Corporate Debt Maturity Matters For Monetary Policy*

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June 29, 2026

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 deflation*). At the aggregate level, we find that endogenous debt maturity generates important differences between the transmission of conventional and unconventional 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.”*
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> —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.

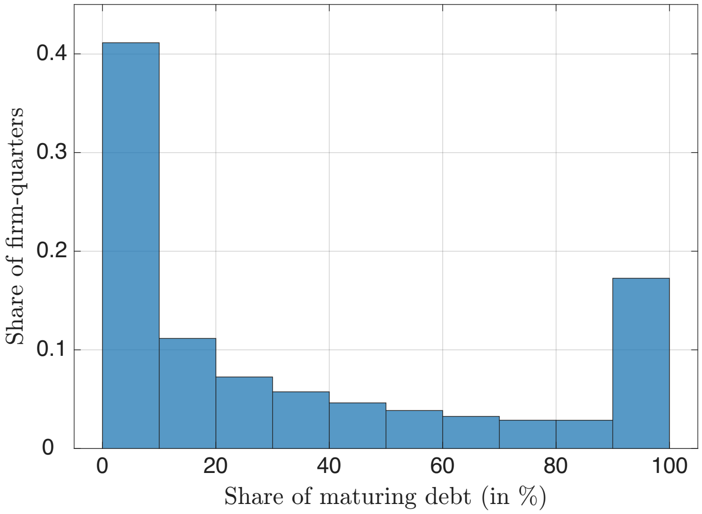
We begin by providing novel empirical evidence showing that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. After a tightening of monetary policy, firms with higher shares of maturing bonds experience a larger fall in investment, borrowing, sales, and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

To understand the mechanisms behind this result and its macroeconomic implications, we develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. Firms have an incentive to use long-term debt because it saves debt issuance costs and provides insurance against interest rate fluctuations. The downside of long-term debt is that it generates debt overhang: Firms with large stocks of outstanding long-term debt have weaker incentives to invest (Myers, 1977). Firms with higher default risk are more exposed to debt overhang and therefore choose to borrow at shorter maturities, implying higher shares of maturing debt per period.

The model rationalizes the empirical evidence that firms with higher shares of maturing debt respond more strongly to monetary policy shocks. Two channels are key for this result: (1.) *Roll-over risk*: Firms with more maturing debt have larger roll-over needs and are therefore more exposed to fluctuations in the real interest rate. (2.) *Debt deflation*: Monetary policy affects inflation and thereby changes the real burden of outstanding nominal debt for all firms. However, as described above, firms with more maturing debt have higher default risk and are therefore more responsive to changes in debt overhang caused by debt deflation. Both roll-over risk and debt deflation therefore contribute to the stronger investment response of firms with higher maturing debt shares.

Because in the model firms borrow at different maturities, it provides a natural laboratory to study the aggregate effects of unconventional monetary policy (UMP) operating through the term structure of interest rates (e.g., quantitative easing). In contrast to conventional monetary policy, UMP has large effects on firms’ maturity choice. When UMP lowers long-term interest rates, it pushes firms into borrowing at long maturities. The resulting increase in debt overhang persistently drives up default risk and affects investment. The mechanisms

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 1995Q1–2019Q4 from Compustat.

which allow the model to replicate the empirical relationship between maturing debt and firms' response to conventional monetary policy therefore also govern the transmission of UMP. We show that the persistent increase in firms' debt maturity after expansionary UMP can dampen the output stimulus at longer horizons, especially when leverage is high.

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. We complement this data with high-frequency identified monetary policy shocks and estimate their effect on firm-level outcomes using panel local projections. A key variable is the maturing bond share, defined as the ratio of maturing bonds to total outstanding debt. The main result is that firms' investment is more responsive to monetary policy when their maturing bond share is larger at the time of a monetary policy 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.

We develop a heterogeneous firm New Keynesian model which can rationalize the evidence. Firms finance investment using equity and nominal debt. Debt has a tax advantage relative to equity but introduces the risk of costly default. Debt maturity is endogenous: firms can choose a mix of short-term and long-term debt. We calibrate the model to empirical moments that 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, in line with the data. Following a conventional monetary policy shock, firms with higher shares of maturing debt exhibit stronger investment responses. The model accounts for 84% of the peak cross-sectional differential in capital responses associated with the maturing bond share. In addition, it rationalizes the empirical role of the maturing bond share for the firm-level responses of credit spreads, debt, sales, and employment.

Because the model matches important empirical moments related to debt maturity, we use it to quantify the aggregate effects of conventional and unconventional monetary policy. We study an expansionary UMP shock which lowers long-term interest rates while leaving short-term rates unchanged. A key difference relative to conventional monetary policy is that firms strongly increase their debt maturity in response to UMP. Initially, this lowers default risk because firms are less exposed to fluctuations in the price of their debt. However, as long-term debt accumulates, debt overhang increases and eventually raises firms' default risk above its steady-state level. At longer horizons, firms' endogenous debt maturity response leads to a persistent dampening of the output stimulus. The dampening effect is stronger in economies with higher leverage where the buildup of debt overhang is more pronounced. In such cases, the cumulative output effect of "expansionary" UMP can even become negative. These results show that firms' debt maturity response can generate important differences in the transmission of conventional and unconventional 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 four strands of the literature.

First, our work contributes to empirical studies of how debt maturity shapes firms' investment response to aggregate shocks. Duchin, Ozbas, and Sensoy (2010) and Almeida, Campello, Laranjeira, and Weisbenner (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, Frydman, and Papanikolaou, 2019) and during the 2010–2012 European sovereign debt crisis (Buera and Karmakar, 2022; Kalemli-Özcan, Laeven, and Moreno, 2022). We complement these event studies of financial crises by providing evidence on how debt maturity shapes the investment response to monetary policy shocks.

Second, a number of empirical papers study 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, Ferreira, Froemel, and Surico, 2023), liquidity (Jeenas, 2019), the share of floating-rate debt (Ippolito, Ozdagli, and Perez-Orive, 2018; Gürkaynak, Karasoy-Can, and Lee, 2022), and the share of bond financing (Darmouni, Giesecke, and Rodnyansky, 2021). We contribute to this literature by showing that not only the *level* of debt (or leverage) is important, but also the precise *timing* of when this debt comes due.[1]

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[1] Drechsel, Lewis, Melcangi, and Pilossoph (2025) estimate the full distribution of firms' investment responses to monetary policy and identify debt maturity as one of the correlates of investment sensitivity. Fabiani, Falasconi, and Heineken (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 monetary policy. While their results are qualitatively consistent with

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, Jermann, and Schmid (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, Gertler, and Gilchrist (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, Sim, and Zakrajšek (2014), Khan, Senga, and Thomas (2016), Begenau and Salomao (2018), Crouzet (2018), and Arellano, Bai, and Kehoe (2019). 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]

Finally, the paper contributes to the quantitative-theoretical literature studying unconventional monetary policy. Gertler and Karadi (2011), Carlstrom, Fuerst, and Paustian (2017), and Sims and Wu (2021) emphasize transmission through financial intermediaries' balance sheets. In contrast, our paper highlights the role of firms' debt maturity response in shaping the effects of unconventional monetary policy.[3]

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 maturing bond shares experience a larger fall in investment, borrowing, sales, and employment, and a larger increase in their credit spreads.

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our findings, we show that detailed bond-level information is important for precisely and robustly 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 an additional state variable. For quantitative models which explore the implications of long-term debt for firm financing and investment, see also Crouzet (2017), Caggese, Gutierrez, and Pérez-Orive (2019), 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), Perla, Pflueger, and Szkup (2024), or Xiang (2024). None of these models studies the role of debt maturity for monetary policy. Bhamra, Fisher, and Kuehn (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, DeMarzo, Hellwig, and Pfleiderer (2018), Crouzet and Tourre (2021), Dangl and Zechner (2021), DeMarzo and He (2021), or Friewald, Nagler, and Wagner (2022).

[3] For empirical evidence on the effects of unconventional monetary policy, see, e.g., Gagnon, Raskin, Remache, and Sack (2011), Krishnamurthy and Vissing-Jorgensen (2011), Swanson (2011), D'Amico and King (2013), or Ray, Droste, and Gorodnichenko (2024).

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.[4] 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 $t-4$.[5]

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

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

[5] 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-month-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&P 500 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.[6]

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.[7] 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

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[6] We show the monetary policy shock time series in Figure A.1 (a). The shocks contain non-trivial variation even during the zero lower-bound period, 2009-2015. We consider alternative samples and monetary policy shock series in Section 2.5.

[7] 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.[8] Finally, Table 1 documents the distribution of the monetary policy shock time series. The mean is approximately zero and the standard deviation is 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

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

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, $\varepsilon_t^{\mathrm{mp}}$ is the monetary policy shock, $\Delta \mathrm{gdp}_{t-1}$ 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.[9]

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

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

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.[10]

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

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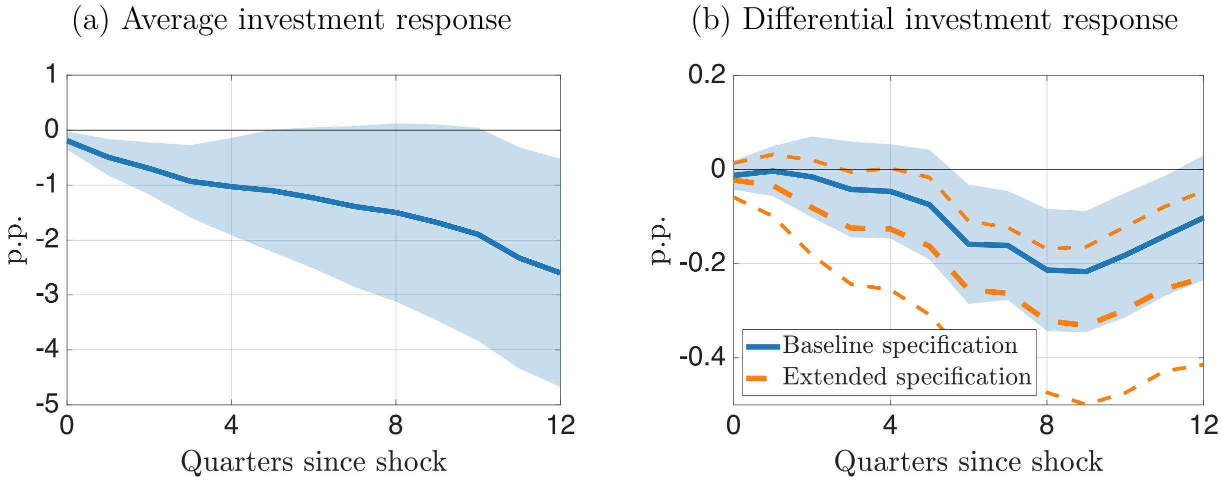
[8] A comparison of bond-issuing and non-issuing firms is provided in Table A.1. Bond-issuing firms are, on average, larger and older but have similar leverage as non-bond-issuing firms.

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

[10] 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 $\Delta \mathrm{gdp}_{t-1}$ 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


(a) Average investment response

(b) Differential investment response

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 $\varepsilon_t^{\text{mp}}$. 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 $\varepsilon_t^{\text{mp}}$ 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.

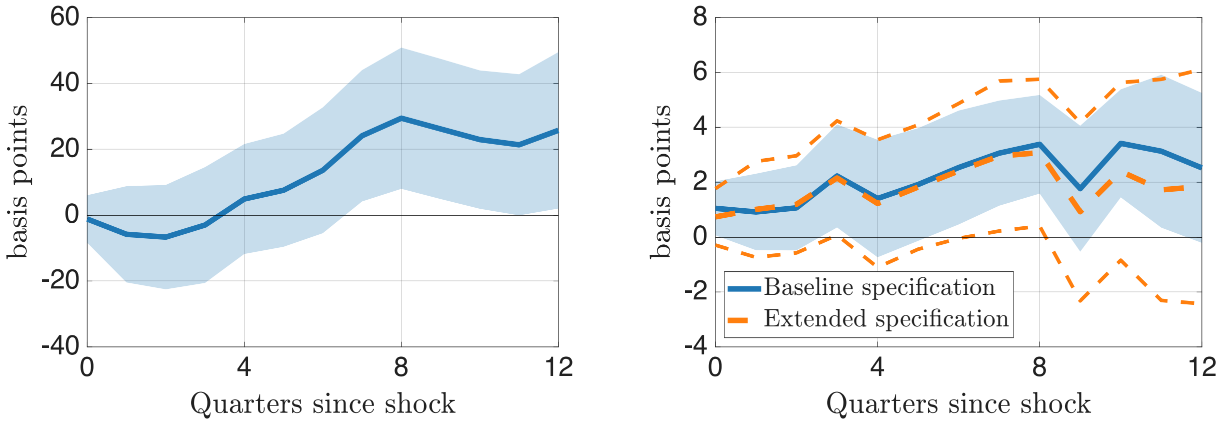
from zero at the 5% significance level at horizons between six and eleven quarters after the shock. The estimated coefficients β_1^h are standardized to reflect the differential response of firms that have a one standard deviation higher $\mathcal{M}_{it}$ at the time of a one standard deviation contractionary 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:

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

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


(a) Average credit spread response

(b) Differential credit spread response

Note: Panels (a) and (b) are analogous to those of Figure 2, with changes in credit spreads on the left-hand side of equations (2.2), (2.3), and (2.4).

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.[11] 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 (see Figure A.1), we include a dummy variable for the four quarters 2008Q3–2009Q2, which is interacted with $\varepsilon_t^{\text{mp}}$ and Δgdp_{t-1}, respectively.[12]

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 shock, the response is significant at the 5% level. We estimate $\alpha_1^8 = 29$ which means that

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[11] For a full list of coefficient estimates (in both specifications), see Online Appendix Tables F.1 and F.2.

[12] 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.

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).[13] These responses are less precisely estimated than the differential investment response but, overall, they indicate that high maturing bond shares are associated with more contractionary responses.

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 point estimate of the differential decline in debt growth is 0.40 p.p. The estimates are 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 tends to decline 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 the eight-quarter horizon.

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-month-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.

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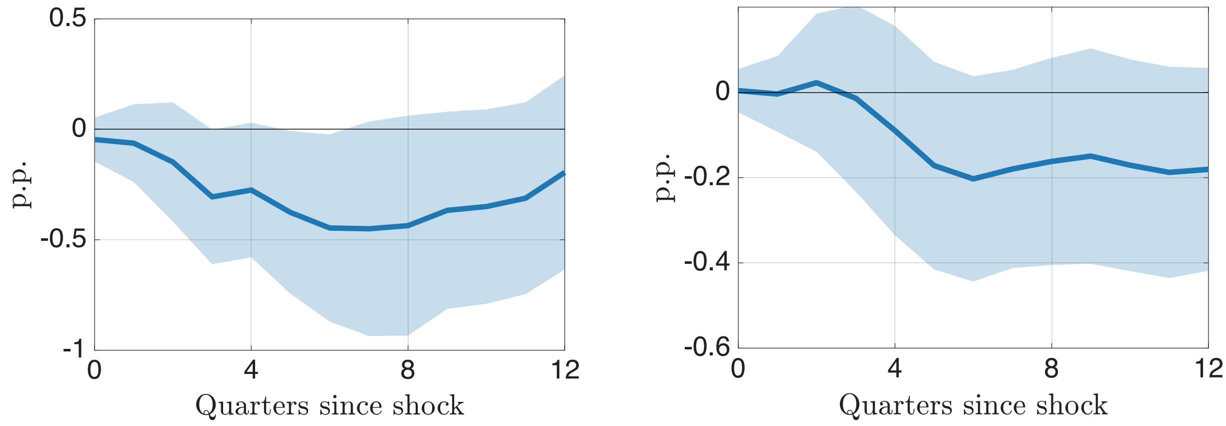
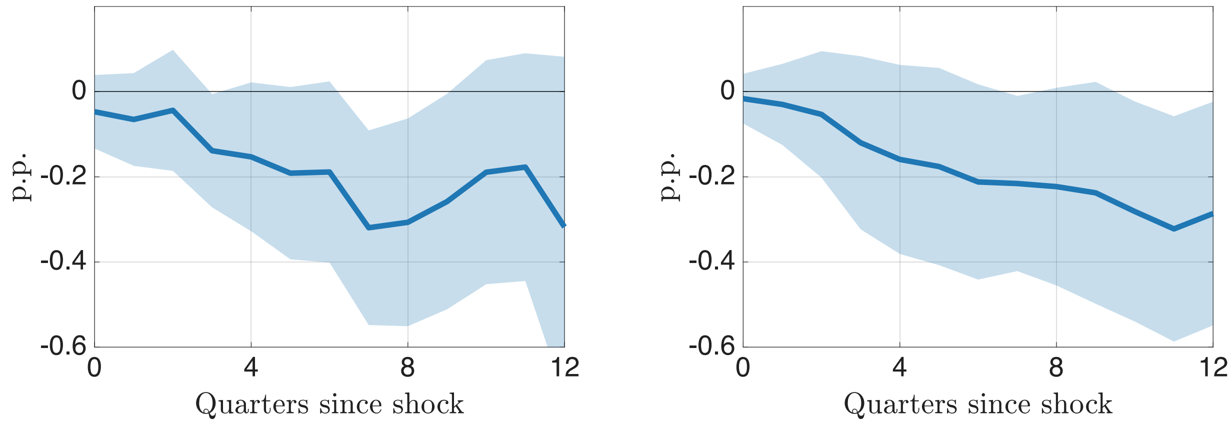
[13] Debt, sales, and cost of goods sold are backward-looking four-quarter moving averages to smooth out firm-specific seasonal factors and other transitory fluctuations. Annual employment data is imputed at quarterly frequency using quarterly data on cost of goods sold. For further details, see Appendix 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

(a) Debt (b) Sales



(c) Employment (d) Cost of goods sold



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 $\varepsilon_t^{\text{mp}}$ 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 until 2008Q2, i.e., excluding the Great Recession and subsequent years largely characterized by a binding zero lower bound. The responses are estimated less precisely, potentially due to the substantially shorter time series. Overall, however, our main findings appear robust. Panel (c) of Figure B.3 excludes only the Great Recession period 2008Q3–2009Q2. The resulting estimates are highly similar to the baseline. 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 Figure B.8 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.4 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 is 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.4 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 three times fewer variable-coupon bonds than fixed-coupon bonds in our sample. Figure B.5 repeats the corresponding exercises with credit spreads as the 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.6 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.7 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 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.[14] Our baseline measure of the maturing bond share in equation (2.1) defines $\mathcal{M}_{it}$ as the ratio of maturing bonds to 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 the threshold for the maturing bond share, but barely present for the 0%-threshold.[15]

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 responses when allowing for size- or age-specific differences in the association with the maturing bond share. Figures B.14 and B.15 show that within the groups of old and large firms, a higher maturing bond share is associated with a significantly stronger investment response to monetary policy shocks. The point estimates within the groups of young and small firms are less precise but point in the same direction.

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 mechanisms behind this result and its implications for the aggregate effects of monetary

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[14] 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.

[15] 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.

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 debt issuance costs and insures firms against fluctuations in bond prices, 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 interest rate.

3.1 Production firms

A production firm i begins 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

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

where p_t is the price of undifferentiated output, w_t the wage rate, Q_t the price of capital goods, δ the depreciation rate, and f a fixed cost of production. Prices (p_t, w_t, Q_t) are expressed in terms of time t final goods. The random variable ε_{it} is a firm-specific i.i.d. capital quality shock with mean zero and continuous probability distribution $\varphi(\varepsilon_{it}|z_{it})$.[16] 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}.

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[16] 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.

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 value of firms' cash-on-hand 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 the remaining cash-on-hand to shareholders. Exiting firms are replaced by an equal mass of entrants with initial productivity $z_{it+1} = Z^e$ and without initial cash-on-hand or debt. 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. The market value of next period's capital is given by the cash flow constraint

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

The term e_{it} denotes net issuance of outside equity. A negative value of e_{it} indicates dividend payments to firm shareholders. Firms sell new short-term bonds with face value b_{it+1}^S at price p_{it}^S. The face value of outstanding long-term bonds is $(1-\gamma)b_{it}^L/\pi_t$. Firms can sell new long-term bonds at price p_{it}^L and thereby choose the amount of next period's long-term debt b_{it+1}^L. Issuing equity and debt is costly.[17]

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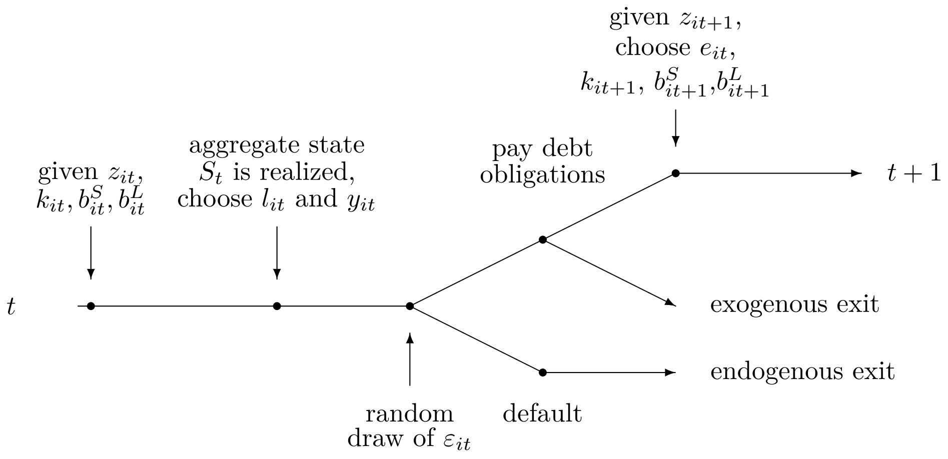
[17] Equity and debt issuance costs capture underwriting fees charged by investment banks to firms. Equity issuance costs may also capture costs from adverse selection on the stock market (*cf.* Myers and Majluf, 1984). Altınkılıç and Hansen (2000) provide empirical evidence of increasing marginal issuance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

Figure 5: Timing



Definition. 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

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

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 begins 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} 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

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

After servicing current debt obligations, with probability κ a firm exits exogenously. In that case, it repurchases all outstanding long-term debt and pays out the remaining cash-on-hand to shareholders. Otherwise, the firm continues and chooses next period's capital and its financing structure. The value $W_t(x_{it}, \varepsilon_{it}; S_t)$ is therefore given by

$$W_t(x_{it}, \varepsilon_{it}; S_t) = \mathbb{E}_{z_{it+1}|z_{it}} \left[(1-\kappa) \cdot W_t^C(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) + \kappa \cdot W_t^X(x_{it}, \varepsilon_{it}, z_{it+1}; S_t)\right], \tag{3.8}$$

where the value of exogenous exit is given by

$$W_t^X(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) = q_{it} - \frac{(1-\gamma)b_{it}^L}{\pi_t} p_{it}^L, \tag{3.9}$$

and the value of a continuing firm is

$$\begin{aligned} W_t^C(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) = \max_{\substack{k_{it+1}, e_{it} \geq \underline{e}, \\ b_{it+1}^S \geq 0, b_{it+1}^L \geq 0}} \quad & -e_{it} - G(e_{it}) - H\left(b_{it+1}^S, b_{it+1}^L, \frac{b_{it}^L}{\pi_t}\right) \\ & + \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \int_{\varepsilon_{it+1}} V_{t+1}(x_{it+1}, \varepsilon_{it+1}; S_{t+1}) \varphi(\varepsilon_{it+1}|z_{it+1}) d\varepsilon_{it+1} \end{aligned} \tag{3.10}$$

Firms maximize shareholder value, i.e., the present discounted value of the expected stream of future dividends. Dividends (negative values of e_{it}) are pinned down by the cash flow constraint (3.4).[18] Because all firms are owned by the representative household, firms optimize using the household's stochastic discount factor $\Lambda_{t,t+1}$.

