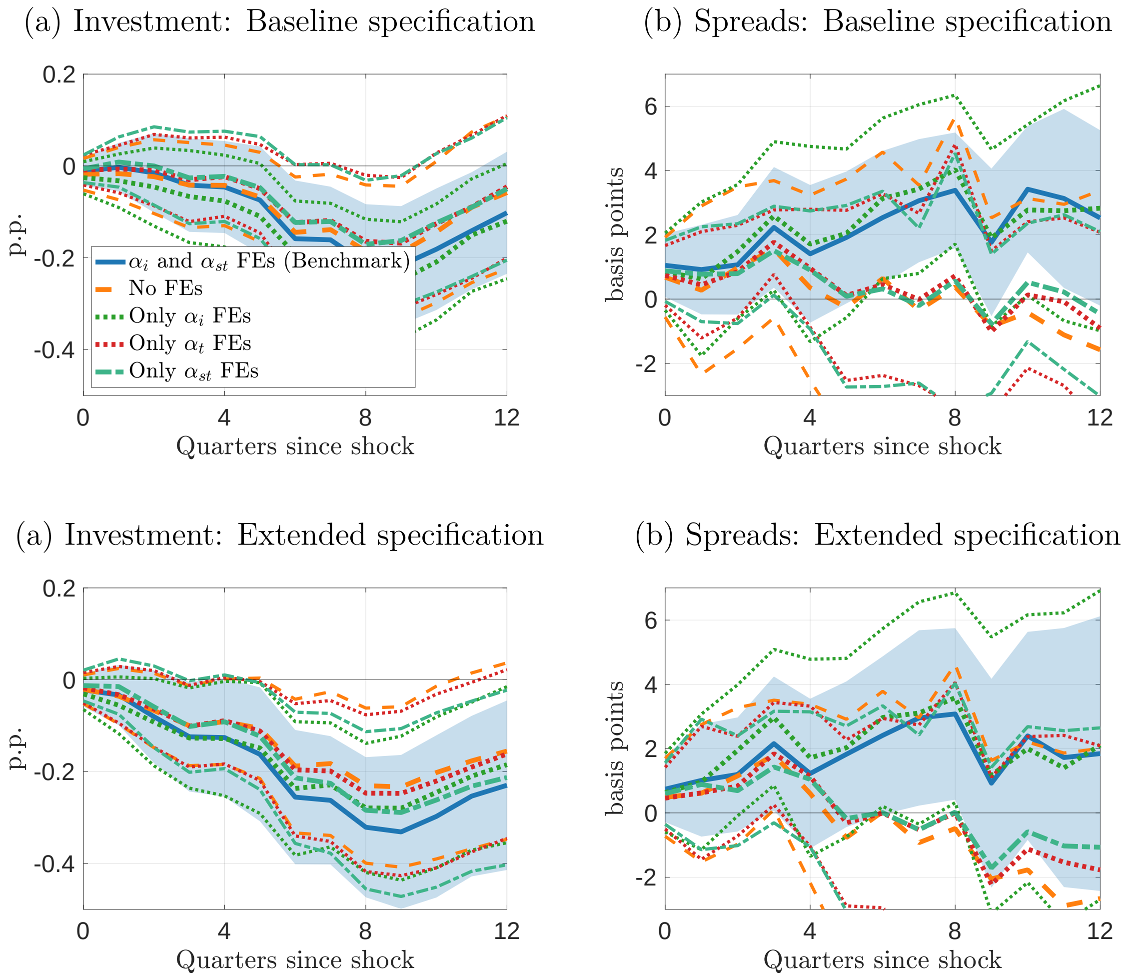
Note: The table shows all estimated coefficients from the baseline local projection (2.3). The coefficient estimates are standardized to capture the effects of a one standard deviation change in $\mathcal{M}_{it}$, a one standard deviation change in the monetary policy shock, and a 1 p.p. change in GDP growth. Standard errors (in parentheses) are clustered by firm and quarter.

Table F.2: Full list of coefficients in extended local projection for selected forecast horizons h