3.2 Creditors

A firm's choice of capital, equity, short-term debt, and long-term debt crucially depends on the two bond prices p_{it}^S and p_{it}^L 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 $(1+c)b_{it+1}^S/\pi_{t+1}$, while long-term creditors receive $(\gamma+c)b_{it+1}^L/\pi_{t+1}$. In case of default, the value of firm assets left for creditors is:

$$\underline{q}_{it+1} \equiv \max\left\{Q_{t+1}k_{it+1} + (1-\tau)\left[A_{it+1}k_{it+1}^{\alpha} + (\varepsilon_{it+1} - \delta)Q_{t+1}k_{it+1} - f\right], 0\right\} \tag{3.11}$$

Because default is costly, creditors only receive $(1-\xi)\underline{q}_{it+1}$.

Creditors are perfectly competitive. Because 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

$$p_{it}^S = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \int_{\varepsilon_{it+1}} \left[(1-\mathcal{D}_{it+1})\frac{1+c}{\pi_{t+1}} + \mathcal{D}_{it+1}\frac{(1-\xi)\underline{q}_{it+1}}{b_{it+1}^S + b_{it+1}^L}\right] \varphi(\varepsilon_{it+1}|z_{it+1}) d\varepsilon_{it+1}, \tag{3.12}$$

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[18] There is an upper bound on dividend payments: $e_{it} \geq \underline{e}$, with $\underline{e} < 0$. If the stock of previously issued outstanding debt $(1-\gamma)b_{it}^L/\pi_t$ is sufficiently large, a firm may find it optimal to choose a corner solution and pay out all cash-on-hand 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. A second constraint in (3.10) is that firm debt cannot be negative ($b_{it+1}^S \geq 0$, $b_{it+1}^L \geq 0$), i.e., we do not allow firms to accumulate financial savings.

where the indicator function $\mathcal{D}_{it+1}$ is one if and only if the firm defaults in period $t+1$. The price of long-term debt p^L_{it} also depends on the future price of long-term debt:

$$p^L_{it} = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\int_{\varepsilon_{it+1}}\Bigg[(1-\mathcal{D}_{it+1})\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z_{it+2}|z_{it+1}} g_{t+1}(x_{it+1}, \varepsilon_{it+1}, z_{it+2}; S_{t+1})}{\pi_{t+1}} \\ + \mathcal{D}_{it+1}\frac{(1-\xi)\underline{q}_{it+1}}{b^S_{it+1}+b^L_{it+1}}\Bigg]\varphi(\varepsilon_{it+1}|z_{it+1})d\varepsilon_{it+1}. \tag{3.13}$$

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.[19]

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

$$1 - \rho\,(1-p_t) - \lambda\pi_t(\pi_t - 1) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{Y_t}\pi_{t+1}(\pi_{t+1}-1) = 0, \tag{3.14}$$

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 (3.14) 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 (3.14). 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 that adjusts the aggregate stock of capital using an amount I_t of final goods with decreasing returns (determined by $\phi > 1$):

$$K_{t+1} = \Phi\left(\frac{I_t}{K_t}\right)K_t + (1-\delta)K_t, \quad \text{where} \quad \Phi\left(\frac{I_t}{K_t}\right) = \frac{\delta^{\frac{1}{\phi}}}{1-\frac{1}{\phi}}\left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\phi}} - \frac{\delta}{\phi - 1}. \tag{3.15}$$

Profit maximization pins down the price of capital goods:

$$Q_t = \left(\frac{I_t}{\delta K_t}\right)^{\frac{1}{\phi}} \tag{3.16}$$

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[19] Appendix C shows the corresponding expressions for risk-free short-term and long-term bond prices and how they are linked to short-term and long-term interest rates.

3.5 Government and conventional 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 *conventional* monetary policy by setting the risk-free nominal short-term interest rate i_t according to the Taylor rule

$$1 + i_t = \frac{1}{\beta} \pi_t^{\varphi^{\mathrm{mp}}} e^{\eta_t^{\mathrm{mp}}}, \tag{3.17}$$

where $\beta \in (0, 1)$ is the representative household's discount rate.[20] 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

$$\eta_t^{\mathrm{mp}} = \rho^{\mathrm{mp}} \eta_{t-1}^{\mathrm{mp}} + \varepsilon_t^{\mathrm{mp}}, \quad \text{with} \quad \varepsilon_t^{\mathrm{mp}} \sim N(0, \sigma_{\mathrm{mp}}^2). \tag{3.18}$$

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

$$\log(C_t) - \frac{L_t^{1+\theta}}{1+\theta}, \quad \text{with} \quad \theta > 0. \tag{3.19}$$

The stochastic discount factor of the representative household is

$$\Lambda_{t,t+1} = \beta \frac{C_t}{C_{t+1}}. \tag{3.20}$$

3.7 General equilibrium

A firm maximizes shareholder value (3.10) subject to the firm's cash flow constraint (3.4) and creditors' bond pricing equations (3.12) and (3.13). The combination of long-term debt and default implies a commitment problem for firms (Jungherr and Schott, 2021, 2022). 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, Krusell, and Ríos-Rull (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.

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[20] In Section 4.6 we introduce a model extension with *unconventional* monetary policy.

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, firms choose a policy vector $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$ which solves

$$W^C(x, \varepsilon, z'; S) = \max_{\phi(x,\varepsilon,z';S)=\left\{\begin{smallmatrix} k', e \geq \underline{e}, \\ b^{S'} \geq 0, \\ b^{L'} \geq 0 \end{smallmatrix}\right\}} -e - G(e) - H\left(b^{S'}, b^{L'}, \frac{b^L}{\pi}\right) + \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} V(x', \varepsilon'; S')\varphi(\varepsilon'|z')d\varepsilon' \tag{3.21}$$

subject to:

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

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

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

$$W(x', \varepsilon'; S') = \mathbb{E}_{z''|z'}\left[(1-\kappa)W^C(x', \varepsilon', z''; S') + \kappa W^X(x', \varepsilon', z''; S')\right]$$

$$W^X(x', \varepsilon', z''; S') = q(x', \varepsilon'; S') - \frac{(1-\gamma)b^{L'}}{\pi'}p^{L'},$$

where bond prices p^S and p^L are determined by (3.12) and (3.13). Given firm policies $\phi(x, \varepsilon, z'; S) = \{k', e, b^{S'}, b^{L'}\}$, the continuum of production firms is characterized by the distribution $\mu(x)$ with law of motion

$$\mu(x') = \int_x \int_\varepsilon \mathcal{I}(k', b^{S'}, b^{L'}, x, \varepsilon, z'; S)\left(1 - \mathcal{D}(x, \varepsilon; S)\right)\varphi(\varepsilon|z)d\varepsilon(1-\kappa)\Pi(z'|z)\mu(x)dx + \mathcal{E}(x'; S). \tag{3.22}$$

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 $\phi(x, \varepsilon, z'; S) = \{k', e, b^{S'}, b^{L'}\}$. 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 $V(x, \varepsilon; S)$, $W(x, \varepsilon; S)$, $W^C(x, \varepsilon, z'; S)$, and $W^X(x, \varepsilon, z'; S)$, *(ii)* a policy vector $\phi(x, \varepsilon, z'; S) = \{k', e, b^{S'}, b^{L'}\}$, *(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 $V(x, \varepsilon; S)$, $W(x, \varepsilon; S)$, $W^C(x, \varepsilon, z'; S)$, $W^X(x, \varepsilon, z'; S)$, and policy functions $\phi(x, \varepsilon, z'; S) = \{k', e, b^{S'}, b^{L'}\}$ solve the firm problem (3.21).

2. *Creditors:* The bond prices p^S and p^L are given by (3.12) and (3.13).

3. *Retail firms:* p and π follow the New Keynesian Phillips curve (3.14).

4. *Capital producers:* The price of capital Q is given by (3.16).

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 (3.17).

7. *Firm distribution:* $\mu(x') = \Gamma(\mu(x); S)$ as in (3.22).

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

3.8 Model mechanisms

This subsection describes the key mechanisms of the model. We explain the determinants of firms' debt maturity choice, and how debt maturity shapes their investment response to monetary policy. We highlight four key model implications which are important for understanding the quantitative results presented in Section 4.[21]

3.8.1 Debt maturity choice

Every period, firms choose their capital stock, the amounts of short-term and long-term debt, and equity issuance (respectively dividend payout). A given amount of total debt can be achieved through different combinations of short-term debt $b^{S'}$ and long-term debt $b^{L'}$, generating a continuous debt maturity choice.

Benefits of long-term debt: Debt issuance costs and insurance. Long-term debt has two benefits relative to short-term debt. The first one arises because debt issuance is costly. Maintaining a given amount of debt requires that maturing debt is replaced by new debt issuance (*roll-over*). Only a fraction γ of long-term debt matures per period. Because it matures more slowly than short-term debt, long-term debt requires less roll-over per period. A higher long-term debt share therefore saves debt issuance costs.

The second benefit of long-term debt is that it provides insurance against fluctuations in bond prices. Consider the firm's cash flow constraint (3.4), reprinted here:

$$e = Qk' - q(x,\varepsilon;S) \underbrace{-b^{S'}p^S - \left(b^{L'} - \tfrac{(1-\gamma)b^L}{\pi}\right)p^L}_{\text{bond market revenue}} \tag{3.23}$$

Even in the absence of aggregate shocks, the firm's bond prices p^S and p^L vary over time because of fluctuations in idiosyncratic default risk. For example, a large negative capital quality shock ε results in low cash on hand $q(x,\varepsilon;S)$, which raises the firm's default risk and

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[21] The discussion in this section focuses on economic intuition and abstracts from technical details and special cases in order to clarify the key quantitative mechanisms at play in Section 4. A formal treatment, using a two-period version of the model presented above, is provided in Online Appendix I.

lowers its bond prices p^S and p^L. Given the firm's choices of k', $b^{S'}$, and $b^{L'}$, this reduction in bond prices lowers bond market revenue and increases the need for equity issuance e. Because equity issuance is costly, firms have an incentive to avoid fluctuations in bond market revenue. A higher share of long-term debt reduces roll-over per period and thereby mitigates the pass-through of bond price fluctuations to cash flow. In this way, long-term debt provides insurance against fluctuations in bond prices.

Cost of long-term debt: Debt overhang. The downside of long-term debt is that it creates debt overhang: part of the gains from new investment accrue to existing creditors rather than shareholders. As a result, firms with large stocks of outstanding long-term debt have weaker incentives to invest (Myers, 1977). This effect can be identified in the firm's first order condition for capital:[22]

$$\left[1+\frac{\partial G(e)}{\partial e}\right]\Bigg[\underbrace{-Q}_{\text{cost of capital}}\underbrace{+b^{S'}\frac{\partial p^S}{\partial k'}+\left(b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}}_{\text{indirect benefit of capital}}\Bigg]$$

$$\underbrace{+\mathbb{E}\Lambda\int_{\varepsilon'}(1-\mathcal{D})\frac{\partial q'}{\partial k'}\left(1+\frac{\partial G(e')}{\partial e'}\right)\varphi(\varepsilon'|z')d\varepsilon'}_{\text{direct benefit of capital}}=0 \tag{3.24}$$

First, consider the marginal cost of capital. For given choices of short- and long-term debt, $b^{S'}$ and $b^{L'}$, a marginal increase in capital k' requires higher equity issuance e. The marginal cost of capital therefore depends on the price of capital Q and the marginal equity issuance cost $\partial G(e)/\partial e$. The marginal benefit of capital consists of two parts. The first one is direct: capital increases production which raises future cash-on hand q' and reduces the need for future equity issuance. The second benefit is indirect. For a given choice of debt, an increase in capital reduces default risk and increases bond prices, $\partial p^S/\partial k' > 0$ and $\partial p^L/\partial k' > 0$. However, in the presence of long-term debt, part of this gain accrues to existing bondholders who benefit from reduced default risk and the increased bond price p^L. The higher the amount of outstanding long-term debt $(1-\gamma)b^L/\pi$, the higher the share of the investment benefits captured by the owners of outstanding long-term debt and the smaller the marginal benefit of capital that remains for shareholders. In this way, debt overhang reduces the marginal benefit of capital and weakens investment incentives.

When a firm issues long-term debt, it would like to promise creditors that it will maintain a high capital stock and a low default risk in the future, because this would raise today's long-term bond price p^L. But such a promise is not credible: in the future, some of the benefits of additional investment accrue to the owners of outstanding long-term debt. This reduces the firm's incentive to invest and increases its default risk. Creditors anticipate this commitment problem and pay lower bond prices if the firm issues long-term debt instead of short-term debt. This is the downside of long-term debt.

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[22] Equation (3.24) shows the first-order condition of the firm problem (3.21) with respect to capital k'. For ease of exposition, the first-order condition is derived assuming no exogenous exit ($\kappa = 0$). See Online Appendix G for detailed derivations of all first-order conditions in the general case with $\kappa > 0$.

Importantly, this cost of issuing long-term debt is larger for firms with higher default risk. In the first-order condition (3.24) this effect is captured by the derivative $\partial p^L/\partial k'$. Consider first a firm with low default risk. Changes in capital have little effect on its future default probability and therefore only a small effect on the long-term bond price p^L. In this case, the derivative $\partial p^L/\partial k'$ is small and outstanding long-term debt has little impact on the firm's investment incentives. By contrast, when default risk is high, changes in capital have a larger effect on default risk and therefore on the long-term bond price. The derivative $\partial p^L/\partial k'$ is larger, strengthening the debt overhang problem and reducing investment incentives. As a result, firms with high default risk find long-term borrowing particularly costly and optimally choose shorter maturities.

Implication 1. The cost of long-term debt is larger for firms with higher default risk.

In Section 4.3, we show that Implication 1 allows the quantitative model to replicate how firms' empirical debt maturity choices vary across the size distribution.

3.8.2 Debt maturity and the investment response to monetary policy

The mechanism described above generates heterogeneity in firms' debt maturity choices. We now describe how the resulting differences in firms' maturing debt shares shape their investment response to conventional monetary policy. Two channels are key: (1.) *roll-over risk* and (2.) *debt deflation.* Firms' exposure to roll-over risk increases with their share of maturing debt. Exposure to debt deflation falls with the share of maturing debt, but increases with default risk.

Roll-over risk. Monetary policy shocks affect the real interest rate, which affects bond prices p^S and p^L through the household's stochastic discount factor Λ, see (3.12) and (3.13). This affects firms' capital choice in two ways. First, a contractionary monetary policy shock reduces the stochastic discount factor, lowers bond prices, and reduces bond market revenue. For given choices of capital and debt, this requires an increase in net equity issuance. For equity-issuing firms, this increases the marginal cost of equity issuance and thereby the marginal cost of capital in (3.24). Through this cash-flow channel, a higher real interest rate reduces investment. Second, the indirect benefit of capital in (3.24) is that it reduces default risk. This increases expected future payments to creditors and raises bond prices. However, a reduction in creditors' stochastic discount factor lowers their valuation of future payments. As a result, a given reduction in default risk raises bond prices by less. This weakens the indirect benefit of capital in (3.24). Importantly, both effects are stronger for firms with a larger share of maturing debt as they need to roll over more debt at higher interest rates. Long-term debt insulates firms against this roll-over risk by reducing the maturing debt share.

Implication 2. A higher share of maturing debt amplifies a firm's investment response to monetary policy through roll-over risk.

Debt deflation. Monetary policy also affects inflation. Because firm debt is nominal, lower inflation π raises the real burden of outstanding long-term debt $(1-\gamma)b^L/\pi$ (Fisher, 1933). This intensifies the debt overhang problem and thereby reduces firm investment. Holding default risk fixed, this effect is more pronounced for firms with higher shares of outstanding long-term debt, i.e., lower shares of maturing debt.

> *Implication 3.* Conditional on default risk, a lower maturing debt share amplifies a firm's investment response to monetary policy through debt deflation.

Importantly, the effect of debt deflation on firm investment depends on default risk. As discussed above, higher default risk increases the sensitivity of the firm's long-term bond price to changes in capital, $\partial p^L/\partial k'$, and thereby intensifies debt overhang. As a result, a given increase in the real burden of outstanding long-term debt leads to a larger reduction in investment for firms with higher default risk. For a given maturity structure, a fall in inflation therefore reduces investment by more for high-default-risk firms.

> *Implication 4.* Conditional on the share of maturing debt, higher default risk amplifies a firm's investment response to monetary policy through debt deflation.

As we show in the next section, these model implications are key for understanding the role of debt maturity in shaping firms' investment responses to monetary policy.

4 Quantitative Analysis

To compare the model results to the empirical evidence, we now proceed with a quantitative analysis. In this section, we show that the calibrated model replicates several targeted and non-targeted moments that characterize the financing choices of U.S. firms. Importantly, the model rationalizes the empirical result that firms with higher shares of maturing debt react more strongly to monetary policy shocks. At the aggregate level, we find that endogenous debt maturity generates important differences in the transmission of conventional and unconventional monetary policy.

4.1 Solution method

We compute the equilibrium of our model using value function iteration and interpolation. There are three main computational 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 the aggregate state S and the capital quality shock 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 (3.21) 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 challenge is finding the equilibrium prices of risky debt. In particular, the price of long-term debt, p^L, is a key ingredient for a solution of the model. Optimal firm

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

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 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 nonlinear global solution of the steady state with idiosyncratic firm-level uncertainty but without aggregate shocks. We then use a first-order perturbation method to approximate the equilibrium dynamics of the model around the steady state in response to aggregate shocks.[23]

4.2 Calibration

A number of parameters can be set externally using standard values from the existing literature. 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, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018). The quarterly depreciation rate δ is 2.5%. We follow Gomes et al. (2016) in setting the tax rate to $\tau = 0.4$ and the repayment rate of long-term debt to $\gamma = 0.05$.[24] The choice of γ implies a Macaulay duration of $(1 + r^*)/(\gamma + r^*) = 16.8$ quarters or 4.2 years. This choice is conservative relative to the average duration of 6.5 years in Gilchrist and Zakrajšek (2012) for a sample of U.S. corporate bonds with remaining term to maturity above one year. Figure D.1 shows that the calibrated model is successful in generating an empirically realistic maturity structure of debt at various time horizons.

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

[24] 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).

As in Kaplan, Moll, and Violante (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 $\varphi^{\mathrm{mp}} = 1.25$ and $\rho^{\mathrm{mp}} = 0.5$. The price adjustment cost parameter λ and the parameter of the capital goods technology ϕ are taken from Ottonello and Winberry (2020). The parameters 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, Eichenbaum, and Evans, 2005). All externally set parameters are summarized in Table 2.

Internally calibrated parameters. Firm-level productivity z follows a productivity ladder with discrete support $\{Z_1, \ldots, Z_J\}$. Entrants start at the lowest productivity level $Z^{\mathrm{e}} = Z_1$, 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. The parameter ς_z controls the dispersion of the productivity ladder: $\log Z_1 = -\varsigma_z$ and $\log Z_J = +\varsigma_z$. This productivity process has two desirable features. First, it captures the positive skewness of empirical firm growth (Decker, Haltiwanger, Jarmin, and Miranda, 2014). Second, it facilitates the computation of the Markov perfect equilibrium.[25]

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.[26]

We internally calibrate nine parameters—ρ_z, ς_z, $\sigma_{\varepsilon|z\leq\mathbb{E}(z)}$, $\sigma_{\varepsilon|z>\mathbb{E}(z)}$, ξ, η, ν, κ, and f—to match key empirical moments which are informative about the financing and investment behavior of firms. To discipline firms' debt choices, we use Compustat information on leverage and on the share of total debt due within a year.[27] We further use firm-level data on capital, age (quarters since initial public offering), and equity issuance from Compustat. Finally, we calculate credit spreads 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

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[25] 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 (3.10) to bind for any value of $\underline{e}$. The productivity process described above avoids such counterfactual firm behavior.

[26] This improves the model fit by better capturing how leverage varies with firm size and age in the data. We allow the standard deviation of ε to differ between firms with below-average productivity ($\sigma_{\varepsilon|z\leq\mathbb{E}(z)}$) and above-average productivity ($\sigma_{\varepsilon|z>\mathbb{E}(z)}$).

[27] 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.

Table 3: Internally calibrated parameters

Parameter	Value	Target	Data	Model
ρ_z	0.988	Regression $\log(k)$ on age	0.022	0.024
ς_z	0.300	Std. of firm capital growth *(in %)*	16.8	14.6
$\sigma_{\varepsilon\|z\leq\mathbb{E}(z)}$	0.60	Average firm leverage *(in %)*	34.4	30.3
$\sigma_{\varepsilon\|z>\mathbb{E}(z)}$	0.88	Regression leverage on age	0.196	0.229
ξ	0.54	Average credit spread on long-term debt *(in %)*	3.1	2.7
η	0.0045	Average share of debt due within a year *(in %)*	30.5	30.8
ν	0.0005	Average equity issuance *(in %)*	11.4	14.8
κ	0.0151	Firm exit rate *(in %)*	2.2	2.1
f	0.2585	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.

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 ς_z, which are pinned down through *(1.)* the relationship between firm size and firm age (captured through a linear regression) and *(2.)* 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 chosen to match 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 controls how fast leverage increases with firm age in the model. The average credit spread is directly affected by the default cost ξ. The average share of debt due within a year responds to 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.[28]

Table 3 shows that the model matches the data well. Average firm leverage and the share of debt due within a year are both about 30%. The average annual credit spread on long-term debt is close to 3 percent. Aggregate equity and debt issuance costs amount to 0.27% and 0.04% of GDP, respectively. The model generates a quarterly default rate of 0.6%. Although untargeted, the default rate is 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, Kayhan, and Titman (2011).

4.3 Cross-sectional implications

The steady state of the calibrated model replicates how empirical firm financing choices vary across the size distribution. While the calibration targeted average values of the maturing

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[28] See Appendix D.1 for a definition of the model variables used in Table 3.

debt share and the credit spread, their variation across size quartiles is non-targeted.

Figure 6 shows three important empirical facts. First, leverage increases with firm size. Second, smaller firms pay higher credit spreads. Third, smaller firms have larger shares of maturing debt. The last panel further 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. Because the fixed operating cost f weighs more heavily on smaller firms, they are less profitable and therefore face higher default risk for a given amount of leverage. As a result, smaller firms pay higher credit spreads and choose lower leverage. Because average firm productivity increases with age in the model, older firms are also larger on average.

Panel (c) shows that the model also replicates the fact that smaller firms have higher maturing debt shares. As emphasized in Implication 1 in Section 3.8, debt overhang is more distortive for firms with higher default risk, raising their cost of long-term debt. Because smaller firms have higher default risk, they face higher costs of long-term debt and optimally choose shorter maturities, implying higher shares of maturing debt per period.[29]

These financing patterns are important for the quantitative results below. In particular, the cross-sectional variation in maturing debt shares generated by firms' maturity choices is the source of the heterogeneous exposure to monetary policy in Section 4.5.

4.4 Aggregate effects of conventional monetary policy shocks

The previous results 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 analyzing the model's aggregate implications.

Figure 7 shows the aggregate effects of a conventional monetary policy shock, $\varepsilon_t^{\mathrm{mp}}$ in equation (3.18), that increases the nominal interest rate i_t by 30bp on impact. 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, defined in (C.5). 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

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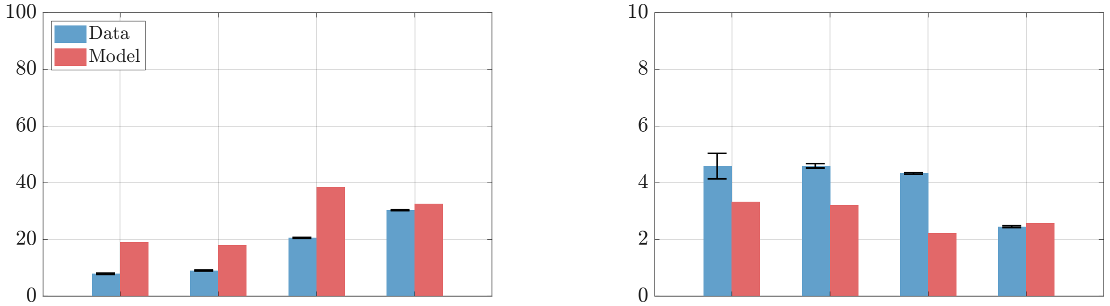
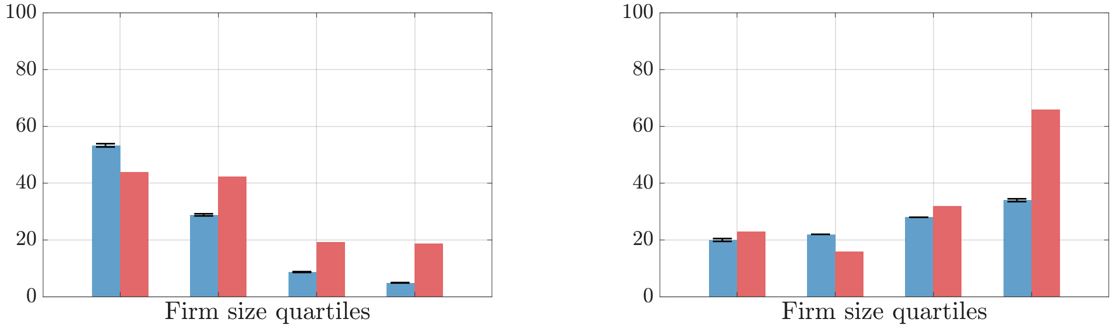
[29] This mechanism is illustrated in Figures D.2 and D.3 in the Appendix. Firms with lower productivity have higher default risk and are therefore more exposed to debt overhang. For these firms, issuing additional long-term debt b_{t+1}^L distorts future investment and default risk by more. It therefore has a larger negative effect on their long-term bond price p_t^L (Figure D.2). Firms whose policies (including the long-term bond price p_t^L) are more sensitive to the amount of outstanding long-term debt choose shorter maturities and higher maturing debt shares (Figure D.3).

Figure 6: Firm variables conditional on size



(a) Firm leverage (in %)

(b) Credit spread on long-term debt (in %)



(c) Share of debt due within a year (in %)

(d) Firm age (quarters since IPO)

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.

price depends on default risk in all future periods. Firms react by increasing the average maturity of their debt portfolio.

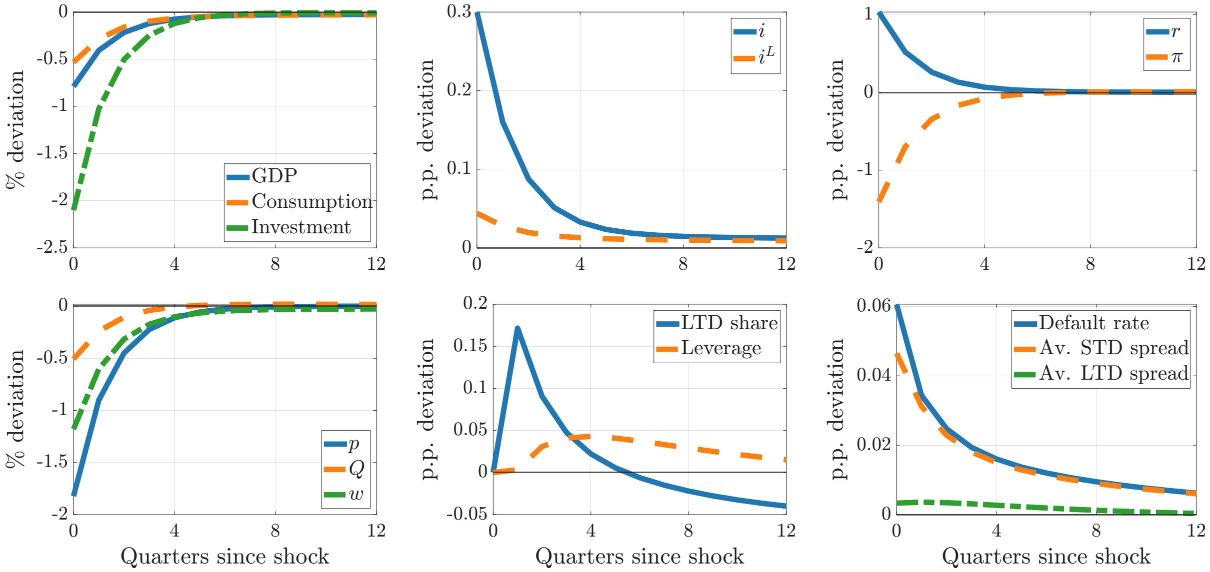
4.5 Heterogeneous effects of conventional monetary policy shocks

Our empirical analysis in Section 2 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 consider the baseline local projection (2.3) using simulated data generated by the model. We estimate:

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

Figure 7: Aggregate response to a contractionary monetary policy shock



Note: The nominal short-term interest rate i, the nominal long-term interest 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.

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

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

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.[30] 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 a monetary policy shock that increases the nominal interest rate i by 30bp.

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 18 bp, which is 84% of the peak differential response in the data. 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 the 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.4 in the Appendix shows that a higher $\mathcal{M}_{it}$

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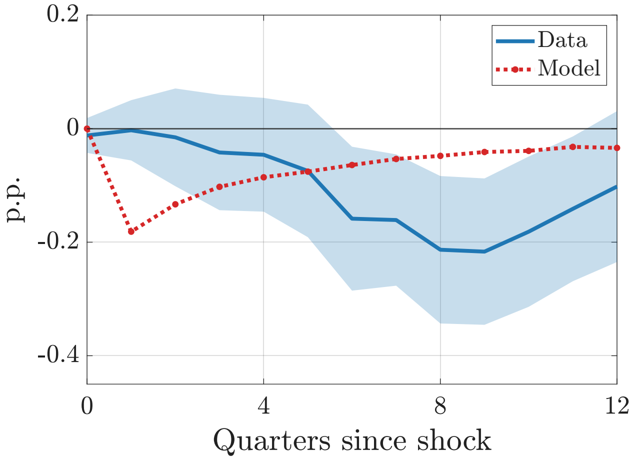
[30] Note that in the model b_{it}^S and b_{it}^L denote predetermined debt levels at the beginning of period t. This corresponds to debt$_{it-1}$ in the empirical part of the paper. As in the empirical specification, we use average total debt over the preceding four quarters as the denominator for $\mathcal{M}_{it}$.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

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



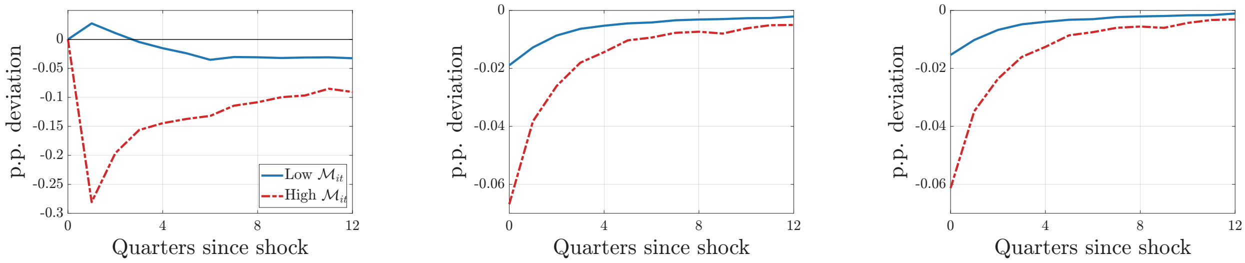
Note: The red dotted line shows the estimated β_1^h coefficients based on equation (4.2) using simulated model data. The β_1^h estimates are standardized to capture the differential cumulative capital growth response (in p.p.) to a one standard deviation (30bp) increase in the nominal interest rate i 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.

at the time of the shock is associated with a larger increase in 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.

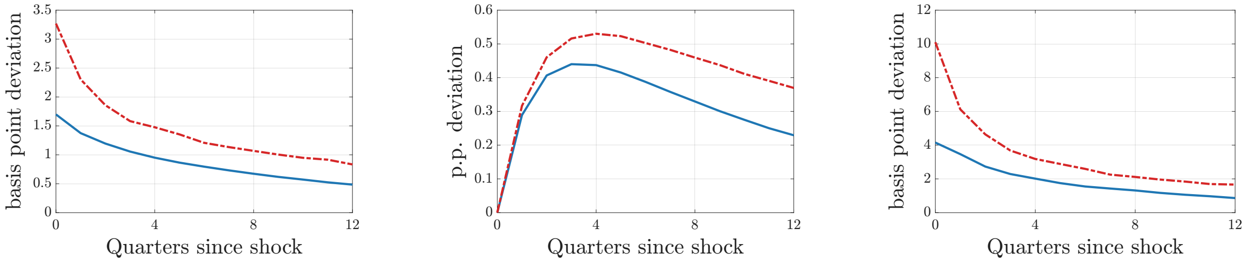
Monetary transmission and the maturing bond share. The model rationalizes the main empirical result of the paper: a higher share of maturing debt at the time of a monetary policy shock is associated with a stronger response of firm investment, credit spreads, debt, sales, and employment. Figure 9 provides further insights into the role of the maturing bond share in the transmission of monetary policy shocks in the model. 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 for both groups of firms. Panel (a) shows that capital of high-$\mathcal{M}$ firms falls by about 30 bp after a contractionary monetary policy shock. In contrast, capital of low-$\mathcal{M}$ firms initially increases. These firms benefit from falling factor prices for labor and capital goods. 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 insures against roll-over risk. However, as panel (e) shows, the decline in inflation raises the real burden of outstanding nominal long-term debt, thereby increasing debt overhang. The associated rise in default risk, shown in panel (f), is larger for high-$\mathcal{M}$ firms, explaining the larger increase in credit spreads.

Decomposing the transmission channels. In the model, debt maturity matters for the transmission of monetary policy because of two channels: (1.) Debt maturity determines

Figure 9: Heterogeneous responses to a contractionary monetary policy shock



(a) Capital (b) Bond market revenue (c) Debt issuance



(d) Average credit spread (e) Outstanding long-term debt (f) Default rate

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.

roll-over risk and thereby affects firms' investment response to interest rate changes (Implication 2 in Section 3.8). (2.) Debt maturity determines firms' exposure to *debt deflation* and thereby affects their investment response to changes in inflation. Conditional on default risk, a lower maturing debt share increases exposure to debt deflation (Imp. 3). On the other hand, exposure to debt deflation increases in default risk (Imp. 4), and firms with higher default risk choose higher maturing debt shares (Imp. 1). Whether debt deflation has a stronger impact on firms with high or low maturing debt shares is therefore a quantitative question.

To quantify the importance of *roll-over risk* and *debt deflation* in generating the model estimates in Figure 8, we design two model experiments. The first experiment eliminates the cash-flow effects of roll-over risk by compensating firms for the cash shortfall due to changes in interest rates. Formally, this experiment introduces a cash transfer $T(q, b, z', S)$ into the cash flow constraint (3.4), which now reads

$$Qk' = q + e + \underbrace{b^{S'}p^S + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)p^L}_{\text{bond market revenue}} + \underbrace{T(q, b, z', S)}_{\text{cash transfer}} . \tag{4.4}$$

We construct the cash transfer $T(q, b, z', S)$ as 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. Because the cash-flow effects of interest rate changes are larger for firms that roll over more debt, the transfer is larger for firms with higher maturing bond shares (see Figure H.4 in the Online Appendix). In a model without financial frictions, this transfer would not have any effect on firms' capital choices.

The results are summarized in Figure 10. We first compare the differential investment response from our benchmark model (red dotted line) to the model with compensating cash transfers (solid orange line). The cash transfer reduces the peak differential capital response associated with $\mathcal{M}$ by 28% (five basis points). The 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 results of the experiment show that cash-flow effects of roll-over risk contribute significantly to the stronger response of high-$\mathcal{M}$ firms documented in Figure 8.

Our second experiment eliminates debt deflation by introducing real (i.e., inflation-indexed) debt. This avoids the increase in debt overhang after a contractionary monetary policy shock due to lower inflation. Formally, in this model experiment we replace all nominal debt variables (e.g., b^S/π and b^L/π) with real ones that 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. The peak differential capital response associated with $\mathcal{M}$ is reduced by about 69% (12 basis points). This implies that debt deflation has a stronger impact on firms with high maturing debt shares. These firms are characterized by higher default risk (Imp. 1) and therefore face a stronger debt overhang response to changes in inflation (Imp. 4). Although their shorter maturity structure mitigates exposure to debt deflation (Imp. 3), this effect is dominated by the increased exposure due to higher default risk.[31]

Finally, the blue dash-dotted line in Figure 10 shows the results of combining both model experiments. Once the cash flow effects of roll-over risk 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 roll-over risk and debt deflation. 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 further assess how debt maturity shapes the transmission of monetary policy, we conduct a model experiment in which $\mathcal{M}$ is varied exogenously. Because debt maturity is endogenous in the model, it is systematically related to other firm characteristics, including default risk, firm size, and firm age. Exogenously varying $\mathcal{M}$ therefore allows us to isolate how debt maturity affects firms' responses to monetary policy shocks.

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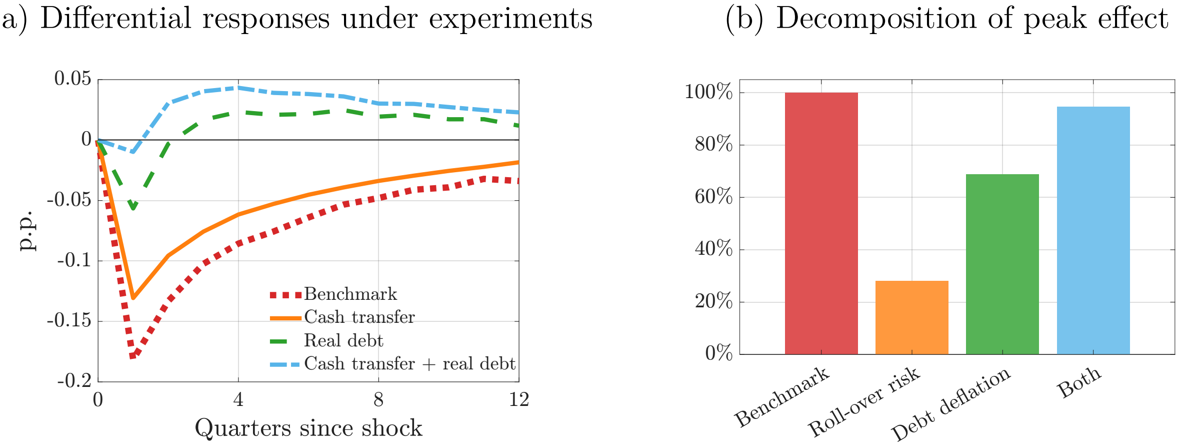
[31] Debt deflation also has cash-flow effects. By increasing the real value of debt payments in (3.3), lower inflation erodes firms' cash-on-hand, in particular for high-$\mathcal{M}$ firms. Quantitatively, however, this cash-flow channel of debt deflation only has minor effects on the differential investment response associated with $\mathcal{M}$ (see Figure H.5 in Online Appendix H.3). Debt deflation operates in the model primarily through debt overhang rather than through cash-flow effects.

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



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 the cash-flow effects of *roll-over risk*. The green dashed line shows the corresponding differential response in the *real debt* model experiment, which we use to offset *debt deflation*. 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*, *debt deflation*, or the combination of both. The shares are defined as relative reductions in the impulse responses under the model experiments compared to the benchmark.

We take a representative sample of firms of zero mass from our benchmark economy and subject them to a one-time exogenous increase in $\mathcal{M}$ by converting all of their long-term debt b^L to short-term debt b^S.[32] 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 examine the effects of unconventional monetary policy (UMP) operating through the term structure of interest rates (e.g., quantitative easing). Because in the model firms borrow at different maturities, it provides a natural setting to study this policy. We ask whether UMP can substitute for conventional monetary policy, or whether endogenous debt maturity generates important differences in the transmission mechanisms. We find that, in contrast to conventional monetary policy, UMP strongly affects firms' maturity choice. A decline in long-term rates induces firms to shift toward long-term debt. This maturity

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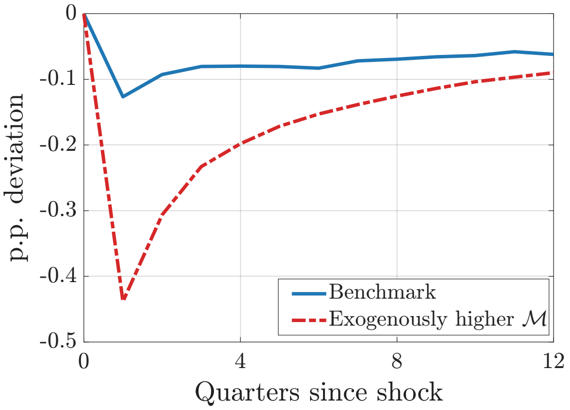
[32] Because the sample of selected firms has zero mass, this experiment has no general equilibrium effects (i.e., aggregate price adjustments which might dampen the responsiveness of the selected firms). Figure H.7 in Online Appendix H.3 shows that in our model experiment the average share of debt due in one year initially increases from about 30% to 100% for the selected firm sample. After this exogenous increase, it endogenously converges back to steady state.

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.

adjustment initially lowers roll-over risk, but over time raises debt overhang and increases default risk. As a result, endogenous debt maturity can dampen the stimulative effects of expansionary UMP at longer horizons. We show that the strength of this dampening mechanism depends on firm leverage.

Model extension. We model UMP by introducing a new shock that drives a wedge between the valuation of short- and long-duration assets. Instead of one single stochastic discount factor (SDF) that prices all assets in the economy, we now distinguish between $\Lambda^S_{t,t+1}$, which prices short-term bonds in (3.12), and $\Lambda^L_{t,t+1}$, which prices dividends in (3.10) and long-term bonds in (3.13), and which is tied to the intertemporal rate of substitution (3.20). An unconventional monetary policy shock $\varepsilon^{\text{ump}}_t$ drives a temporary wedge between these two SDFs:

$$\Lambda^L_{t,t+1} = (1 + \eta^{\text{ump}}_t)\Lambda^S_{t,t+1}\,, \tag{4.5}$$

where η^{ump}_t follows an AR(1)-process $\eta^{\text{ump}}_t = \rho^{\text{ump}} \cdot \eta^{\text{ump}}_{t-1} + \varepsilon^{\text{ump}}_t$ with $\rho^{\text{ump}} \in (0, 1)$ and $\varepsilon^{\text{ump}}_t \sim N(0, \sigma^2_{\text{ump}})$. When $\eta^{\text{ump}}_t = 0$, arbitrage between short-term and long-term asset markets works without frictions. When $\eta^{\text{ump}}_t \neq 0$, markets are temporarily segmented. A positive UMP shock realization $\varepsilon^{\text{ump}}_t$ increases the valuation of long-term assets relative to short-term assets. In this way, the model captures the effects of UMP on the term structure of interest rates.[33]

Effects of an expansionary unconventional monetary policy shock. Figure 12 shows the effects of an expansionary UMP shock, i.e., a positive realization of $\varepsilon^{\text{ump}}_t$. The

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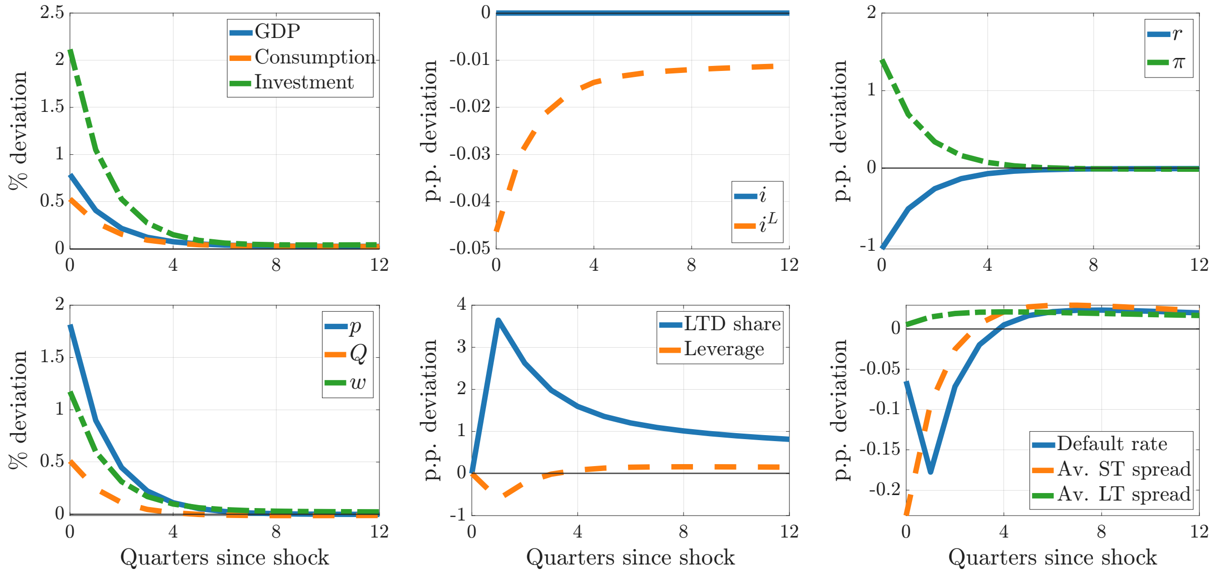
[33] Preferred habitat models (Vayanos and Vila, 2021; Kekre, Lenel, and Mainardi, 2024) are a micro-founded approach to modeling segmented asset markets. Risk-averse arbitrageurs can buy and sell both short- and long-term assets but require a time-varying term premium to engage in carry trades across the two markets.