	$\Delta^{h+1} \log k_{it+h}$			
	$h = 0$	$h = 4$	$h = 8$	$h = 12$
$\mathcal{M}_{it}$	-0.0161	-0.129	-0.142	-0.0308
	(0.0237)	(0.0837)	(0.0856)	(0.107)
$\mathcal{M}_{it}$ × MP shock	-0.0221	-0.126*	-0.321***	-0.230**
	(0.0186)	(0.0658)	(0.0779)	(0.0942)
$\mathcal{M}_{it}$ × GDP growth	0.00794	0.203**	0.376***	0.228
	(0.0375)	(0.0959)	(0.140)	(0.158)
Avg. bond maturity	-0.00592	-0.240	-0.396	-0.445
	(0.0486)	(0.271)	(0.438)	(0.564)
Avg. bond maturity × MP shock	0.0255	0.00266	0.00278	0.0175
	(0.0326)	(0.196)	(0.202)	(0.129)
Avg. bond maturity × GDP growth	0.0599	0.425	0.639	0.541
	(0.0574)	(0.286)	(0.410)	(0.369)
Leverage	-0.284**	-2.304***	-3.330***	-4.198***
	(0.128)	(0.582)	(1.019)	(1.235)
Leverage × MP shock	-0.0367	-0.113	0.0699	0.339**
	(0.0453)	(0.268)	(0.286)	(0.151)
Leverage × GDP growth	-0.213*	-0.675*	-1.061	-0.899
	(0.120)	(0.382)	(0.710)	(0.777)
Liquidity	0.519***	1.230**	2.513***	2.972***
	(0.103)	(0.483)	(0.764)	(0.927)
Liquidity × MP shock	0.122**	-0.0768	0.0132	0.223
	(0.0606)	(0.170)	(0.263)	(0.338)
Liquidity × GDP growth	-0.166**	0.278	-0.559	-0.275
	(0.0822)	(0.405)	(0.646)	(0.656)
Size	-0.694***	-5.301***	-10.04***	-15.56***
	(0.181)	(0.908)	(1.739)	(2.367)
Size × MP shock	-0.0200	0.0612	-0.205	-0.658
	(0.0903)	(0.321)	(0.417)	(0.513)
Size × GDP growth	0.0736	-0.0759	-0.100	0.418
	(0.168)	(0.548)	(1.040)	(1.115)
Sales growth	0.104	0.947***	0.821***	1.018***
	(0.0689)	(0.197)	(0.236)	(0.268)
Sales growth × MP shock	0.0461	-0.108	-0.264	-0.371**
	(0.0632)	(0.136)	(0.196)	(0.164)
Sales growth × GDP growth	-0.0328	0.255	0.457	0.122
	(0.0777)	(0.231)	(0.311)	(0.303)
Age × MP shock	-0.00197	0.0368	-0.104*	-0.165***
	(0.0203)	(0.0527)	(0.0547)	(0.0558)
Age × GDP growth	0.00708	0.195	0.431*	0.374
	(0.0258)	(0.124)	(0.224)	(0.278)
Firm FE	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes
R^2	.2	.37	.48	.56
N	13,570	13,492	13,112	12,639

Note: The table shows all estimated coefficients from the extended local projection (2.4). The coefficient estimates are standardized to capture the effects of a one standard deviation change in demeaned $\mathcal{M}_{it}$ and other covariates, a one standard deviation change in the monetary policy shock, and a 1 p.p. change in GDP growth. Standard errors (in parentheses) are clustered by firm and quarter.

Figure F.1: Differential investment and spread responses associated with higher maturing bond share using different sets of fixed effects



Note: The figures show the estimated β_1^h coefficients, when using different sets of fixed effects (FEs) as indicated in the legends, using the baseline specification in equation (2.3) in panel (a) and using the extended specification in equation (2.4) in panel (b). The local projections with the credit spread as left-hand side additionally control for a Great Recession dummy variable interacted with the regressors. The β_1^h estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher maturing bond share. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Appendix G Model: First Order Conditions

To derive the first-order conditions in Section 3.8 we express the firm problem (3.22) in terms of three choice variables: the scale of production k', and the amounts of short-term debt $b^{S'}$ and long-term debt $b^{L'}$:

$$W^C(x,\varepsilon,z';S) = q(x,\varepsilon;S) - Qk' + b^{S'}p^S + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)p^L - G\left(e\right) - H\left(b^{S'}, b^{L'}, \frac{b^L}{\pi}\right) + \mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'} V(x',\varepsilon';S')\varphi(\varepsilon'|z')d\varepsilon', \tag{G.1}$$

where $x = (z, k, b^S, b^L)$ and the real market value of firm assets $q(x,\varepsilon;S)$ is specified in (3.3). The firm's short-term bond price p^S is

$$p^S = \mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\left[[1-\mathcal{D}(x',\varepsilon';S')]\frac{1+c}{\pi'} + \mathcal{D}(x',\varepsilon';S')\frac{(1-\xi)\underline{q}(\varepsilon')}{b^{S'}+b^{L'}}\right]\varphi(\varepsilon'|z')d\varepsilon', \tag{G.2}$$

where $\mathcal{D}(x',\varepsilon';S') = 1$ iff $W(x',\varepsilon';S') < 0$ in (3.22), $x' = (z', k', b^{S'}, b^{L'})$, and:

$$\underline{q}(\varepsilon') \equiv \max\left\{0, Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f\right]\right\}. \tag{G.3}$$

The long-term bond price p^L is

$$p^L = \mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\left[[1-\mathcal{D}(x',\varepsilon';S')]\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}g(x',\varepsilon',z'';S')}{\pi'} + \mathcal{D}(x',\varepsilon';S')\frac{(1-\xi)\underline{q}(\varepsilon')}{b^{S'}+b^{L'}}\right]\varphi(\varepsilon'|z')d\varepsilon'. \tag{G.4}$$

It follows that both p^S and p^L are functions of k', $b^{S'}$, and $b^{L'}$. Equity issuance costs are

$$G\left(e\right) = \nu\left(\max\left\{e, 0\right\}\right)^2, \quad \text{where:} \quad e = Qk' - q(x,\varepsilon;S) - b^{S'}p^S - \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)p^L. \tag{G.5}$$

Debt issuance costs are

$$H\left(b^{S'}, b^{L'}, \frac{b^L}{\pi}\right) = \eta\left(b^{S'} + \max\left\{b^{L'} - \frac{(1-\gamma)b^L}{\pi}, 0\right\}\right)^2. \tag{G.6}$$

It follows that the firm objective (G.1) is a function of the three choice variables k', $b^{S'}$, and $b^{L'}$.