Figure 12: Aggregate response to an expansionary unconventional 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.

shock raises the valuation of long-term assets and thereby lowers the long-term nominal interest rate i_t^L. To mimic the environment of the zero lower bound period, we hold the short-term riskless interest rate i_t fixed at its steady-state level. The UMP shock therefore generates a persistent decline in the term spread $i_t^L - i_t$. The size of the shock is chosen such that the impact response of GDP matches the absolute value of the GDP response to the conventional monetary policy shock studied above.[34]

Figure 12 shows that firms' financing choices react very differently to UMP compared to conventional monetary policy. Although the UMP shock matches the initial output response under conventional monetary policy, it induces a much stronger response of firms' share of long-term debt. On impact, it increases by more than 3.6 percentage points (compared to a 0.2 p.p. decrease after an expansionary conventional monetary policy shock).[35] The persistent decline in the term spread $i^L - i$ lowers firms' cost of long-term borrowing. In response, firms substitute away from short-term debt and increase their share of long-term debt. This maturity shift has two opposing effects. In the short run, the larger share of

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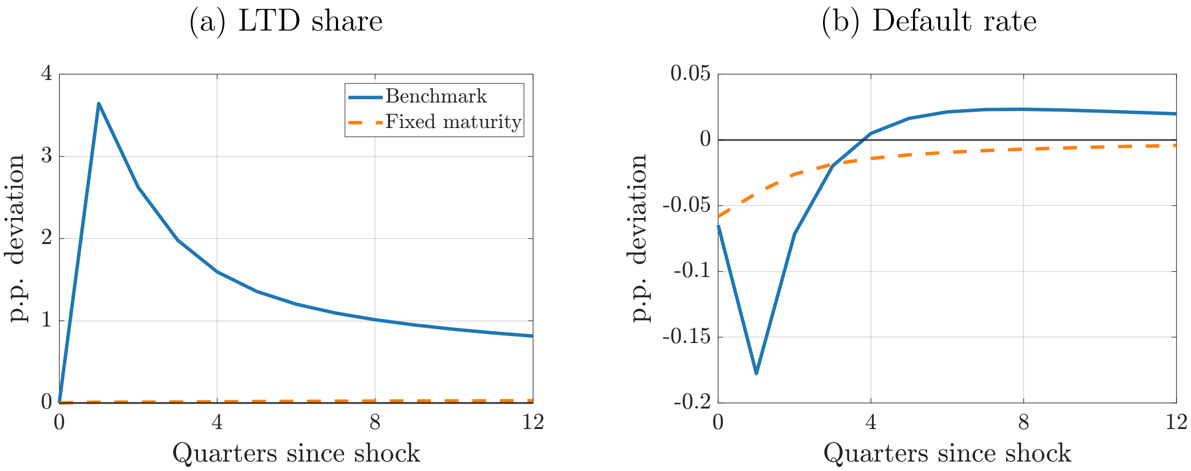
[34] Because the model solution is linear with respect to aggregate shocks, the effects of an expansionary conventional monetary policy shock are given by the sign-reversed responses to the contractionary conventional shock in Figure 7. The persistence ρ^{ump} of the UMP shock is set equal to the persistence ρ^{mp} of the conventional monetary policy shock. See Appendix D.5 for details of the modified model setup with UMP shocks.

[35] In line with this model prediction, Figure B.16 provides empirical evidence that expansionary UMP shocks significantly increase corporate debt maturity. In contrast, the empirical response of debt maturity to conventional monetary policy shocks is statistically insignificant.

Figure 13: Unconventional monetary policy: The role of endogenous debt maturity


(a) LTD share

(b) Default rate

Note: Solid orange lines show the results from the experiment with fixed debt maturity. Dotted blue lines show the baseline results from Figure 12 for comparison. The long-term debt share (*LTD share*) is a cross-sectional average. The default rate is annual.

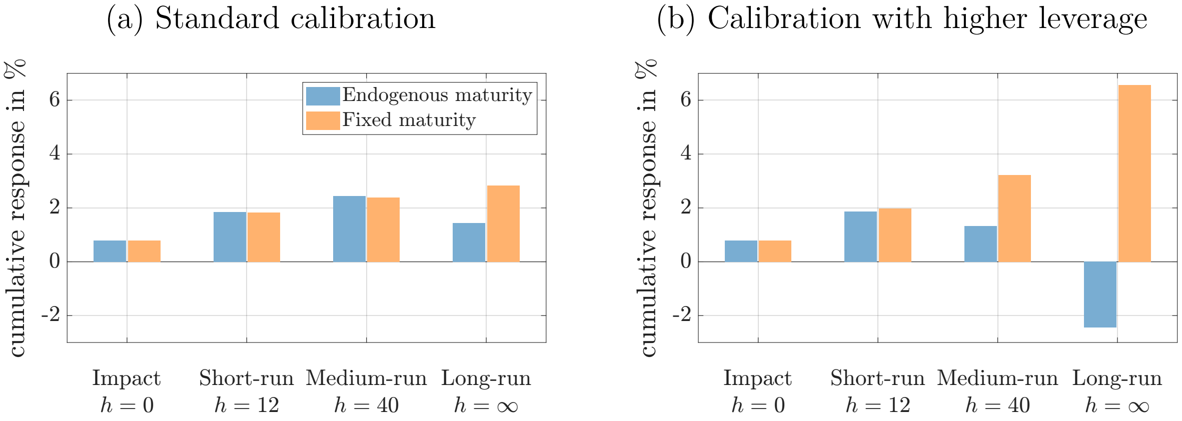
long-term debt lowers roll-over needs and insures firms against fluctuations in bond prices. As a result, the default rate drops by about 18 basis points on impact (compared to about 6 basis points after a conventional monetary policy shock). Over time, however, the gradual accumulation of long-term debt increases debt overhang and eventually pushes the default rate above its steady state level, despite the expansionary nature of the UMP shock.

The role of endogenous debt maturity. To understand the role of firms' maturity adjustment in generating the overshooting of the default rate, we repeat the UMP experiment in an alternative economy in which firms cannot adjust the maturity of their debt in response to aggregate shocks. In this alternative economy, firms' maturity choice responds only to idiosyncratic shocks. In response to the UMP shock, firms can adjust capital and total debt, but not the mix between short-term debt $b^{S'}$ and long-term debt $b^{L'}$.

Figure 13 compares the benchmark UMP experiment to the corresponding responses in the fixed-maturity economy. By construction, the long-term debt share does not respond in the fixed-maturity economy. Once this margin is shut down, the default-rate response is close to that under conventional monetary policy, both qualitatively and quantitatively. This shows that the sharp initial decline of the default rate and its subsequent persistent overshooting above its steady-state level are both driven by firms' endogenous maturity response.

Figure 14 (a) shows how endogenous debt maturity shapes the output effects of UMP. In the fixed-maturity economy, the cumulative GDP response to the UMP shock increases monotonically over time. In the benchmark economy with endogenous maturity the cumulative output response is very similar in the short to medium run, but the two economies diverge at longer horizons. The reason is that firms' endogenous maturity response dampens the later output gains from UMP, adding up to sizable differences in the cumulative response. As a result, endogenous debt maturity roughly halves the long-run cumulative output effect.

Figure 14: The role of endogenous debt maturity for GDP


(a) Standard calibration

(b) Calibration with higher leverage

Note: The figure shows cumulative GDP responses following a UMP shock $\varepsilon_t^{\text{ump}}$ of identical size. Blue bars correspond to the benchmark economy with endogenous debt maturity. Orange bars correspond to the alternative fixed-maturity model. Panel (b) is computed using the counterfactual calibration with higher average firm leverage.

This shows that endogenous debt maturity can materially dampen the output stimulus of UMP at longer horizons, even though the dampening effect is small in the short to medium run in the calibrated model.[36]

Counterfactual calibration of a high-leverage economy. Because the importance of debt maturity depends on the total amount of debt in the economy, one could expect that endogenous debt maturity has larger effects if the overall amount of debt is higher. To study this relationship, we consider a counterfactual calibration in which average firm leverage is twice as high as in the standard calibration.[37]

Figure 14 (b) repeats the comparison in panel (a) under the high-leverage calibration: it contrasts the cumulative output response to UMP under endogenous debt maturity with the response in the alternative economy in which firms cannot adjust their debt maturity in response to aggregate shocks. The size of the UMP shock is chosen to generate the same impact response of GDP as in Figure 12. While the initial responses are similar, the cumulative output effect becomes noticeably smaller under endogenous debt maturity already twelve quarters after the shock. Because leverage is higher in this calibration, the increase in long-term debt has stronger effects on debt overhang and investment. With endogenous debt maturity, aggregate investment falls below steady state already six quarters after the shock (*cf.* Figure D.5); aggregate output falls below steady state 20 quarters after the shock (*cf.* Figure D.6 (b)). As a result, after 40 quarters the cumulative output effect is only about one third of that in the fixed-maturity economy. In the long run, it even turns negative.

Overall, these results show that firms' endogenous debt maturity response can weaken

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[36] The cumulative inflation response is comparatively insensitive to endogenous debt maturity (see Online Appendix H.5).

[37] In the counterfactual calibration, average firm leverage is 62% (compared to 31% in the standard calibration presented in Table 3 in Section 4.2). See Appendix D.6 for details of the counterfactual calibration.

the output stimulus from UMP at longer horizons. This channel is especially important when firm leverage is high, since the induced shift toward long-term debt generates stronger debt-overhang effects. Accounting for endogenous debt maturity is therefore important for predicting the aggregate effects of unconventional monetary policy.

5 Conclusion

More than twenty-five years after the first seminal contributions introduced frictional firm financing into quantitative dynamic macroeconomic models (e.g., Bernanke et al., 1999), the contemporaneous literature offers new insights by focusing on debt heterogeneity.[38] As part of this research agenda, our paper documents the vast amount of heterogeneity in U.S. public firms' maturity choices. The maturity dimension of debt heterogeneity is absent from standard one-period-debt macro models.

We show that heterogeneous debt maturity matters for monetary policy. We use micro data to show that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. We then develop 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 find that endogenous debt maturity generates important differences between the transmission of conventional and unconventional monetary policy.

These results raise new questions for the conduct of systematic monetary policy. How should central banks 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, especially when firm leverage is high. The model developed in this paper provides a quantitative framework for studying this question.

The model could also be used to further investigate the state-dependent effectiveness of monetary policy. We have shown that the aggregate effects of unconventional monetary policy depend on the amount of firm debt in the economy. The results suggest that the maturity structure of this debt is another aggregate state variable shaping monetary-policy transmission. This question is empirically relevant because Compustat data shows an upward trend in corporate debt maturity over the last twenty-five years. The framework presented in this paper allows studying the implications of this trend for the ability of central banks to stabilize the economy through monetary policy.

Several open questions remain. The empirical analysis deliberately focuses on maturing bonds, as this allows for a tight mapping from the data to the quantitative-theoretical model. It is an important question to what extent the empirical results presented in this paper carry over to loan maturity. Loans differ from bonds in several important ways (e.g., due to adjustable rates, collateral, and frequent renegotiations). A quantitative model of loan maturity might need to take these institutional features into account.

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[38] 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, Krainer, and Paul, 2025).

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Corporate Debt Maturity Matters For Monetary Policy

Appendix

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June 29, 2026

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 with a maturity date at or before their issuance date (144; 688bn US$; 688bn US$). These bond types are not mutually exclusive and partially overlap. Dropping these types of bonds leaves us with a sample of 245,646 bonds with a value at issue date of 59.7tn US$ and a value at maturity date of 47.8tn US$. Of these bonds, we focus on fixed-coupon, non-callable bonds (74,166; 36.2tn; 35.8tn), which account for the majority of the value of bonds at maturity date. Our extended analysis includes bonds that are callable (144,449; 16.3tn; 5.0tn) or have a variable coupon (53,353; 9.3tn; 7.7tn).

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 occurs before maturity. Among the total sample of bonds, an action is recorded for about half of the bonds, while for only 3% 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 firms' `cusip` identifiers frequently change over time, we need to identify the historic `cusip` identifiers that are 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 `cusip` identifiers, 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 `cusip` and historical `cusip` 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 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 using the Thomson–Reuters SDC database. It records events at which firms — 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 issuer 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 debtor 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. Three iterations yield convergence. By accounting for M&A activities, we additionally map bonds issued by subsidiary firms before acquisition to the parent 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).[39] We exclude firm-

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[39] We do not use data on capital expenditures (`capxy`) because it does not precisely track the evolution of a firm's capital stock over time. Compustat (`capxy`) is informative with respect to gross investment, but it does not include information about capital retirements and capital sales (Clementi and Palazzo, 2019).

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. We define these as 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 using (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.

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%.[40] 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.

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

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[40] 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.

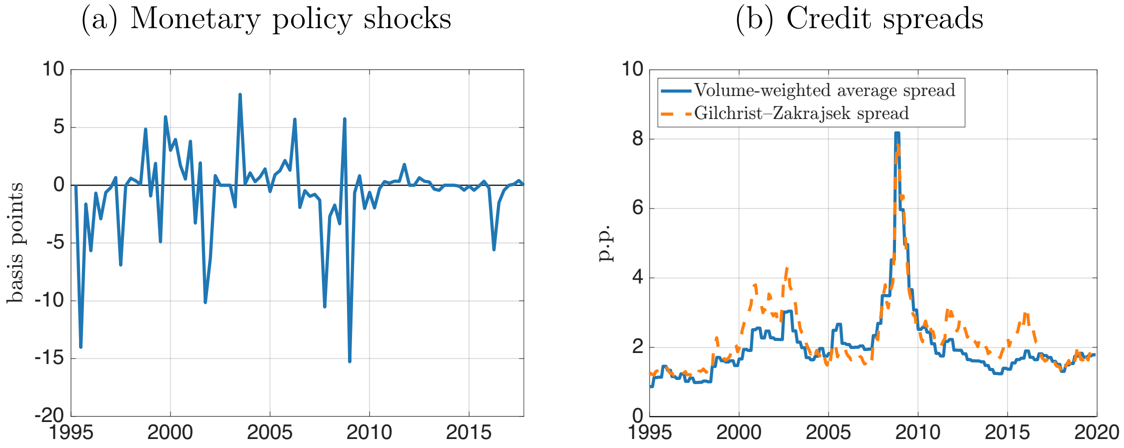
transitory fluctuations by using the backward-looking four-quarter moving average of debt, sales, and cost of goods sold. We then estimate local projections on the log differences of these smoothed variables. This yields similar results as Smooth Local Projections proposed by Barnichon and Brownlees (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, `cogsq`, which contains employment expenses and may thus be informative about quarterly variation in 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	3.95	35,545	1.47	8.73	415,409
Leverage *(debt/assets in %)*	34.02	18.52	35,545	31.96	58.67	395,536
Liquidity *(cash/assets in %)*	7.62	8.46	35,544	22.32	25.83	411,703
Total assets *(in bln. 2005 USD)*	13.50	26.35	35,545	0.90	3.72	411,899
Sales growth *(in %)*	0.75	17.79	35,489	1.82	40.25	370,079
Age *(in years)*	42.06	31.52	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

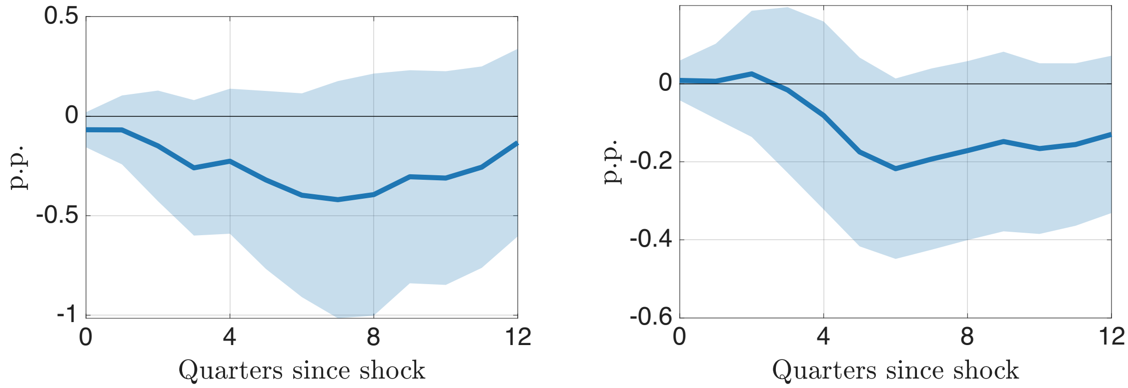

(a) Monetary policy shocks

(b) Credit spreads

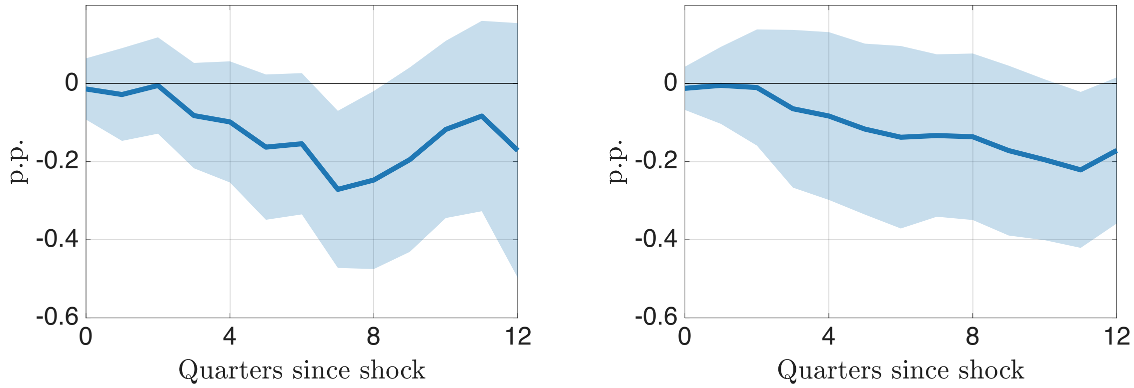
Note: Panel (a) shows the baseline monetary policy shock series at quarterly frequency as described in Section 2.1. In panel (b), the solid line shows the volume-weighted cross-sectional average credit spread based on Refinitiv data as described above. The dashed line shows the Gilchrist and Zakrajšek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


(a) Debt

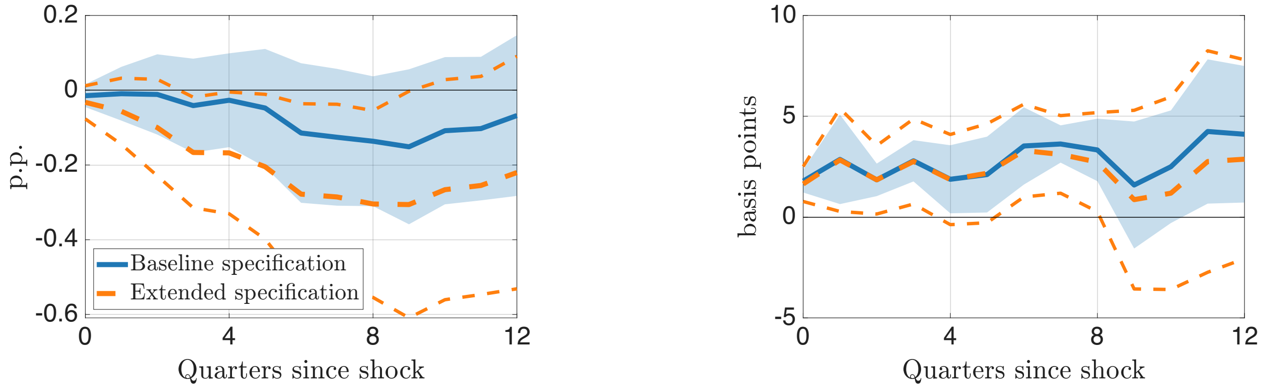
(b) Sales


(c) Employment

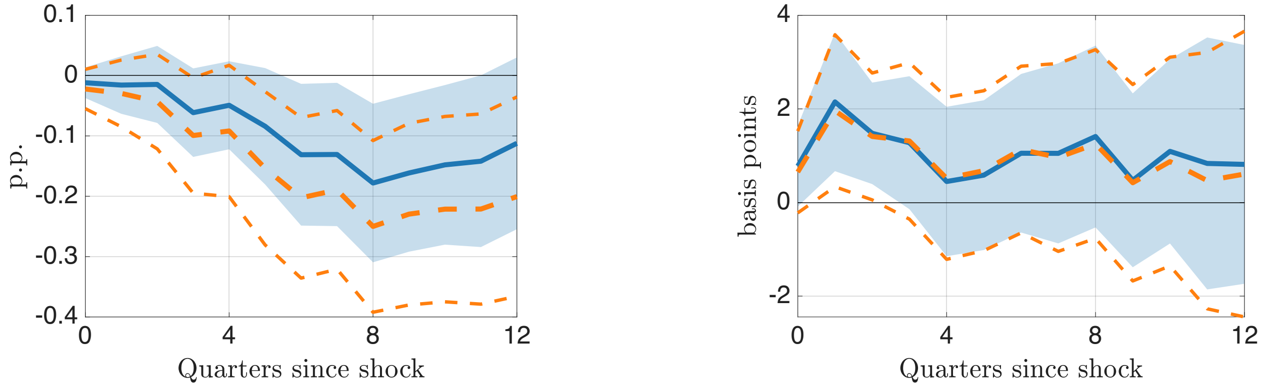
(d) Cost of goods sold

Note: The figure shows the estimated β_1^h coefficients based on equation (2.3), but where the left-hand side is $\Delta^{h+1}\log\left(\text{debt}\right)_{it+h}$ in panel (a), $\Delta^{h+1}\log\left(\text{sales}\right)_{it+h}$ in panel (b), $\Delta^{h+1}\log\left(\text{employment}\right)_{it+h}$ in panel (c), and $\Delta^{h+1}\log\left(\text{cost of goods sold}\right)_{it+h}$ 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