First-order condition for capital. The firm's first-order condition with respect to capital k' is:

$$\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[-Q + b^{S'}\frac{\partial p^S}{\partial k'} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}\right] + \mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}[1-\mathcal{D}(x',\varepsilon';S')]\frac{\partial W(x',\varepsilon';S')}{\partial k'}\varphi(\varepsilon'|z')d\varepsilon' = 0\,, \tag{G.7}$$

where

$$\frac{\partial W(x',\varepsilon';S')}{\partial k'} = \frac{\partial q'}{\partial k'}\left[(1-\kappa)\mathbb{E}_{z''|z'}\left(1+\frac{\partial G(e')}{\partial e'}\right)+\kappa\left(1-\frac{(1-\gamma)b^{L'}}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial \tilde{g}(q',b',z'';S')}{\partial q'}\right)\right], \tag{G.8}$$

and $$\frac{\partial q'}{\partial k'} = \left[Q'+(1-\tau)\left[A'\alpha k'^{\alpha-1}+(\varepsilon'-\delta)Q'\right]\right]. \tag{G.9}$$

Equation (G.8) uses the fact that the future price of long-term debt $g(x',\bar{\varepsilon}',z'';S')$ can be expressed as a function of the reduced state vector $(q',b',z'';S')$ (as explained in Section 4.1). Written in this way, the future price of long-term debt $\tilde{g}(q',b',z'';S')$ depends on the endogenous firm states

$$q' = q(x',\varepsilon';S') = Q'k' - \frac{b^{S'}}{\pi'} - \frac{\gamma b^{L'}}{\pi'} + (1-\tau)\left[A'k'^{\alpha}+(\varepsilon'-\delta)Q'k' - f - \frac{c(b^{S'}+b^{L'})}{\pi'}\right] \tag{G.10}$$

and $b' = (1-\gamma)b^{L'}$. To compute $\partial p^S/\partial k'$ and $\partial p^L/\partial k'$ in (G.7), we first derive how k' affects the firm's default decision. Let $\bar{\varepsilon}'$ denote the threshold realization of the capital quality shock ε' such that $W(x',\bar{\varepsilon}';S')=0$ in (3.22). At this threshold realization $\bar{\varepsilon}'$, the firm is indifferent between defaulting and servicing its current debt obligations, i.e.,

$$(1-\kappa)\mathbb{E}_{z''|z'}W^C(x',\bar{\varepsilon}',z'';S') + \kappa\left(q' - \frac{(1-\gamma)b^{L'}}{\pi'}\mathbb{E}_{z''|z'}\tilde{g}(q',b',z'';S')\right) = 0. \tag{G.11}$$

Applying the implicit function theorem to (G.11), we derive

$$\frac{\partial \bar{\varepsilon}'}{\partial k'} = -\frac{\frac{\partial q'}{\partial k'}}{\frac{\partial q'}{\partial \bar{\varepsilon}'}} = -\frac{Q'+(1-\tau)\left[A'\alpha k'^{\alpha-1}+(\bar{\varepsilon}'-\delta)Q'\right]}{(1-\tau)Q'k'}. \tag{G.12}$$

The derivative of p^S with respect to k' is then given by

$$\begin{aligned}\frac{\partial p^S}{\partial k'} = \mathbb{E}_{S'|S}\Lambda\Bigg[&\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{b^{S'}+b^{L'}}\left[Q'+(1-\tau)\left[A'\alpha k'^{\alpha-1}+(\varepsilon'-\delta)Q'\right]\right]\varphi(\varepsilon'|z')d\varepsilon' \\ &+\varphi(\bar{\varepsilon}'|z')\frac{\partial \bar{\varepsilon}'}{\partial k'}\left[-\frac{1+c}{\pi'}+\frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg],\end{aligned} \tag{G.13}$$

where $\underline{\varepsilon}'$ denotes the threshold realization of the capital quality shock ε' such that:

$$Q'k' + (1-\tau)\left[A'k'^{\alpha}+(\underline{\varepsilon}'-\delta)Q'k' - f\right] = 0. \tag{G.14}$$

It follows for the derivative of p^L with respect to k':

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

First-order condition for short-term debt. The firm's first-order condition with respect to $b^{S'}$ is

$$\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[p^S + b^{S'}\frac{\partial p^S}{\partial b^{S'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{S'}}\right] - \frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^{S'}}$$
$$+ \mathbb{E}_{S'|S}\Lambda \int_{\bar{\varepsilon}'}^{\infty} \frac{\partial W(x', \varepsilon'; S')}{\partial b^{S'}} \varphi(\varepsilon'|z')d\varepsilon' = 0\,, \tag{G.16}$$

where

$$\frac{\partial W(x', \varepsilon'; S')}{\partial b^{S'}} = \frac{\partial q'}{\partial b^{S'}}\left[(1-\kappa)\mathbb{E}_{z''|z'}\left(1 + \frac{\partial G(e')}{\partial e'}\right) + \kappa\left(1 - \frac{(1-\gamma)b^{L'}}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial \tilde{g}(q', b', z''; S')}{\partial q'}\right)\right], \tag{G.17}$$

and $$\frac{\partial q'}{\partial b^{S'}} = -\frac{1 + (1-\tau)c}{\pi'}. \tag{G.18}$$