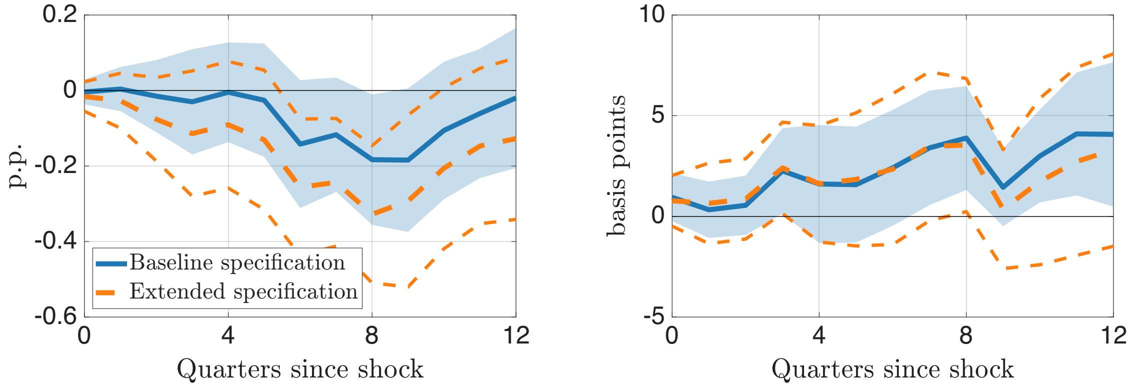
(a) Investment: Miranda-Agrippino and Ricco (2021) (b) Spread: Miranda-Agrippino and Ricco (2021)



(c) Investment: Bauer and Swanson (2023) (d) Spread: Bauer and Swanson (2023)

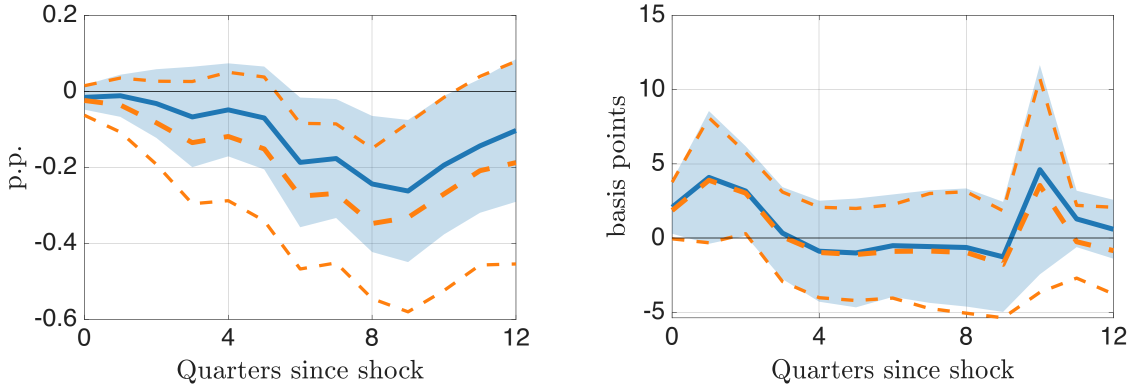
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) using various alternative monetary policy shocks $\varepsilon_t^{\mathrm{mp}}$. In panels (a) and (b), we use the shocks of Miranda-Agrippino and Ricco (2021). In panels (c) and (d) we use the shocks 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 $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.3: Differential investment and credit spread responses associated with maturing bond share based on alternative sample periods



(a) Investment: Pre-Great Recession

(b) Spread: Pre-Great Recession



(c) Investment: Exclude Great Recession

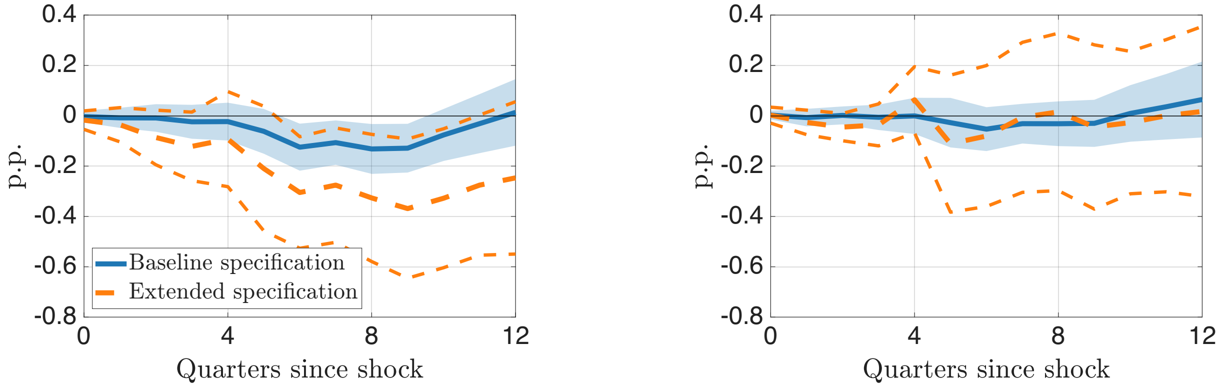
(d) Spread: No Great Recession dummies

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 (b) use only observations until 2008Q2. Panel (c) 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 with maturing bond share including callable bonds or bonds with variable coupon

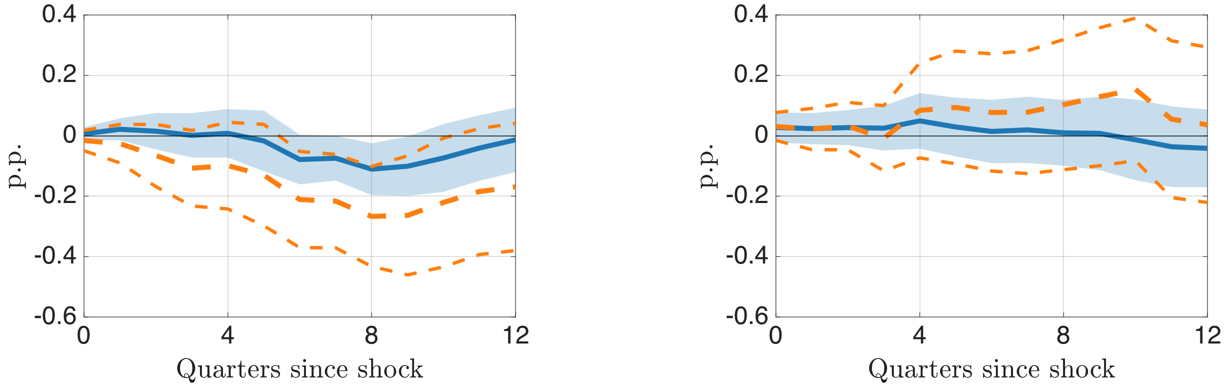
(a) $\mathcal{M}_{it}$ including callable and non-callable bonds

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



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

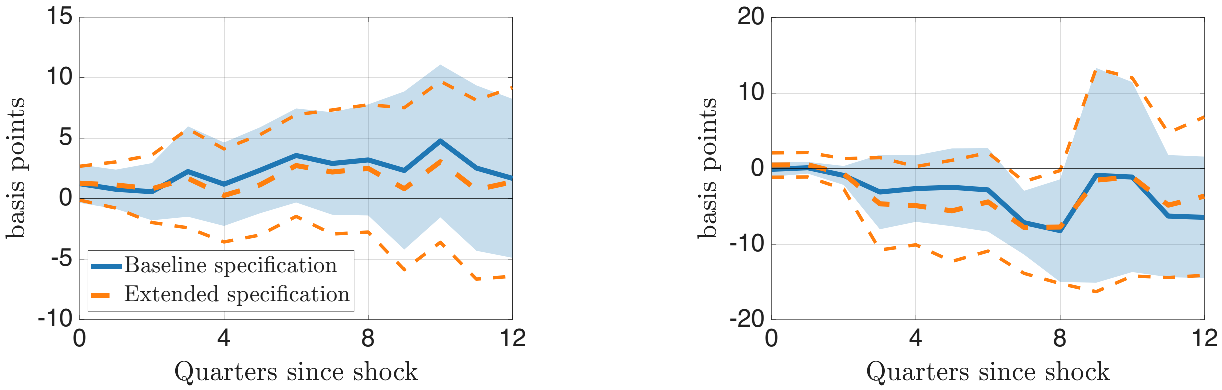
(d) $\mathcal{M}_{it}$ including only variable coupon bonds



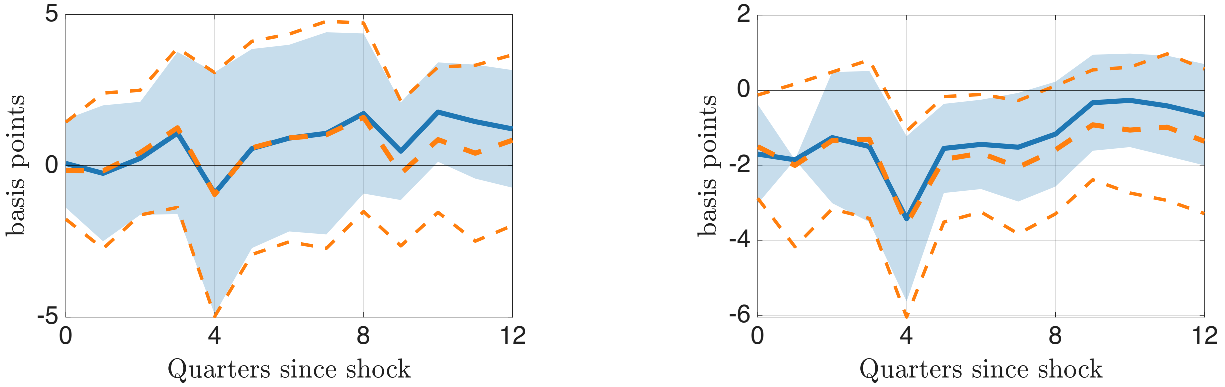
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), for various alternative definitions of the maturing bond share $\mathcal{M}_{it}$. In our main findings, $\mathcal{M}_{it}$ includes only non-callable fixed coupon 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.5: 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

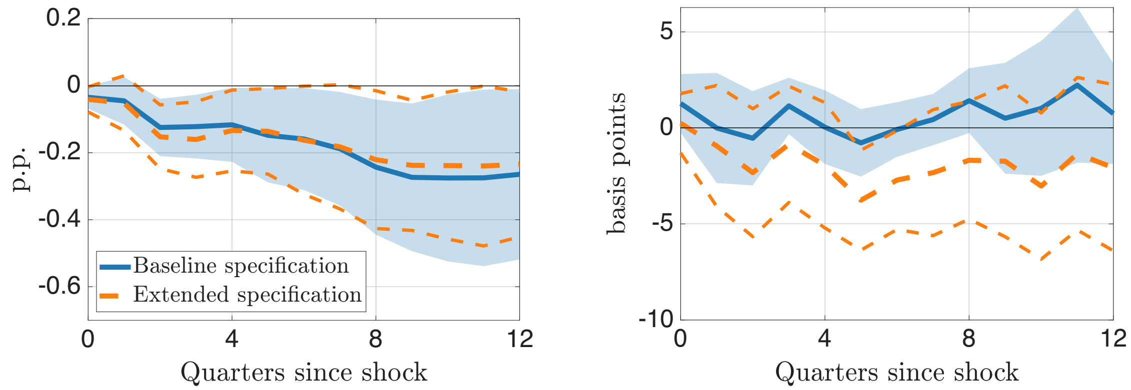


(c) $\mathcal{M}_{it}$ including variable and fixed coupon bonds (d) $\mathcal{M}_{it}$ including only variable coupon bonds



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 $\varepsilon_t^{\text{mp}}$ 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 investment and credit spread responses associated with one-year maturing bond share

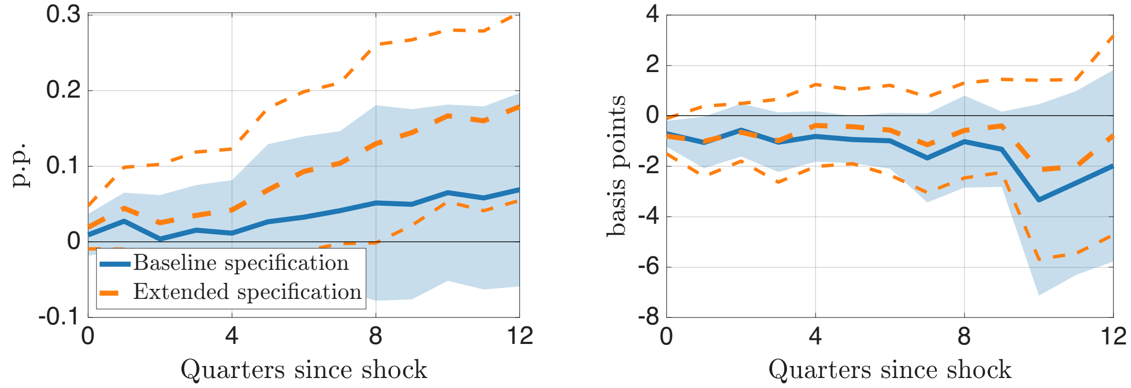


(a) Investment

(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 through $t+3$). 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 $\varepsilon_t^{\text{mp}}$ 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.7: Differential investment and credit spread responses associated with lagged maturing bond share

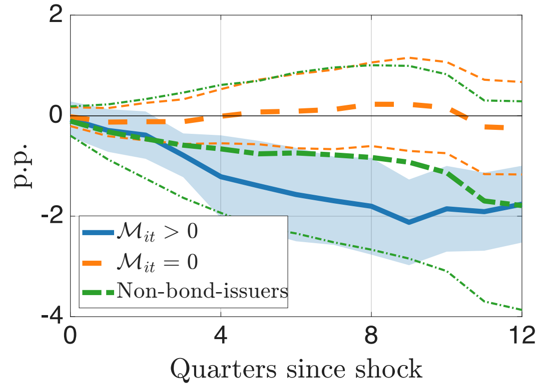


(a) Investment

(b) Credit spreads

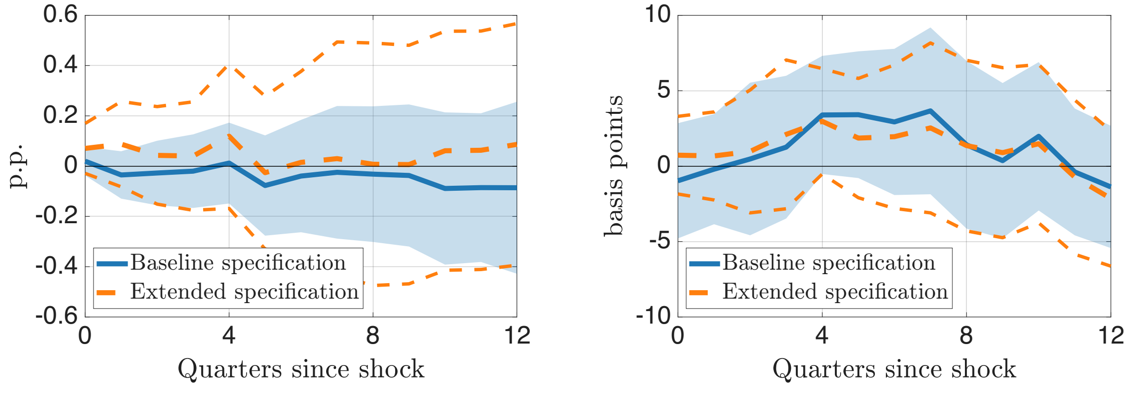
Note: This figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and the extended local projection (2.4), using $\mathcal{M}_{it-1}$ instead of $\mathcal{M}_{it}$. The local projections with credit spreads as left-hand side in panel (b) additionally control for a 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 $\varepsilon_t^{\text{mp}}$ 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.8: Differential investment response 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 $\Delta^{h+1} \log k_{it+h} = \beta^h_{\mathcal{M}>0,0} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{\mathcal{M}=0,0} \mathbb{1}\{\mathcal{M}_{it} = 0\} + \beta^h_{\mathcal{M}>0,1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\text{mp}}_t + \beta^h_{\mathcal{M}=0,1} \mathbb{1}\{\mathcal{M}_{it} = 0\} \varepsilon^{\text{mp}}_t + \beta^h_{non\text{-}issuer,1} \mathbb{1}\{Non\text{-}bond\text{-}issuer_i\} \varepsilon^{\text{mp}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$. Shaded areas (and outer dashed lines) indicate 95% confidence bands two-way clustered by firms and quarters.

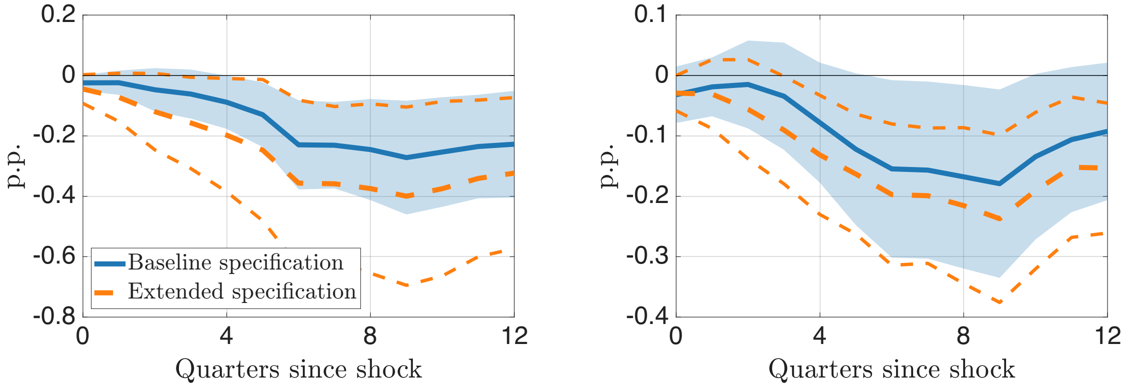
Figure B.9: Differential investment and credit spread responses associated with Compustat maturing debt share


(a) Investment

(b) Credit spreads

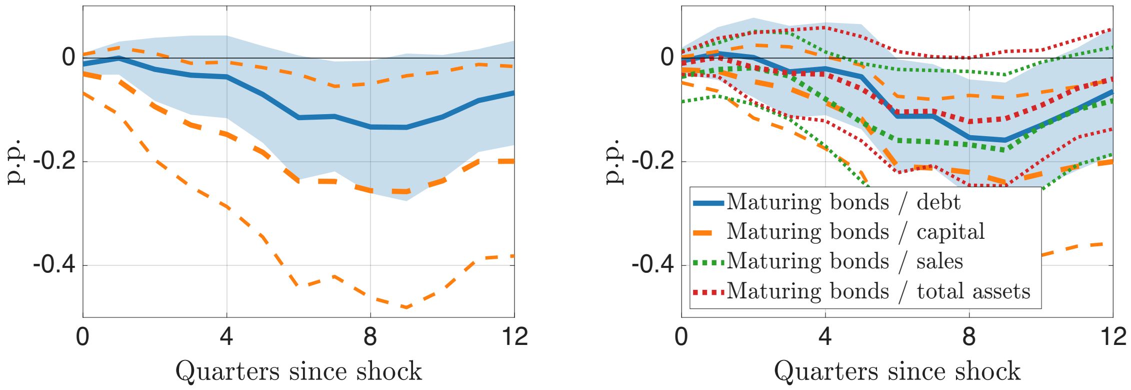
Note: This figure shows the estimated β^h_1 coefficients based on the local projections (2.3) and (2.4), using $\widetilde{\mathcal{M}}_{it}$ instead of $\mathcal{M}_{it}$. $\widetilde{\mathcal{M}}_{it} = (\text{debt in current liabilities})_{it}/(\text{total debt})_{it-1}$ measures maturing debt based 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^h_1 estimates are standardized to capture the differential response to a one standard deviation increase in $\varepsilon^{\text{mp}}_t$ associated with a one standard deviation higher maturing debt share. Shaded areas (and outer dashed lines) 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



(a) Capital denominator

(b) Sales denominator

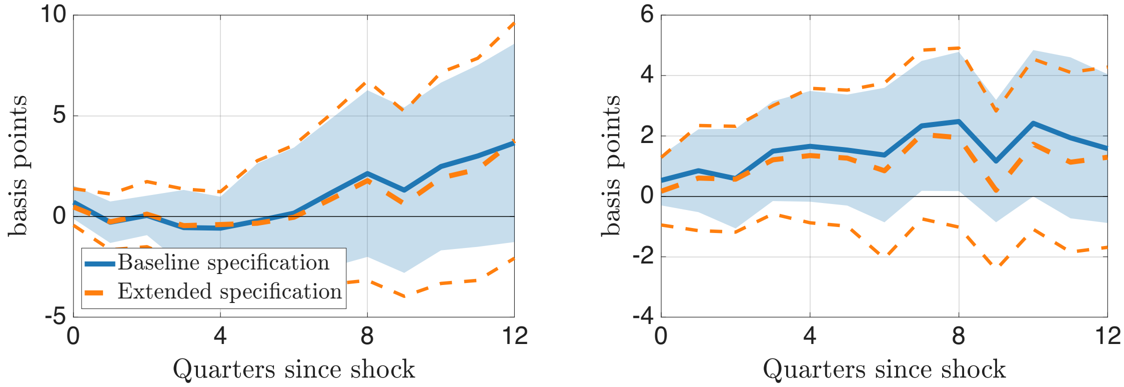


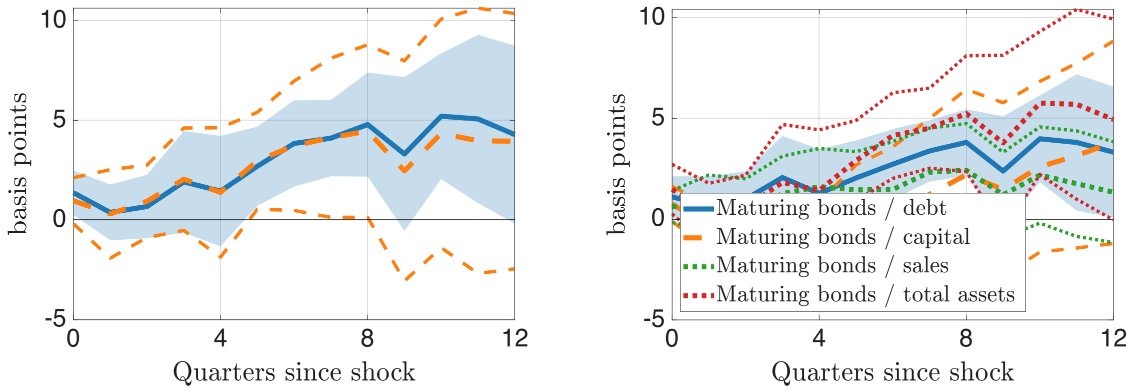
(c) Assets denominator

(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 to 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.