The derivative of p^S with respect to $b^{S'}$ is

$$\frac{\partial p^S}{\partial b^{S'}} = \mathbb{E}\Lambda\Bigg[-\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'} \frac{1-\xi}{(b^{S'} + b^{L'})^2}\left[Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon' - \delta)Q'k' - f\right]\right]\varphi(\varepsilon'|z')d\varepsilon'$$
$$+ \varphi(\bar{\varepsilon}'|z')\frac{\partial \bar{\varepsilon}'}{\partial b^{S'}}\left[-\frac{1+c}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'} + b^{L'}}\right]\Bigg], \tag{G.19}$$

where $$\frac{\partial \bar{\varepsilon}'}{\partial b^{S'}} = -\frac{\frac{\partial q'}{\partial b^{S'}}}{\frac{\partial q'}{\partial \bar{\varepsilon}'}} = \frac{1 + (1-\tau)c}{\pi'(1-\tau)Q'k'}. \tag{G.20}$$

Finally, we derive the derivative of p^L with respect to $b^{S'}$:

$$\frac{\partial p^L}{\partial b^{S'}} = \mathbb{E}_{S'|S}\Lambda\Bigg[\int_{\bar{\varepsilon}'}^{\infty} \frac{1-\gamma}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial \tilde{g}(q', b', z''; S')}{\partial q'}\frac{\partial q'}{\partial b^{S'}}\varphi(\varepsilon'|z')d\varepsilon'$$
$$- \int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'} \frac{1-\xi}{(b^{S'} + b^{L'})^2}\left[Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon' - \delta)Q'k' - f\right]\right]\varphi(\varepsilon'|z')d\varepsilon'$$
$$+ \varphi(\bar{\varepsilon}'|z')\frac{\partial \bar{\varepsilon}'}{\partial b^{S'}}\left[-\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q', b', z''; S')}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'} + b^{L'}}\right]\Bigg] \tag{G.21}$$

First-order condition for long-term debt. The firm's first-order condition with respect to $b^{L'}$ is

$$\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[p^L + b^{S'}\frac{\partial p^S}{\partial b^{L'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{L'}}\right] - \frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^{L'}}$$
$$+ \mathbb{E}_{S'|S}\Lambda \int_{\bar{\varepsilon}'}^{\infty} \frac{\partial W(x', \varepsilon'; S')}{\partial b^{L'}} \varphi(\varepsilon'|z')d\varepsilon' = 0\,, \tag{G.22}$$

where

$$\frac{\partial W(x',\varepsilon';S')}{\partial b^{L'}} = \frac{\partial q'}{\partial b^{L'}}\left[(1-\kappa)\mathbb{E}_{z''|z'}\left(1+\frac{\partial G(e')}{\partial e'}\right)+\kappa\left(1-\frac{(1-\gamma)b^{L'}}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial\tilde{g}(q',b',z'';S')}{\partial q'}\right)\right]$$
$$+\frac{\partial b'}{\partial b^{L'}}\,\mathbb{E}_{z''|z'}\left[(1-\kappa)\,\frac{\partial\tilde{W}^C(q',b',z'';S')}{\partial b'}-\frac{\kappa}{\pi'}\left(\tilde{g}(q',b',z'';S')+\,b'\,\frac{\partial\tilde{g}(q',b',z'';S')}{\partial b'}\right)\right], \tag{G.23}$$

$$\text{with}\quad \frac{\partial q'}{\partial b^{L'}} = -\frac{\gamma+(1-\tau)c}{\pi'}\quad\text{and}\quad\frac{\partial b'}{\partial b^{L'}} = 1-\gamma. \tag{G.24}$$

Equation (G.23) uses the fact that the future value $W^C(x',\bar{\varepsilon}',z'';S')$ can be expressed as a function of the reduced state vector $\tilde{W}^C(q',b',z'';S')$ (as explained in Section 4.1). The derivative of p^S with respect to $b^{L'}$ is

$$\frac{\partial p^S}{\partial b^{L'}} = \mathbb{E}_{S'|S}\Lambda\Bigg[-\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{(b^{S'}+b^{L'})^2}\left[Q'k'+(1-\tau)\left[A'k'^{\alpha}+(\varepsilon'-\delta)Q'k'-f\right]\right]\varphi(\varepsilon'|z')d\varepsilon'$$
$$+\varphi(\bar{\varepsilon}'|z')\frac{\partial\bar{\varepsilon}'}{\partial b^{L'}}\left[-\frac{1+c}{\pi'}+\frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg], \tag{G.25}$$

where

$$\frac{\partial\bar{\varepsilon}'}{\partial b^{L'}} = -\frac{\frac{\partial q'}{\partial b^{L'}}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}}-\frac{\frac{\partial b'}{\partial b^{L'}}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}}\,\frac{\mathbb{E}_{z''|z'}\left[(1-\kappa)\,\frac{\partial\tilde{W}^C(q',b',z'';S')}{\partial b'}-\frac{\kappa}{\pi'}\left(\tilde{g}(q',b',z'';S')+\,b'\,\frac{\partial\tilde{g}(q',b',z'';S')}{\partial b'}\right)\right]}{\left[(1-\kappa)\,\mathbb{E}_{z''|z'}\left(1+\frac{\partial G(e')}{\partial e'}\right)+\kappa\left(1-\frac{b'}{\pi'}\,\mathbb{E}_{z''|z'}\,\frac{\partial\tilde{g}(q',b',z'';S')}{\partial q'}\right)\right]}. \tag{G.26}$$

Similarly, we derive the derivative of p^L with respect to $b^{L'}$:

$$\frac{\partial p^L}{\partial b^{L'}} = \mathbb{E}\Lambda\Bigg[\int_{\bar{\varepsilon}'}^{\infty}\frac{1-\gamma}{\pi'}\mathbb{E}_{z''|z'}\left(\frac{\partial\tilde{g}(q',b',z'';S')}{\partial q'}\frac{\partial q'}{\partial b^{L'}}+\frac{\partial\tilde{g}(q',b',z'';S')}{\partial b'}\frac{\partial b'}{\partial b^{L'}}\right)\varphi(\varepsilon'|z')d\varepsilon'$$
$$-\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{(b^{S'}+b^{L'})^2}\left[Q'k'+(1-\tau)\left[A'k'^{\alpha}+(\varepsilon'-\delta)Q'k'-f\right]\right]\varphi(\varepsilon'|z')d\varepsilon'$$
$$+\varphi(\bar{\varepsilon}'|z')\frac{\partial\bar{\varepsilon}'}{\partial b^{L'}}\left[-\frac{\gamma+c+(1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q',b',z'';S')}{\pi'}+\frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg] \tag{G.27}$$

The effect of a marginal increase in b' on $\tilde{W}^C(q',b',z'';S')$ in (G.23) can be derived using (G.1):

$$\frac{\partial\tilde{W}^C(q,b,z';S)}{\partial b} = \frac{\partial W(x',\varepsilon';S')}{\partial(1-\gamma)b^L} = -\frac{1}{\pi}\frac{\partial H(b^{S'},b^{L'},b^L/\pi)}{\partial\frac{(1-\gamma)b^L}{\pi}}-\frac{p^L}{\pi}\left[1+\frac{\partial G(e)}{\partial e}\right] \tag{G.28}$$

Iterating forward one time period, this implies

$$\frac{\partial\tilde{W}^C(q',b',z'';S')}{\partial b'} = -\frac{1}{\pi'}\left(\frac{\partial H(b^{S''},b^{L''},b^{L'}/\pi')}{\partial\frac{(1-\gamma)b^{L'}}{\pi'}}+\tilde{g}\left(q',b',z'';S'\right)\left[1+\frac{\partial G(e')}{\partial e'}\right]\right). \tag{G.29}$$

Appendix H Quantitative Analysis: Additional Material

H.1 Solution method

As discussed in Section 4.1, our solution method uses value function iteration and interpolation to compute the Markov perfect equilibrium of the model. For each firm state, we solve for the optimal choice of capital, equity issuance, short-term debt, and long-term debt.

Steady state solution. We first compute the fully non-linear global solution of the stationary equilibrium with idiosyncratic firm-level uncertainty. The key computational challenge for a precise solution of the model is finding the equilibrium price function of risky long-term debt p^L in (3.12). 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 current choices will affect its own future behavior and thereby the current bond price p^L. 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 and bond prices as the equilibrium of the infinite-horizon problem.

- To solve the model, we exploit the fact that the idiosyncratic state $(z, k, b^S, b^L, \varepsilon, z'; S)$ in the firm problem (3.22) can be summarized by the reduced state vector $(q, b, z'; S)$ which includes firm assets after production $q = q(z, k, b^S, b^L, \varepsilon; S)$ and outstanding long-term debt $b = (1 - \gamma)b^L$. Shareholder value $W^C(x, \varepsilon, z'; S)$ in (3.22) can be expressed as a function of the reduced state vector $\tilde{W}^C(q, b, z'; S)$. Similarly, the future price of long-term debt $g(x, \varepsilon, z'; S)$ in (3.12) can be expressed as a function of the reduced state vector $\tilde{g}(q, b, z'; S)$.

- We create grids for the endogenous firm states q and b which are specific to the exogenous firm state z'. When choosing grids for q, we use the property of the model that, for given b and z', firm policies are constant in q for dividend-paying firms (with $e < 0$). The choice of grids for b is important. For given z', high values of b and low values of q render large dividend payout optimal at the expense of existing long-term creditors. This can change firm behavior in a discontinuous way and therefore constitutes an obstacle to the convergence of the long-term bond price. We choose the grid for b in a way which makes sure that the dividend payout constraint $e \geq \underline{e}$ is not binding in equilibrium. The exact value of $\underline{e}$ does therefore not affect equilibrium variables.

- We iterate simultaneously on the value function $\tilde{W}^C(q, b, z'; S)$ and on the long-term bond price $\tilde{g}(q, b, z'; S)$ (as in Hatchondo and Martinez, 2009).

- The presence of the idiosyncratic i.i.d. capital quality shock ε with continuous probability distribution $\varphi(\varepsilon|z)$ facilitates convergence of the long-term bond price $\tilde{g}(q, b, z'; S)$ (*cf.* Chatterjee and Eyigungor, 2012).

- Firm optimization requires taking expectations over the distribution of possible future firm states. To evaluate future states (q, b, z') between discrete grids points, precise interpolation is important for convergence. For given b and z', firm policies feature a kink at the value of q below which firms issue equity $(e > 0)$ and above which firms pay out dividends $(e < 0)$. We develop an interpolation method which takes this discontinuity in derivatives into account.

- Our solution algorithm uses firms' first order conditions (see Section G). Among other reasons, this is important because it allows us to precisely interpolate the derivatives of the value $\tilde{W}^C(q', b', z''; S')$ and the price of long-term debt $\tilde{g}(q', b', z''; S')$ with respect to q' and b'.