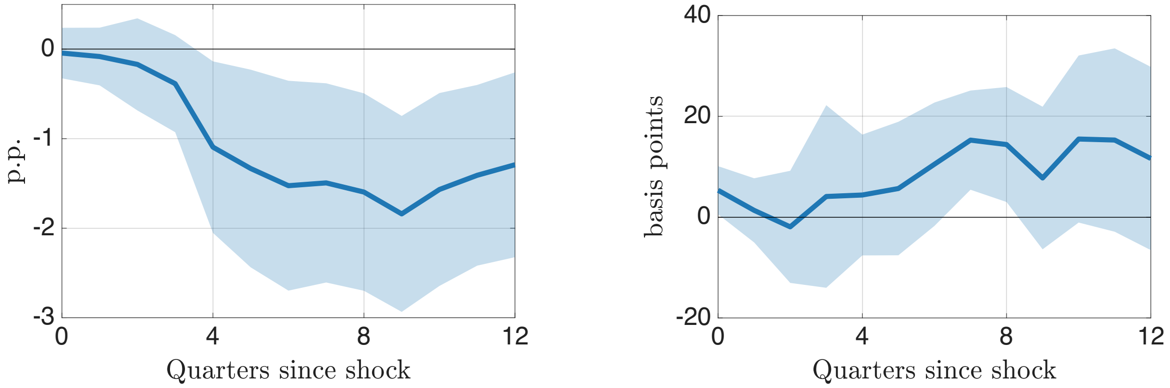
Figure B.11: Differential credit spread response associated with maturing bond share using alternative denominators


(a) Capital denominator (b) Sales denominator


(c) Assets denominator (d) Non-moving average denominator

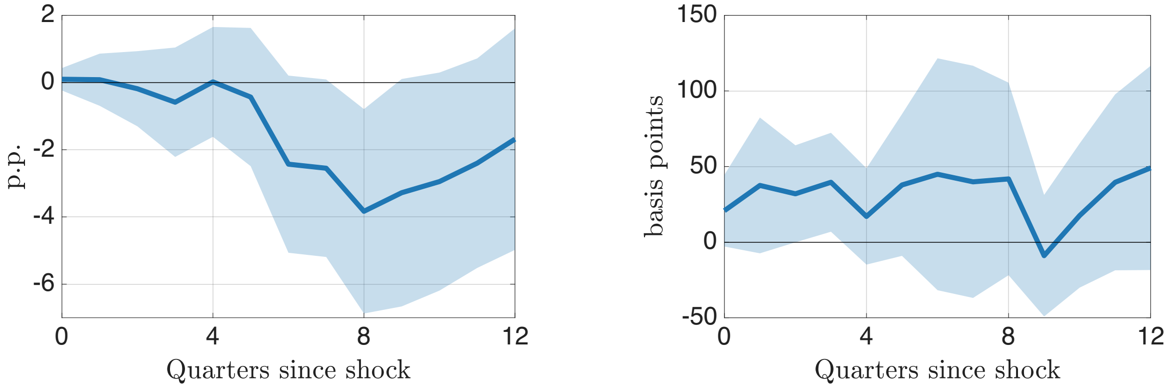
Note: In panels (a) to (c) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3) and extended local projection (2.4), for various alternative definitions of $\mathcal{M}_{it}$. In panel (a), we re-define $\mathcal{M}_{it}$ as the ratio of maturing bonds to the 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



(a) Investment: Differential effect of $\mathcal{M}_{it} > 0$

(b) Spread: Differential effect of $\mathcal{M}_{it} > 0$

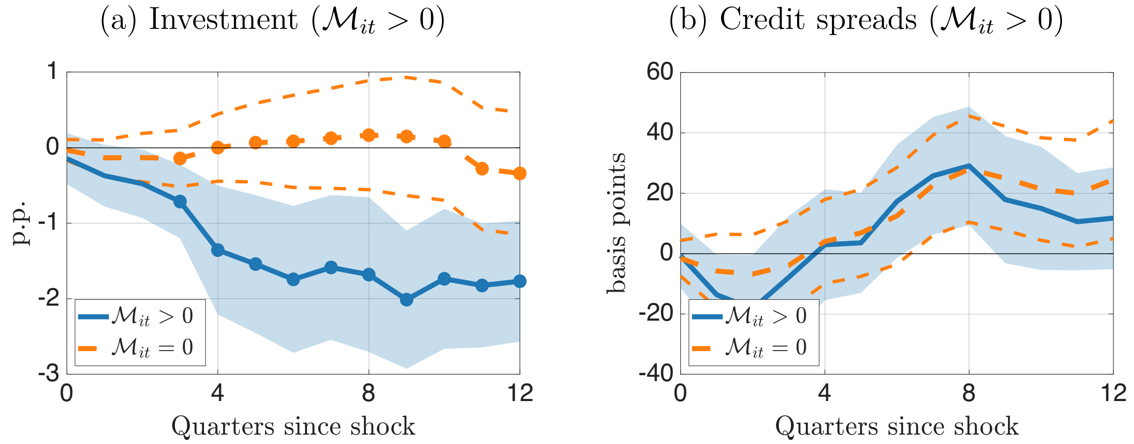


(c) Investment: Differential effect of $\mathcal{M}_{it} > 15$

(d) Spread: Differential effect of $\mathcal{M}_{it} > 15$

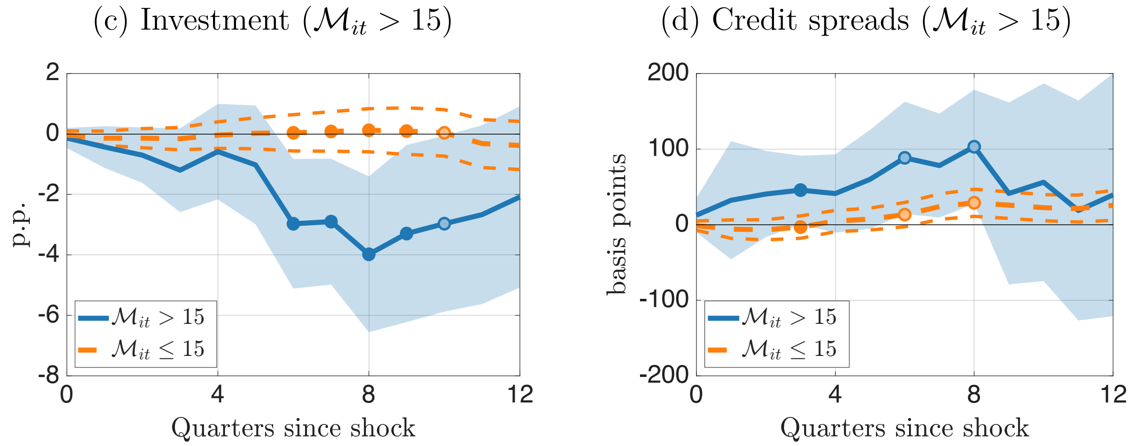
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.3), using $\mathbb{1}\{\mathcal{M}_{it} > 0\}$ instead of $\mathcal{M}_{it}$ in panels (a) and (b), and $\mathbb{1}\{\mathcal{M}_{it} > 15\}$ instead of $\mathcal{M}_{it}$ in panels (c) and (d). The β_1^h 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 panels (b) and (d) 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



(a) Investment ($\mathcal{M}_{it} > 0$)

(b) Credit spreads ($\mathcal{M}_{it} > 0$)

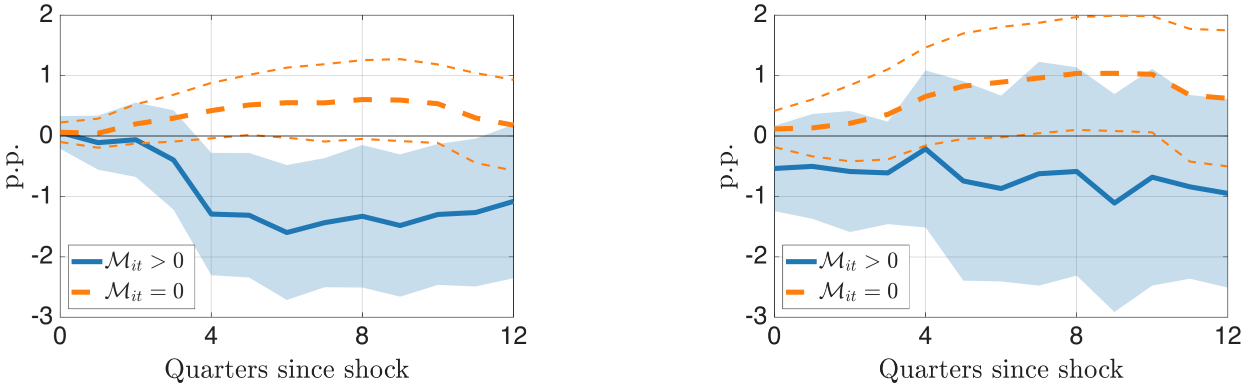


(c) Investment ($\mathcal{M}_{it} > 15$)

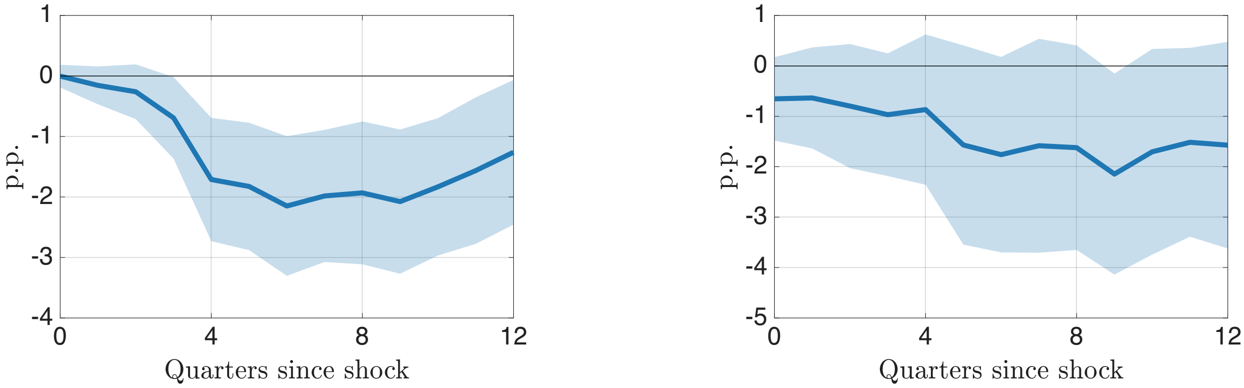
(d) Credit spreads ($\mathcal{M}_{it} > 15$)

Note: The figure shows the estimated $\beta^h_{1,high}$ and $\beta^h_{1,low}$ coefficients based on the local projection $\Delta^{h+1}y_{it+h} = \beta^h_{0,high}\mathbb{1}\{\mathcal{M}_{it} > \widetilde{\mathcal{M}}\} + \beta^h_{1,low}\mathbb{1}\{\mathcal{M}_{it} \leq \widetilde{\mathcal{M}}\} \times \varepsilon^{\text{mp}}_t + \beta^h_{1,high}\mathbb{1}\{\mathcal{M}_{it} > \widetilde{\mathcal{M}}\} \times \varepsilon^{\text{mp}}_t + \beta^h_{2,low}\mathbb{1}\{\mathcal{M}_{it} \leq \widetilde{\mathcal{M}}\} \times \Delta\text{gdp}_{t-1} + \beta^h_{2,high}\mathbb{1}\{\mathcal{M}_{it} > \widetilde{\mathcal{M}}\} \times \Delta\text{gdp}_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$, where $\mathbb{1}\{\cdot\}$ denotes a dummy variable that equals one if the inequality is satisfied and zero otherwise. 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.

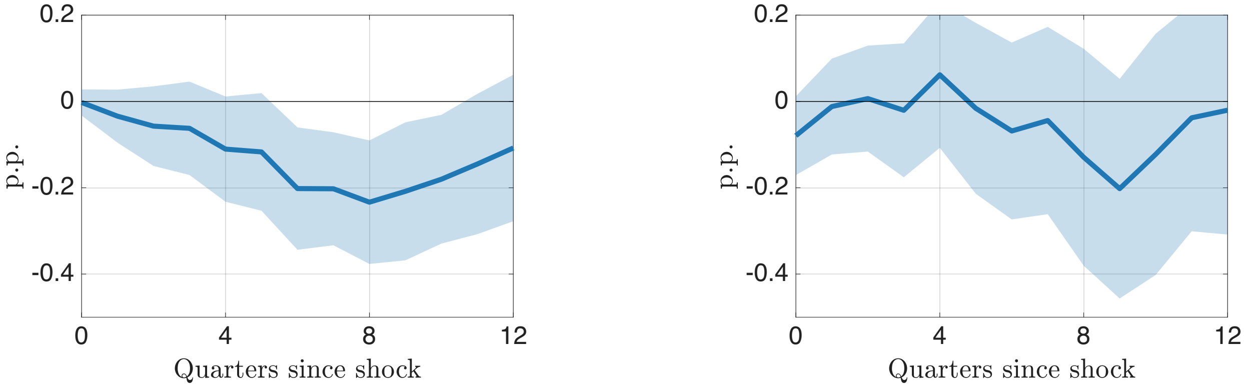
Figure B.14: Differential investment responses due to maturing bond share conditional on firm age group


(a) Old firms by level of $\mathcal{M}_{it}$

(b) Young firms by level of $\mathcal{M}_{it}$


(c) Difference $\mathcal{M}_{it} > 0$ vs. $\mathcal{M}_{it} = 0$ for old firms

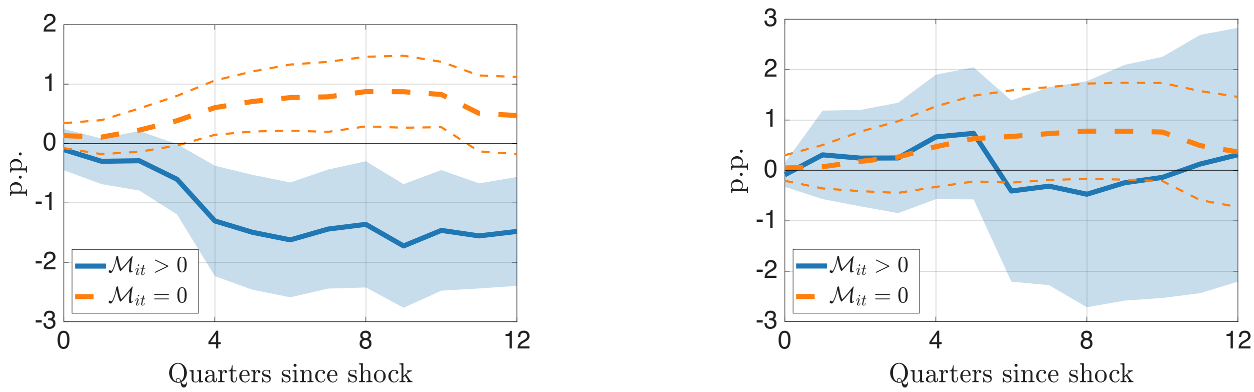
(d) Difference $\mathcal{M}_{it} > 0$ vs. $\mathcal{M}_{it} = 0$ for young firms


(e) Linear effect of $\mathcal{M}_{it}$ for old firms

(f) Linear effect of $\mathcal{M}_{it}$ for young firms

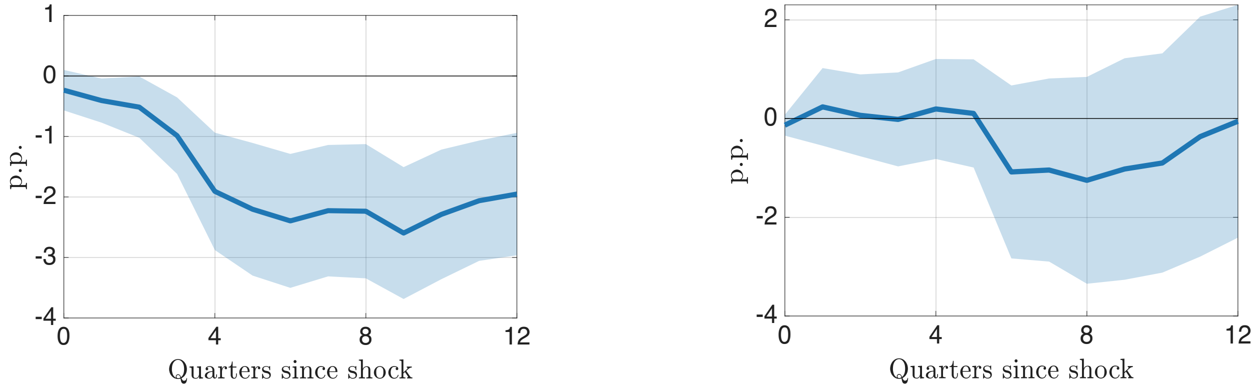
Note: Panels (a) and (b) show in the solid lines the estimated coefficients $\beta^h_{old,\mathcal{M}>0,1}$ and $\beta^h_{young,\mathcal{M}>0,1}$, and in the dashed lines the analogous coefficients for $\mathcal{M} = 0$, from the local projection $\Delta^{h+1}\log k_{it+h} = \beta^h_{young,\mathcal{M}>0,0} Young_{it-1}\mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{old,\mathcal{M}>0,0} Old_{it-1}\mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{young,\mathcal{M}>0,1} Young_{it-1}\mathbb{1}\{\mathcal{M}_{it} > 0\}\varepsilon^{\text{mp}}_t + \beta^h_{old,\mathcal{M}>0,1} Old_{it-1}\mathbb{1}\{\mathcal{M}_{it} > 0\}\varepsilon^{\text{mp}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$ 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



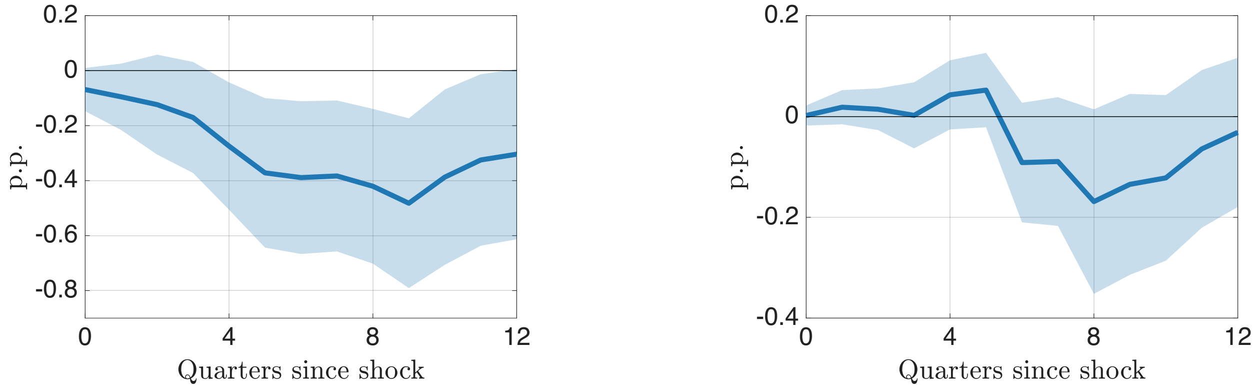
(a) Large firms by level of $\mathcal{M}_{it}$

(b) Small firms by level of $\mathcal{M}_{it}$



(c) Difference $\mathcal{M}_{it} > 0$ vs. $\mathcal{M}_{it} = 0$ for large firms

(d) Difference $\mathcal{M}_{it} > 0$ vs. $\mathcal{M}_{it} = 0$ for small firms



(e) Linear effect of $\mathcal{M}_{it}$ for large firms

(f) Linear effect of $\mathcal{M}_{it}$ for small firms

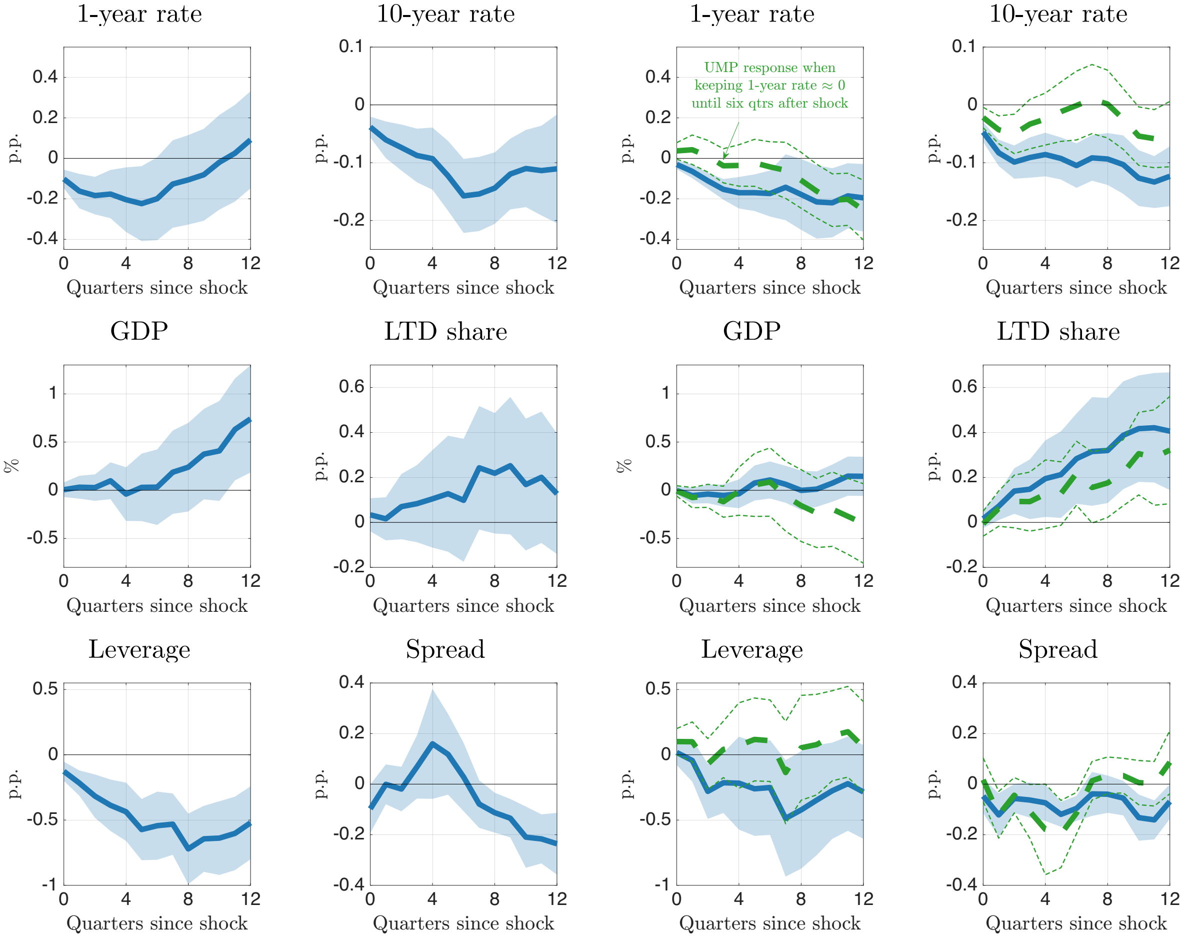
Note: Panels (a) and (b) show in the solid lines the estimated coefficients $\beta^h_{large,\mathcal{M}>0,1}$ and $\beta^h_{small,\mathcal{M}>0,1}$, and in the dashed lines the analogous coefficients for $\mathcal{M} = 0$, from the local projection $\Delta^{h+1} \log k_{it+h} = \beta^h_{small,\mathcal{M}>0,0} Small_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{large,\mathcal{M}>0,0} Large_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} + \beta^h_{small,\mathcal{M}>0,1} Small_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\text{mp}}_t + \beta^h_{large,\mathcal{M}>0,1} Large_{it-1} \mathbb{1}\{\mathcal{M}_{it} > 0\} \varepsilon^{\text{mp}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$ where $Small_{it}$ 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 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 $\Delta^{h+1} \log k_{it+h} = \beta^h_{small,0} Small_{it-1} + \beta^h_{large,0} Large_{it-1} + \beta^h_{\mathcal{M},0} \mathcal{M}_{it} + \beta^h_{small,1} Small_{it-1} \mathcal{M}_{it} \varepsilon^{\text{MP}}_t + \beta^h_{large,1} Large_{it-1} \mathcal{M}_{it} \varepsilon^{\text{MP}}_t + \Gamma Z_{it} + \gamma^h_1 \Delta gdp_{t-1} + \delta^h_i + \delta^h_{sq} + \nu^h_{it+h}$. The vector Z_{it} contains all interactions of size dummies and maturity with lagged GDP growth Δgdp_{t-1}. 95% confidence bands based on standard errors clustered by firms and quarters.