- Crouzet (2017) and Aguiar and Amador (2020) describe how multiple equilibria can arise in related problems involving defaultable long-term debt. When computing the solution to the firm problem, we have experimented with various initial guesses for the future price of long-term debt and have not been able to identify multiple equilibria in our model. In a model of defaultable sovereign long-term debt, Aguiar and Amador (2020) show that multiplicity arises only for intermediate values of debt maturity. It vanishes for sufficiently short and sufficiently long maturities. While a similar analysis is missing for a firm model like ours, it is possible that our calibration precludes multiplicity within our framework.

- Convergence of the value function $\tilde{W}^C(q, b, z'; S)$ and long-term bond price $\tilde{g}(q, b, z'; S)$ takes about 1,000 iterations in this problem. The main reason for slow convergence is the interaction between long-term debt and default. In equilibrium, the long-term bond price p^L reflects firm behavior well into the future (strictly speaking infinity). Recursive optimization requires a large number of iterations until this firm behavior is reflected in the long-term bond price. Once the long-term bond price adjusts to future firm behavior, the firm responds by adjusting its behavior. The lower the parameter value γ and the higher the parameter value β, the longer it takes before convergence occurs. The fact that our model is calibrated at quarterly frequency implies a relatively low γ and a high discount factor β which further raises the computational cost of solving the model.

Aggregate shocks. In the presence of aggregate uncertainty, the aggregate state of our general equilibrium model includes the time-varying firm distribution. The high dimensionality of the aggregate state vector poses well-known computation problems (e.g., Krusell and Smith, 1998). We follow Reiter (2009) in first computing a fully non-linear global solution of the steady state with idiosyncratic firm-level uncertainty but without aggregate shocks. We then use a numerical first-order perturbation method (Schmitt-Grohé and Uribe, 2004) to approximate the dynamics of the model and its endogenous firm distribution around the steady state in response to aggregate shocks. Our model solution is therefore linear with respect to aggregate shocks.

The linear dynamic system consists of a vector of pre-determined state variables x_t and a vector of non-predetermined variables y_t. The pre-determined state variables are:

$$x_t = \left[\eta_t^{\mathrm{mp}}, (\tilde{k}_{st})_{\sigma=1}^{\Sigma}, (\tilde{b}_{st}^S)_{\sigma=1}^{\Sigma}, (\tilde{b}_{st}^L)_{\sigma=1}^{\Sigma}, \tilde{\mu}_{t-1}(q,b,z')\right], \tag{H.1}$$

where s is an indicator of a specific firm state (q,b,z') and $\tilde{\mu}_{t-1}(\cdot)$ is the probability distribution over (q,b,z'). It includes firm assets $q_{it-1} = q(z_{it-1}, \tilde{k}_{it-1}, \tilde{b}_{it-1}^S, \tilde{b}_{it-1}^L, \varepsilon_{it-1}; S_{t-1})$ and outstanding long-term debt $b_{it-1} = (1-\gamma)\tilde{b}_{it-1}^L$.

The non-predetermined variables are:

$$y_t = \left[(k_{st+1})_{\sigma=1}^{\Sigma}, (b_{st+1}^S)_{\sigma=1}^{\Sigma}, (b_{st+1}^L)_{\sigma=1}^{\Sigma}, (\tilde{W}_{st}^C)_{\sigma=1}^{\Sigma}, (\tilde{g}_{st})_{\sigma=1}^{\Sigma}, \Lambda_t, w_t, C_t, L_t, \pi_t, p_t, i_t, Q_t\right] \tag{H.2}$$