Figure B.16 provides empirical evidence on the effects of unconventional monetary policy (UMP) shocks. We construct UMP shocks by applying the factor decomposition and rotation in Gürkaynak, Sack, and Swanson (2005). They consider high-frequency interest rate future surprises across a range of maturities and apply a principal component analysis to extract the two factors that explain most variation across maturities. They rotate the two factors into a target factor and a path factor by imposing a zero restriction such that the path factor has no effect on the shortest-maturity interest rate surprise. The path factor thereby captures surprises about the expected future path of policy beyond the contemporaneous meeting, making it a natural proxy for UMP shocks.

Figure B.16: Empirical aggregate effects of expansionary monetary policy shocks

(a) Conventional MP

(b) Unconventional MP



Note: This figure shows impulse responses to expansionary conventional and unconventional monetary policy shocks using a time series local projection given by $y_{t+h} = a^h + b^h \varepsilon_t^{\mathrm{MP}} + c^h y_{t-1} + u_t^h$, where y_t is the variable of interest. GDP is real GDP growth, leverage and long-term debt share (LTD; the share of debt maturing in more than one year) are averages across firms in Compustat, spread is the average spread as in Figure A.1, the ten-year rate is a 4-quarter backward-looking moving average to smooth excess volatility. Impulse responses of spreads include a Great Recession dummy as in Figure 3. Panel (a) shows responses b^h to a one standard deviation conventional monetary policy shock. In panel (b), the solid blue lines show responses to one standard deviation *unconventional* monetary policy shock. The green dashed line in panel (b) provides a counterfactual. Shaded areas (and dashed lines) show one-standard-error bands based on Newey–West.

Specifically, we construct the path factor by considering high-frequency surprises in Eurodollar futures (one, two, three, and four quarters ahead; ED1-ED4) and Treasury futures (two, five, and ten years ahead) for a sample from 1995Q2 through 2019Q4 using the data from Bauer and Swanson (2023). To be consistent with the conventional monetary policy shock, we only consider surprises around scheduled FOMC meetings and apply the Jarociński and Karadi (2020) sign restrictions on the path factor to account for private central bank information. Finally, we aggregate to quarterly frequency using the same procedure used for the conventional shock (see Section 2.1).

Figure B.16 (b) shows the estimated effects of UMP shocks. Compared to the effects of conventional monetary policy shocks (Figure B.16 (a)), the UMP shock gives rise to a larger impact response of the long-term interest rate (10-year rate) and a smaller impact response of the short-term rate (1-year rate). Different from the UMP exercise in the model, however, the short-term rate responds to the unconventional shock after the impact quarter. For comparability with the model, we construct a second scenario with fixed short-term interest rates by mixing the unconventional shock with a conventional shock (also realized at horizon 0) that is scaled such that it keeps the one-year interest rate response as close as possible to zero during the first six quarters.[41] The green dashed-dotted lines in panel (b) pertain to this second UMP scenario.

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) yields:

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

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).

---

[41] Constructing the counterfactual scenario using only horizon-zero shocks makes it robust to the Lucas critique, see McKay and Wolf (2023).

Interest rates. The risk-free nominal short-term interest rate i_t is linked to the price P^S_{rt} of a risk-free short-term bond with coupon c through

$$i_t = \frac{1+c}{P^S_{rt}} - 1, \qquad \text{where} \qquad P^S_{rt} = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \frac{1+c}{\pi_{t+1}}. \tag{C.4}$$

Similarly, the risk-free nominal long-term interest rate i^L_t is linked to the price P^L_{rt} and cash flow of a risk-free long-term bond through

$$i^L_t = \frac{\gamma + c + (1-\gamma)P^L_{rt}}{P^L_{rt}} - 1, \qquad \text{where} \qquad P^L_{rt} = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1} \frac{\gamma + c + (1-\gamma)P^L_{rt+1}}{\pi_{t+1}}. \tag{C.5}$$

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

$$\tilde{p}_{jt}\tilde{y}_{jt} - p_t y_{jt} - \frac{\lambda}{2}\left(\frac{\tilde{p}_{jt}}{\tilde{p}_{jt-1}} - 1\right)^2 Y_t. \tag{C.6}$$

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:

$$Y_t = \left[\int_0^1 \tilde{y}_{jt}^{\frac{\rho-1}{\rho}} dj\right]^{\frac{\rho}{\rho-1}}, \tag{C.7}$$

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:

$$\tilde{y}_{jt} = \left(\frac{P_t}{\tilde{p}_{jt}}\right)^{\rho} Y_t, \quad \text{with} \quad P_t = \left[\int_0^1 \tilde{p}_{jt}^{1-\rho} dj\right]^{\frac{1}{1-\rho}} \tag{C.8}$$

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

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

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

$$1 - \rho\left(\frac{P_t - p_t}{P_t}\right) - \lambda\frac{1}{P_{t-1}}\left(\frac{P_t}{P_{t-1}} - 1\right) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{P_t Y_t}\left(\frac{P_{t+1}}{P_t} - 1\right)\frac{P_{t+1}}{P_t} = 0. \tag{C.10}$$

Expressing prices in units of the final good in period t, we can normalize $P_t = 1$. Using $\pi_t = P_t/P_{t-1}$ yields the New Keynesian Phillips Curve in (3.14):

$$1 - \rho(1 - p_t) - \lambda\pi_t(\pi_t - 1) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{Y_t}\pi_{t+1}(\pi_{t+1} - 1) = 0. \tag{C.11}$$

Market clearing. Labor market clearing implies

$$L = \int_x l(x;S)\mu(x)dx. \tag{C.12}$$

The aggregate amount of final goods Y is

$$Y = \int_x y(x;S)\mu(x)dx. \tag{C.13}$$

Output net of fixed costs of operation and default costs is

$$Y^{net} \equiv Y - \int_x \Big[f + \xi \int_\varepsilon \mathcal{D}(x,\varepsilon;S)\underline{q}(x,\varepsilon;S)\varphi(\varepsilon|z)d\varepsilon\Big]\mu(x)dx. \tag{C.14}$$

Final goods market clearing implies that

$$Y^{net} = C + \mathcal{G} + \mathcal{H} + I, \tag{C.15}$$

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

$$\mathcal{G} = \int_x \int_\varepsilon \int_{z'} G\left(e(x,\varepsilon,z';S)\right)\Pi(z'|z)dz'(1-\kappa)[1-\mathcal{D}(x,\varepsilon;S)]\varphi(\varepsilon|z)d\varepsilon\mu(x)dx + \int_{x'} \tilde{G}(x';S)\mathcal{E}(x';S)dx', \tag{C.16}$$

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

$$\begin{aligned}\mathcal{H} = &\int_x \int_\varepsilon \int_{z'} H\left(b^{S'}(x,\varepsilon,z';S), b^{L'}(x,\varepsilon,z';S), b^{L}(x)/\pi\right)\Pi(z'|z)dz'(1-\kappa)[1-\mathcal{D}(x,\varepsilon;S)]\varphi(\varepsilon|z)d\varepsilon\mu(x)dx \\ &+ \int_{x'} \tilde{H}(x';S)\mathcal{E}(x';S)dx',\end{aligned} \tag{C.17}$$

where $\tilde{H}(x';S)$ is debt issuance costs of entrants starting in state x'. Aggregate investment I follows from (3.15):

$$I = K\left[\frac{\phi-1}{\phi}\delta^{-\frac{1}{\phi}}\left(\frac{K'}{K} - 1 + \delta\frac{\phi}{\phi-1}\right)\right]^{\frac{\phi}{\phi-1}} \tag{C.18}$$

Capital goods market clearing implies:

$$K = \int_x k(x)\mu(x)dx, \quad \text{and} \quad K' = \int_{x'} k'(x')\mu(x')dx' \tag{C.19}$$

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

Appendix D Quantitative Analysis

This section provides further details on the quantitative analysis in Section 4. We define important model variables (Appendix D.1) and provide 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 conventional monetary policy (Appendix D.4). Details of the modified setup with unconventional monetary policy are provided in Appendix D.5. Finally, Appendix D.6 summarizes the counterfactual calibration studied at the end of Section 4.6.

D.1 Model variables

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

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

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 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:

$$\mu \equiv \frac{1}{P_r^L}\sum_{j=1}^{\infty} j(1-\gamma)^{j-1}\frac{c+\gamma}{(1+r^*)^j} = \frac{c+\gamma}{P_r^L}\frac{1+r^*}{(\gamma+r^*)^2}, \quad \text{(D.4)}$$

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

$$P_r^L = \mathbb{E}\sum_{j=1}^{\infty}(1-\gamma)^{j-1}\frac{c+\gamma}{(1+i)^j} \quad \text{(D.5)}$$

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

$$\mu = \frac{1+r^*}{\gamma+r^*}. \quad \text{(D.6)}$$

The long-term debt share used in Figure 7, Figure 12, and Figure 13 is:

$$\text{Long-term debt share} \equiv \frac{b^L}{b^S + b^L} \quad \text{(D.7)}$$

The riskless nominal short-term and long-term interest rates i and i^L are given by (C.4) and (C.5). The real interest rate r is defined as:

$$\frac{1}{1+r} = \mathbb{E}_{S'|S}\Lambda \quad \text{(D.8)}$$

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:

$$spr^S \equiv \left(\frac{1+c}{p^S}\right)^4 - \left(\frac{1+c}{P_r^S}\right)^4, \tag{D.9}$$

where P_r^S is the price of a riskless short-term bond in (C.4).

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:

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

where P_r^L is the price of a riskless long-term bond in (C.5).[42] The average credit spread used in Figure 9 and Figure D.4 is defined as

$$\text{Average credit spread} \equiv \frac{b^{S'}}{b^{S'}+b^{L'}} spr^S + \frac{b^{L'}}{b^{S'}+b^{L'}} spr^L \tag{D.11}$$

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

$$\text{Equity issuance} \equiv \frac{1}{4} \cdot \Big(\max\{0, e_{it}\} + \max\{0, e_{it-1}\} + \max\{0, e_{it-2}\} + \max\{0, e_{it-3}\}\Big) \cdot \frac{1}{k_{it}} \tag{D.12}$$

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

$$\text{Default rate} \equiv \int_x \int_\varepsilon \mathcal{D}(x, \varepsilon; S)\varphi(\varepsilon) d\varepsilon \mu(x) dx \tag{D.13}$$

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[42] The yield of long-term debt can also be computed by solving for the rate of return r^L that makes the present value of promised cash flows equal to the current market price: $p^L = \sum_{j=1}^{\infty} \frac{(\gamma+c)(1-\gamma)^{j-1}}{(1+r^L)^j} = \frac{\gamma+c}{\gamma+r^L} \Leftrightarrow r^L = \frac{\gamma+c}{p^L} - \gamma$. This implies an annualized gross return of $(1+r^L)^4 = \left(\frac{\gamma+c}{p^L}+1-\gamma\right)^4$, just as in (D.10).

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

$$\text{Firm exit rate} \equiv \text{Default rate} + \kappa \cdot (1 - \text{Default rate}) \tag{D.14}$$

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

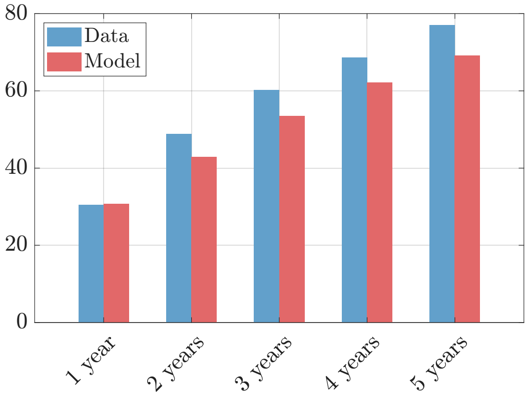
In this section, we provide details on the empirical moments used in Table 3 and Figure 6. As described in Section 2, we use quarterly firm-level balance sheet data from Compustat and FISD bond-level information. The time sample is 1995–2017. We exclude firms that are not incorporated in the U.S. and 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 and Figure 6 is constructed using firm-level credit ratings combined with rating-specific corporate bond spreads, following Arellano et al. (2019). Relative to the Refinitiv data used in Section 2, the ratings-based measure of spreads is available even for bonds without highly liquid secondary markets. 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 Cross-sectional implications

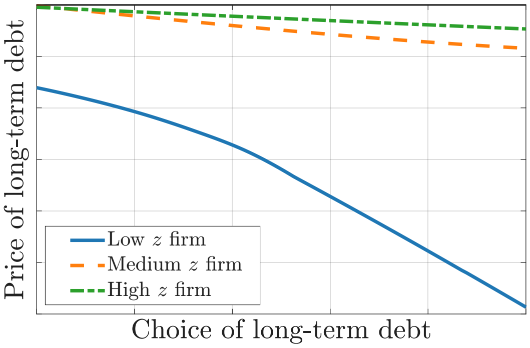
Share of maturing debt at longer time horizons. The calibrated model is successful in generating an empirically realistic maturity structure of debt at various time horizons. Figure D.1 uses Compustat data to calculate the cross-sectional average of firms' share of total maturing debt at various time 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.1: 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.

Figure D.2: Price of long-term debt p^L



Note: The price of long-term debt p^L in (3.13) 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 fixed at their equilibrium values given the respective firm state (q, b, z').

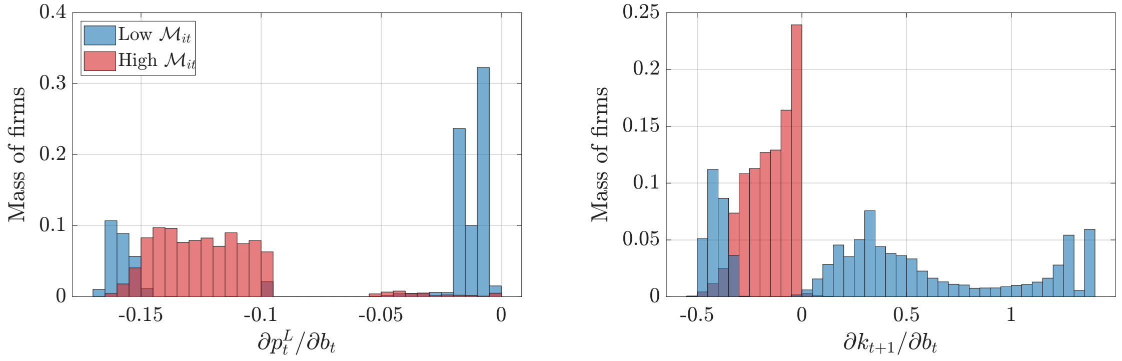
Sensitivity of firm policies with respect to outstanding long-term debt. As discussed in Section 3.8, the price of long-term debt p^L in (3.13) is a key equilibrium object in the model. Firms with lower productivity z' have higher default risk (Section 4.3) and are therefore more exposed to debt overhang (Implication 1 in Section 3.8). For them, issuing additional long-term debt $b^{L'}$ distorts future investment and default risk by more and therefore has a larger negative effect on their long-term bond price p^L (Figure D.2).

The true cost of long-term debt is therefore given by the sensitivity of future firm choices with respect to the amount of outstanding long-term debt b_t. This is illustrated by Figure D.3. Firms whose long-term bond price p^L_t is more responsive to the amount of outstanding long-term debt b_t tend to choose shorter maturities and higher maturing debt shares $\mathcal{M}_{it}$ (panel (a)). Similarly, firms with a larger negative sensitivity of future capital k_{t+1} (panel (b)), and larger positive sensitivities

Figure D.3: Derivatives of firm policies with respect to outstanding long-term debt for firms with low and high maturing bond share $\mathcal{M}_{it}$

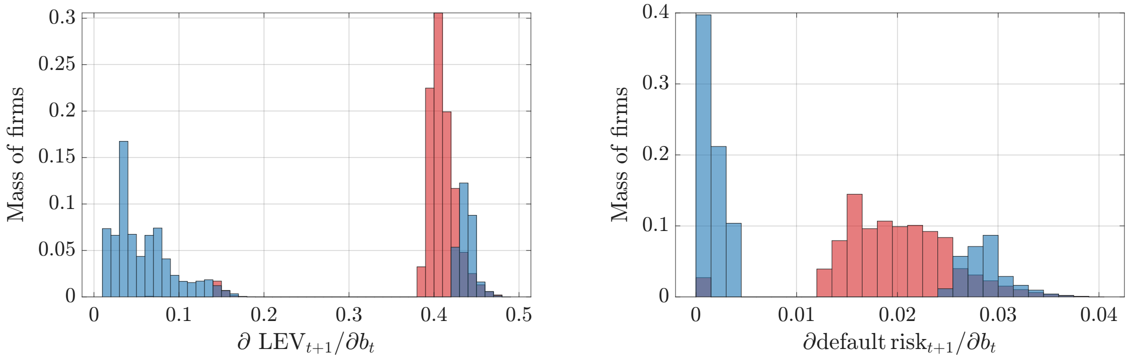
(a) Long-term bond price

(b) Capital



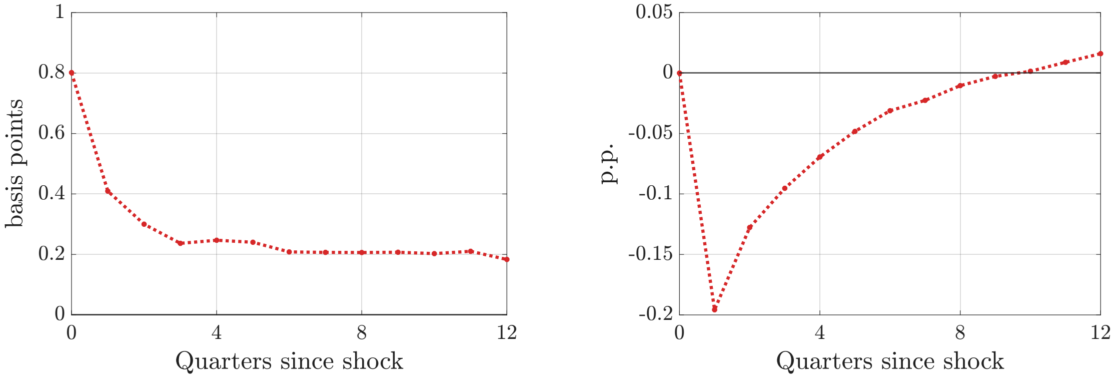
(c) Leverage

(d) Default risk

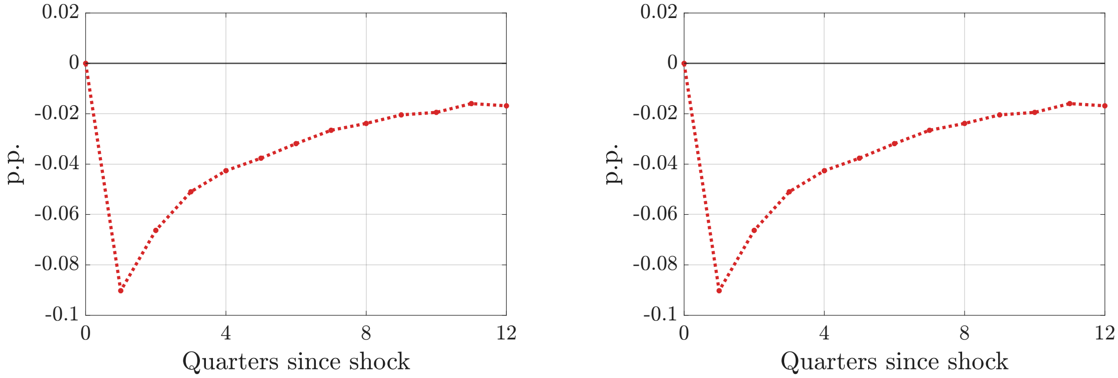


Note: The figure shows the stationary distribution in the calibrated model of the derivative of different firm policies with respect to outstanding long-term debt b_t. Panel (a) shows the derivative of the long-term bond price p^L_t with respect to b_t, panel (b) the derivative of capital k_{t+1} with 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.4: Differential firm-level responses associated with $\mathcal{M}_{it}$


(a) Credit spread

(b) Debt


(c) Sales

(d) Employment

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}.

of future leverage (panel (c)) and future default risk (panel (d)) also choose higher maturing debt shares $\mathcal{M}_{it}$.