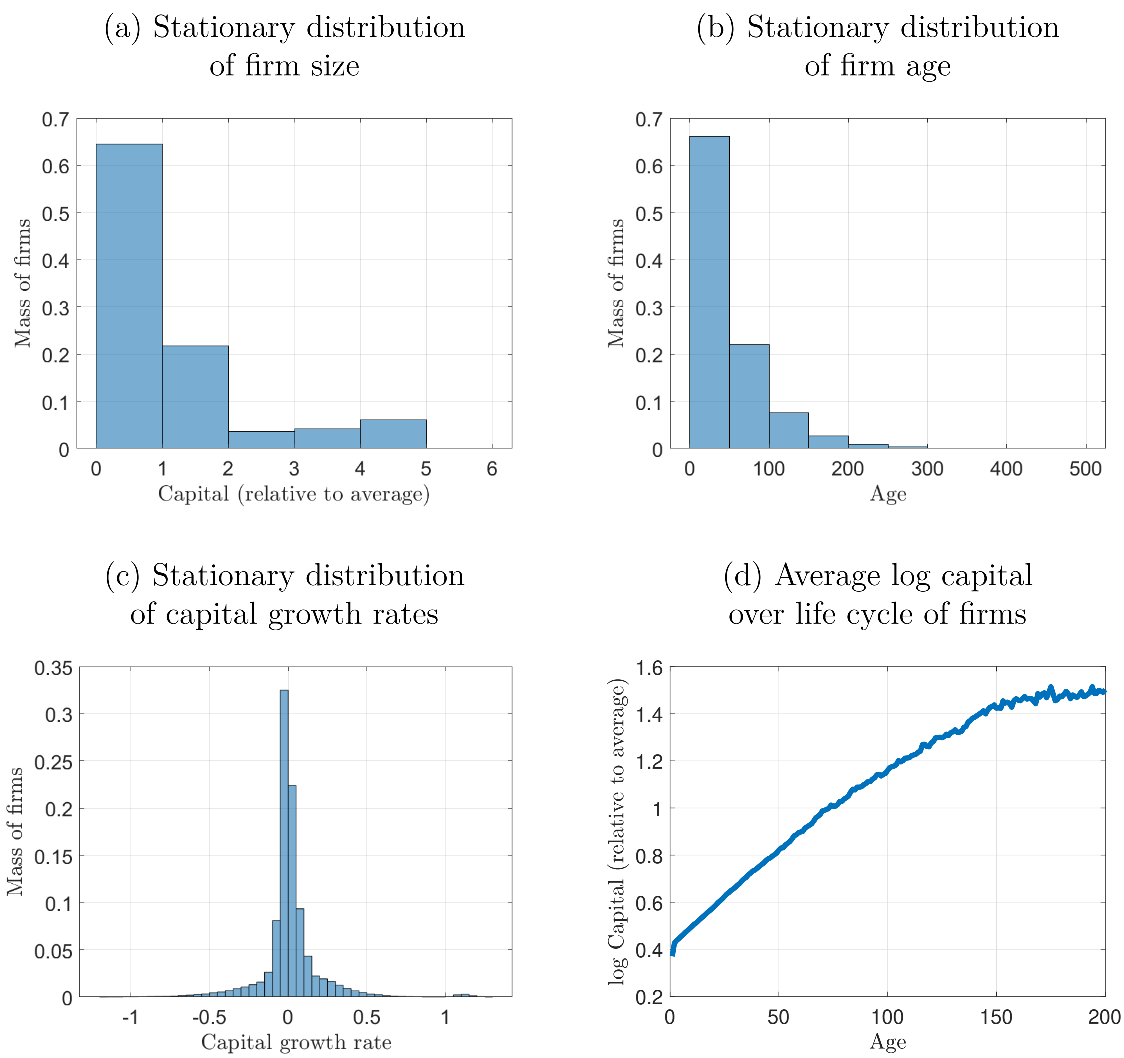
The corresponding equilibrium conditions consist of

- the first order conditions with respect to capital (G.7) for a firm in a given state $s = (q,b,z')$,
- the first order conditions with respect to short-term debt (G.16),
- the first order conditions with respect to long-term debt (G.22),
- the equation for the continuation value W_{st}^C in (3.9),
- the condition for the long-term bond price p_{st}^L in (3.12),
- the stochastic discount factor: $\Lambda_t = \beta C_t / C_{t+1}$,
- optimal labor supply: $w_t = C_t L_t^{\theta}$,
- final goods market clearing: $Y_t^{net} = C_t + I_t + \mathcal{G}_t + \mathcal{H}_t$,
- labor market clearing: $L_t = \int_{\tilde{\mu}_{t-1}} \left[\int_{\varepsilon} l(z_{it}, \tilde{k}_{it}, \tilde{b}_{it}^S, \tilde{b}_{it}^L, \varepsilon_{it}; S_t) d\varphi(\varepsilon)\right] d\tilde{\mu}_{t-1}$
- Fisher equation: $1/(1+i_t) = \mathbb{E}_{S_{t+1}|S_t} \Lambda_t / \pi_{t+1}$,
- Phillips curve: $1 - \rho(1-p_t) - \lambda \pi_t(\pi_t - 1) + \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \lambda \frac{Y_{t+1}}{Y_t} \pi_{t+1}(\pi_{t+1}-1) = 0$,
- Taylor rule: $1 + i_t = \frac{1}{\beta} \pi_t^{\varphi^{\mathrm{mp}}} e^{\eta_t^{\mathrm{mp}}}$,
- price of capital goods: $Q_t = \left(\frac{\frac{I_t}{K_t}}{\hat{\delta}}\right)^{\frac{1}{\phi}}$,
- law of motion for the stochastic component of monetary policy: $\eta_{t+1}^{\mathrm{mp}} = \rho^{\mathrm{mp}} \eta_t^{\mathrm{mp}} + \varepsilon_t^{\mathrm{mp}}$,
- law of motion for firm-level capital: $\tilde{k}_{it+1} = k_{it+1}$,
- law of motion for firm-level short-term debt: $\tilde{b}_{it+1}^S = b_{it+1}^S$,
- law of motion for firm-level long-term debt: $\tilde{b}_{it+1}^L = b_{it+1}^L$,
- law of motion for the firm distribution: $\tilde{\mu}_t(q,b,z') = \Gamma(\tilde{\mu}_{t-1}, \eta_t^{\mathrm{mp}})$.

H.2 Steady state results

Figure H.1 shows additional results regarding the stationary firm distribution of the calibrated model used in Section 4. Panels (a) and (b) show the stationary distribution of firm size (i.e., capital) and firm age. In line with empirical firm distributions, the model generates a large mass of small and young firms and relatively few larger and older firms. Panel (c) shows the unconditional distribution of quarterly capital growth rates. In line with stylized facts, firm-level capital growth is positively skewed and concentrated around zero for the majority of firm-quarters. Growth spikes above 10% or below -10% are rare in the model. Finally, panel (d) shows how average log capital is evolving over the life cycle of firms in our model. The decline in the slope of log capital as age increases shows that the model replicates the typically observed decrease in empirical growth rates over the life cycle of firms.

Figure H.1: Firm dynamics



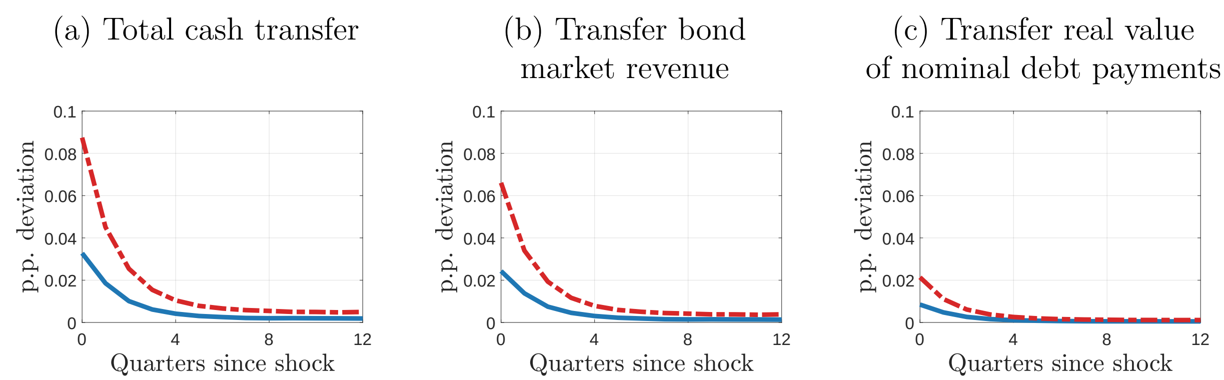
H.3 Heterogeneous effects of monetary policy shocks

Decomposing the transmission channels: Cash transfer experiment. In Section 4.5, we conduct a model experiment in which firms are paid cash transfers which compensate for the cash shortfall due to changes in interest rates and inflation. Results are shown in Figure 10.

The cash transfer $T(q, b, z', S)$ in (4.5) is the sum of two components: (1) the difference between the steady-state bond market revenue of a firm in state (q, b, z', S_{ss}) and the bond market revenue of a firm in state (q, b, z', S) after a monetary policy shock, and (2) the difference in the real market value of firm assets q induced by deviations of inflation π from its steady state value. Changes in inflation affect the value of firm assets q in (3.3) through the real value of nominal debt payments b^S/π and $\gamma b^L/\pi$.

Figure H.2 shows the average cash transfer paid to firms with high (red dashed lines) and low (blue solid lines) maturing bond shares $\mathcal{M}$ at the time of the shock. Because high-$\mathcal{M}$ firms are more exposed to the cash flow effects of monetary policy shocks, they receive higher compensating cash transfers on average (panel (a)). Figure H.2 shows that the majority of the total cash flow effects of monetary policy are accounted for by changes in bond market revenue (panel (b)) and only a small part by changes in the real value of nominal debt payments (panel (c)).

Figure H.2: Model experiment with compensating cash transfer

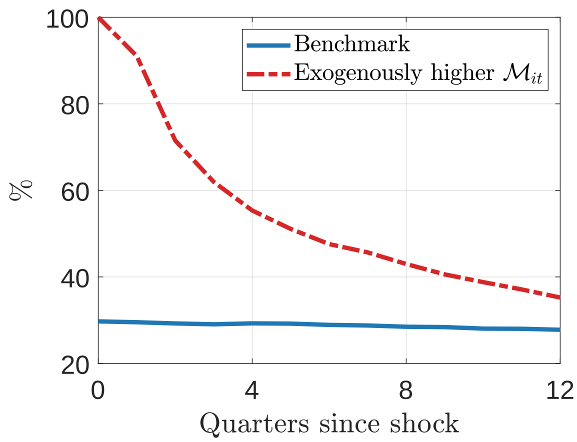


Note: The panels show the effect of an unexpected one-standard deviation (30bp) increase in the nominal interest rate i for firms below (blue solid lines) and above (red dash-dotted lines) the median maturing bond share $\mathcal{M}$ at the time of the shock. The panels show (a) the average total cash transfer paid (relative to pre-shock firm-level capital), (b) the part of the transfer which compensates changes in bond market revenue (relative to pre-shock firm-level capital), and (c) the part of the transfer which compensates changes in the real value of nominal debt payments (relative to pre-shock firm-level capital).

Exogenous variation in maturing bond share. In Section 4.5, we conduct a model experiment with exogenous variation in the maturing bond share. A representative sample of firms of zero mass is drawn from the benchmark economy. For the selected firm sample, we exogenously set $\mathcal{M}$ to a higher value by converting all of their long-term debt b^L to short-term debt b^S. Figure 11 shows the average capital response to a contractionary monetary policy shock for the selected firm sample with and without exogenously higher $\mathcal{M}$. Figure H.3

shows that in this model experiment the average share of debt due in one year increases from about 30% to 100% for the selected firm sample and subsequently slowly converges back to steady state. Both lines are drawn for the case without a monetary policy shock, but look very similar for the case with a monetary policy shock.

Figure H.3: Model experiment with exogenously higher $\mathcal{M}$ - Share of debt due in a year



Note: The lines show the average share of debt due in a year for the representative firm sample selected for the model experiment. The blue solid line shows the benchmark case without exogenous variation of debt maturity. The red dash-dotted line shows the case with an exogenously higher value of $\mathcal{M}$ in the initial period.

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