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 aggregate 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

Table D.1: Counterfactual calibration

Parameter	Value	Target	Model
ρ_z	0.988	Regression log(k) on age	0.022
ς_z	0.300	Std. of firm capital growth *(in %)*	10.7
$\sigma_{\varepsilon\|z\leq\mathbb{E}(z)}$	0.45	Average firm leverage (*in %*)	61.6
$\sigma_{\varepsilon\|z>\mathbb{E}(z)}$	0.66	Regression leverage on age	0.512
ξ	0.54	Average credit spread on long-term debt *(in %)*	1.58
η	0.00075	Average share of debt due within a year *(in %)*	29.5
ν	0.0005	Average equity issuance *(in %)*	11.5
κ	0.0151	Firm exit rate *(in %)*	1.9
f	0.2797	Steady state value of firm entry	0

Note: See Appendix D.1 for details on variable definitions in the model.

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.4 (using the average credit spread, total debt, sales, and employment as additional firm outcomes) are constructed correspondingly.

D.5 Unconventional monetary policy and corporate debt maturity: Model setup

This section provides further details about the model setup with UMP, shown in Section 4.6. The UMP shock $\varepsilon_t^{\text{ump}}$ drives a temporary wedge η_t^{ump} between $\Lambda_{t,t+1}^S$ and $\Lambda_{t,t+1}^L$, see (4.5). To mimic a binding zero lower bound, we assume that the risk-free short-term interest rate i_t in (C.4) does not respond to the UMP shock. It remains at its steady state level, that is:

$$i_t = \left(\mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^S}{\pi_{t+1}}\right)^{-1} - 1 = \beta^{-1} - 1. \tag{D.15}$$

Finally, we need to modify the Taylor rule. The original rule in (3.17) is incompatible with a constant i_t since the UMP shock affects inflation π_t. We therefore assume the modified policy rule

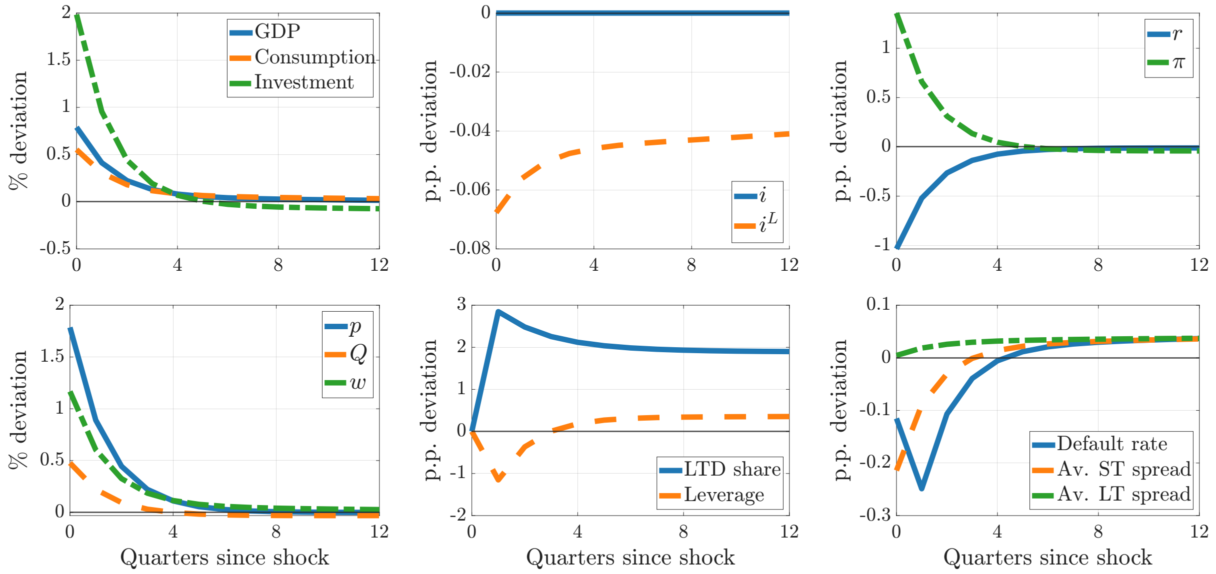
$$1 + \tilde{i}_t = \frac{1}{\beta}\pi_t^{\varphi^{\text{mp}}}, \tag{D.16}$$

where $\tilde{i}_t$ is the risk-free short-term interest rate applying to long-term asset markets (priced by $\Lambda_{t,t+1}^L$):

$$\tilde{i}_t = \frac{1+c}{\tilde{P}_{rt}^S} - 1 \qquad \text{and} \qquad \tilde{P}_{rt}^S = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}^L \frac{1+c}{\pi_{t+1}}. \tag{D.17}$$

The policy rule (D.16) closes the model. In response to movements in π_t, it stabilizes the economy by controlling $\tilde{i}_t$, which is tied to the long-term asset SDF $\Lambda_{t,t+1}^L$ in (D.17). As we show in Online

Figure D.5: Aggregate response to an expansionary unconventional monetary policy shock under the counterfactual high-leverage calibration



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.

Appendix H.4, the effect of the UMP shock $\varepsilon_t^{\text{ump}}$ on the wedge η_t^{ump} between $\Lambda_{t,t+1}^S$ and $\Lambda_{t,t+1}^L$ in (4.5) is equivalent to a shock to the policy rule (D.16).

D.6 Unconventional monetary policy and corporate debt maturity: Counterfactual calibration

This section provides details of the counterfactual calibration studied in Section 4.6. The main difference from the benchmark calibration (Table 3) is that average firm leverage doubles from 31% to 62% (see Table D.1). The increase in firm leverage is achieved by lowering the standard deviation of the idiosyncratic capital quality shock: $\sigma_{\varepsilon|z\leq\mathbb{E}(z)}$ and $\sigma_{\varepsilon|z>\mathbb{E}(z)}$ are both reduced by 25% compared to Table 3. The parameters γ (from 0.05 to 0.03) and η (from 0.0045 to 0.00075) are lowered to keep the average share of debt maturing within a year approximately constant at 29.5% (compared to 30.6% in Table 3). Finally, the fixed cost f is increased (from 0.2585 to 0.2797) to keep the value of firm entry at zero. Figure D.5 shows impulse response functions to a UMP shock under this calibration. Finally, Figure D.6 compares aggregate output responses to a UMP shock in both calibrations under endogenous and fixed maturity.

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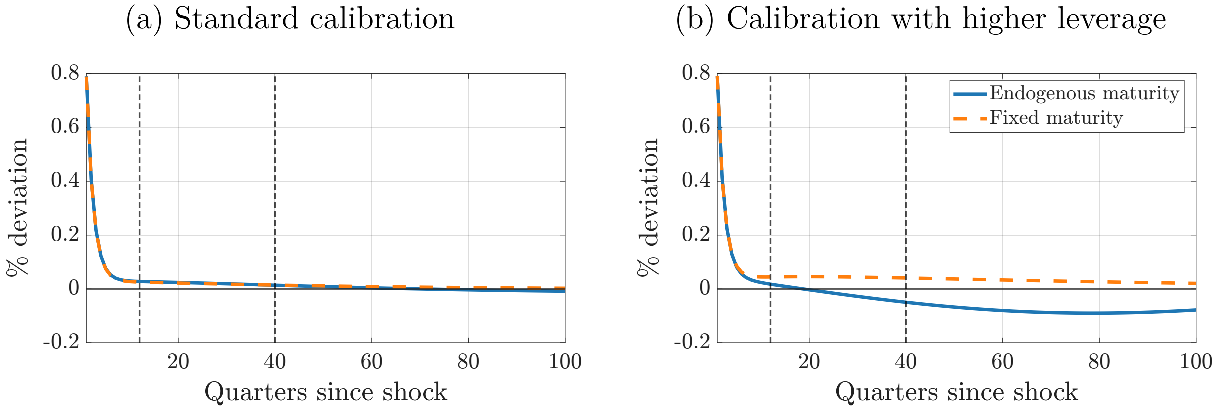
Figure D.6: The role of endogenous debt maturity for GDP


(a) Standard calibration

(b) Calibration with higher leverage

Note: The figure shows impulse response functions of GDP for the first 100 periods after a UMP shock. The size of the shock is identical to that in Figure 14. Blue lines correspond to the benchmark economy with endogenous debt maturity. Orange lines correspond to the alternative fixed-maturity model. Panel (b) is computed using the counterfactual calibration with higher average firm leverage. The vertical dashed lines indicate horizons $h = 12$ (short run) and $h = 40$ (medium run).

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Corporate Debt Maturity Matters For Monetary Policy

Online Appendix – Not intended for publication

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June 29, 2026

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

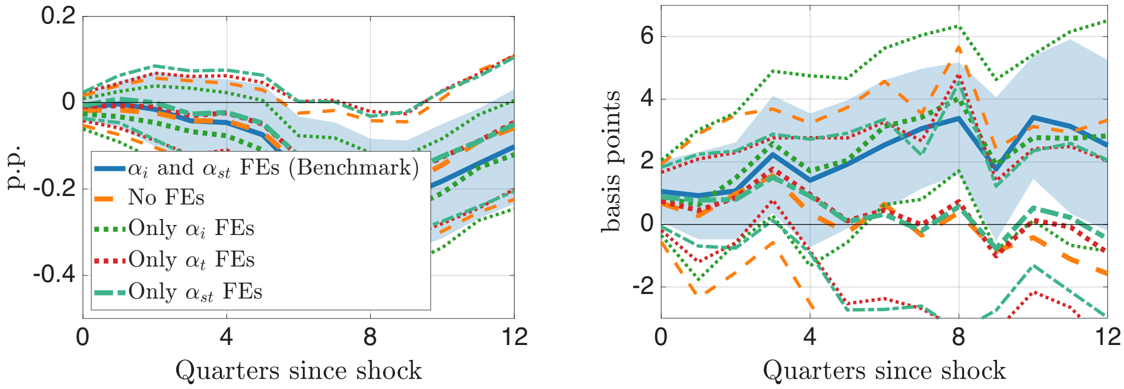
	$\Delta^{h+1}\log k_{it+h}$			
	$h = 0$	$h = 4$	$h = 8$	$h = 12$
$\mathcal{M}_{it}$	-0.0161	-0.129	-0.142	-0.0308
	(0.0237)	(0.0837)	(0.0856)	(0.107)
$\mathcal{M}_{it}$ × MP shock	-0.0221	-0.126*	-0.321***	-0.230**
	(0.0185)	(0.0658)	(0.0779)	(0.0942)
$\mathcal{M}_{it}$ × GDP growth	0.00794	0.203**	0.376***	0.228
	(0.0375)	(0.0958)	(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
	(0.0573)	(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**
	(0.0452)	(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
	(0.0821)	(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)	(1.114)
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)
Constant	0.657***	3.737***	6.533***	8.396***
	(0.0532)	(0.235)	(0.501)	(0.701)
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

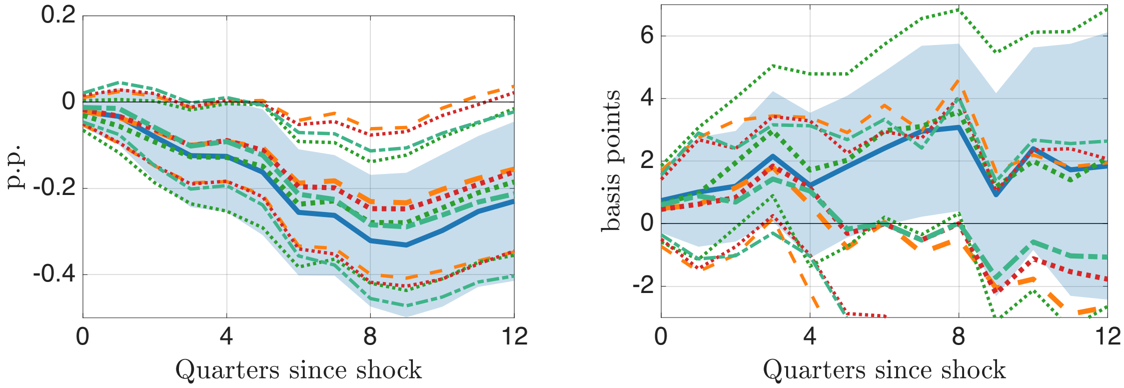
(a) Investment: Baseline specification

(b) Spreads: Baseline specification



(c) Investment: Extended specification

(d) Spreads: Extended specification



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 panels (a) and (b) and using the extended specification in equation (2.4) in panels (c) and (d). 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 of the firm problem presented in Section 3, we express the optimization problem (3.21) in terms of three choice variables: equity issuance (or dividend payout) e, as well as the amounts of short-term debt $b^{S'}$ and long-term debt $b^{L'}$. Given these three firm choices, capital is pinned down by the firm's cash flow constraint (3.4). The value of a continuing firm is:

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

where $x = (z, k, b^S, b^L)$. The firm's cash flow constraint (3.4) is:

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

where the real value of the firm's cash-on-hand $q(x, \varepsilon; S)$ is specified in (3.3). The firm's short-term bond price p^S in (3.12) is

$$p^S = \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} \left[[1 - \mathcal{D}(x', \varepsilon'; S')]\frac{1+c}{\pi'} + \mathcal{D}(x', \varepsilon'; S')\frac{(1-\xi)\underline{q}(\varepsilon')}{b^{S'} + b^{L'}}\right]\varphi(\varepsilon'|z')d\varepsilon', \quad \text{(G.3)}$$

where $\mathcal{D}(x', \varepsilon'; S') = 1$ iff $W(x', \varepsilon'; S') < 0$ in (3.8), $x' = (z', k', b^{S'}, b^{L'})$, and:

$$\underline{q}(\varepsilon') \equiv \max\left\{Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon' - \delta)Q'k' - f\right], 0\right\}. \quad \text{(G.4)}$$

The long-term bond price p^L in (3.13) is

$$\begin{aligned} p^L = \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} \Bigg[&[1 - \mathcal{D}(x', \varepsilon'; S')]\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}g(x', \varepsilon', z''; S')}{\pi'} \\ &+ \mathcal{D}(x', \varepsilon'; S')\frac{(1-\xi)\underline{q}(\varepsilon')}{b^{S'} + b^{L'}}\Bigg]\varphi(\varepsilon'|z')d\varepsilon'. \end{aligned} \quad \text{(G.5)}$$

It follows that both p^S and p^L are functions of k', $b^{S'}$, and $b^{L'}$. Once the three choice variables e, $b^{S'}$, and $b^{L'}$ are set, (G.2) implicitly specifies a unique value of k'. Equity issuance costs are

$$G(e) = \nu\left(\max\{e, 0\}\right)^2. \quad \text{(G.6)}$$

Debt issuance costs are

$$H\left(b^{S'}, b^{L'}, \frac{b^L}{\pi}\right) = \eta\left(b^{S'} + \max\left\{b^{L'} - \frac{(1-\gamma)b^L}{\pi}, 0\right\}\right)^2. \quad \text{(G.7)}$$

It follows that the firm objective (G.1) is determined by the three choice variables e, $b^{S'}$, and $b^{L'}$.

First-order condition for equity issuance (or dividend payout). The firm's first-order condition with respect to equity issuance e is:

$$-\left[1+\frac{\partial G(e)}{\partial e}\right]+\mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\frac{\partial V(x',\varepsilon';S')}{\partial e}\varphi(\varepsilon'|z')d\varepsilon'=0\,, \tag{G.8}$$

where the marginal cost of equity issuance is:

$$\frac{\partial G(e)}{\partial e}=2\nu\cdot(\max\{e,0\}). \tag{G.9}$$

Next period's value $V(x',\varepsilon';S')$ responds to an increase in e according to:

$$\frac{\partial V(x',\varepsilon';S')}{\partial e}=\begin{cases}\frac{\partial k'}{\partial e}\frac{\partial q'}{\partial k'}\mathbb{E}_{z''|z'}\left[(1-\kappa)\frac{\partial W^C(x',\varepsilon',z'';S')}{\partial q'}+\kappa\frac{\partial W^X(x',\varepsilon',z'';S')}{\partial q'}\right] & \text{if}\, W(x',\varepsilon';S')\geq 0,\\ 0 & \text{otherwise.}\end{cases} \tag{G.10}$$

The derivative of next period's cash-on-hand q' with respect to capital k' in (G.10) is:

$$\frac{\partial q'}{\partial k'}=Q'+(1-\tau)\left[A'\alpha k'^{\alpha-1}+(\varepsilon'-\delta)Q'\right]. \tag{G.11}$$

To compute the derivative of capital k' with respect to equity issuance e in (G.10), we use (G.2):

$$Qk'-q(x,\varepsilon;S)-b^{S'}p^S-\left(b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right)p^L-e=0. \tag{G.12}$$

Implicit differentiation yields:

$$\frac{\partial k'}{\partial e}=\frac{1}{Q-b^{S'}\frac{\partial p^S}{\partial k'}-\left(b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}}. \tag{G.13}$$

To compute $\partial p^S/\partial k'$ and $\partial p^L/\partial k'$ in (G.13), 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 (3.8). At this threshold realization $\bar{\varepsilon}'$, the firm is just indifferent between defaulting and servicing its current debt obligations, i.e.,

$$\mathbb{E}_{z''|z'}\left[(1-\kappa)W^C(x',\bar{\varepsilon}',z'';S')+\kappa W^X(x',\bar{\varepsilon}',z'';S')\right]=0. \tag{G.14}$$

Applying the implicit function theorem to (G.14), we derive:

$$\frac{\partial\bar{\varepsilon}'}{\partial k'}=-\frac{\frac{\partial q'}{\partial k'}}{\frac{\partial q'}{\partial\bar{\varepsilon}'}}=-\frac{Q'+(1-\tau)\left[A'\alpha k'^{\alpha-1}+(\bar{\varepsilon}'-\delta)Q'\right]}{(1-\tau)Q'k'}. \tag{G.15}$$

Given $\partial\bar{\varepsilon}/\partial k'$, the derivative of p^S with respect to k' is:

$$\begin{aligned}\frac{\partial p^S}{\partial k'} = \mathbb{E}_{S'|S}\Lambda\Bigg[&\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'} \frac{1-\xi}{b^{S'}+b^{L'}}\left[Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon'-\delta)Q'\right]\right]\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \varphi(\bar{\varepsilon}'|z')\frac{\partial\bar{\varepsilon}'}{\partial k'}\left[-\frac{1+c}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg],\end{aligned} \tag{G.16}$$

where $\underline{\varepsilon}'$ denotes the threshold realization of the capital quality shock ε' such that the value of firm assets left for creditors in case of default is zero:

$$Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\underline{\varepsilon}'-\delta)Q'k' - f\right] = 0. \tag{G.17}$$

The derivative of p^L with respect to k' is:

$$\begin{aligned}\frac{\partial p^L}{\partial k'} =& \mathbb{E}_{S'|S}\Lambda\Bigg[\int_{\bar{\varepsilon}'}^{\infty} \frac{1-\gamma}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial\tilde{g}(q',b',z'';S')}{\partial q'}\frac{\partial q'}{\partial k'}\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'} \frac{1-\xi}{b^{S'}+b^{L'}}\left[Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon'-\delta)Q'\right]\right]\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \varphi(\bar{\varepsilon}'|z')\frac{\partial\bar{\varepsilon}'}{\partial k'}\left[-\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q',b',z'';S')}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg].\end{aligned} \tag{G.18}$$

Equation (G.18) uses the fact that the future price of long-term debt $g(x',\varepsilon',z'';S')$ 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

$$q' = q(x',\varepsilon';S') = Q'k' - \frac{b^{S'}}{\pi'} - \frac{\gamma b^{L'}}{\pi'} + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f - \frac{c(b^{S'}+b^{L'})}{\pi'}\right], \tag{G.19}$$

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

The marginal value of future cash-on-hand q' in case of exogenous exit in (G.10) is straightforward to derive using (3.9):

$$\frac{\partial W^X(x',\varepsilon',z'';S')}{\partial q'} = 1 - \frac{(1-\gamma)b^{L'}}{\pi'}\frac{\partial\tilde{g}(q',b',z'';S')}{\partial q'}. \tag{G.20}$$

To derive the marginal value of future cash-on-hand q' for a continuing firm in (G.10), we consider the effect of a marginal increase in q on (G.1) for given choices of e, $b^{S'}$, and $b^{L'}$. We derive:

$$\frac{\partial W^C(x,\varepsilon,z';S)}{\partial q} = \mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\frac{\partial V(x',\varepsilon';S')}{\partial q}\varphi(\varepsilon'|z')d\varepsilon', \tag{G.21}$$

where:

$$\frac{\partial V(x',\varepsilon';S')}{\partial q}=\begin{cases}\frac{\partial k'}{\partial q}\frac{\partial q'}{\partial k'}\mathbb{E}_{z''|z'}\left[(1-\kappa)\frac{\partial W^C(x',\varepsilon',z'';S')}{\partial q'}+\kappa\frac{\partial W^X(x',\varepsilon',z'';S')}{\partial q'}\right] & \text{if } W(x',\varepsilon';S')\geq 0,\\ 0 & \text{otherwise.}\end{cases} \tag{G.22}$$

Furthermore, using (G.2), we find that $\partial k'/\partial q$ is identical to $\partial k'/\partial e$ in (G.13). It follows that:

$$\frac{\partial V(x',\varepsilon';S')}{\partial q}=\frac{\partial V(x',\varepsilon';S')}{\partial e} \tag{G.23}$$

But from the first-order condition (G.8), we know that

$$\mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\frac{\partial V(x',\varepsilon';S')}{\partial e}\varphi(\varepsilon'|z')d\varepsilon'=1+\frac{\partial G(e)}{\partial e}. \tag{G.24}$$

Equation (G.21) becomes:

$$\frac{\partial W^C(x,\varepsilon,z';S)}{\partial q}=1+\frac{\partial G(e)}{\partial e}. \tag{G.25}$$

Iterating forward one period yields:

$$\frac{\partial W^C(x',\varepsilon',z'';S')}{\partial q'}=1+\frac{\partial G(e')}{\partial e'}. \tag{G.26}$$

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

$$-\frac{\partial H(b^{S'},b^{L'},b^L/\pi)}{\partial b^{S'}}+\mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\frac{\partial V(x',\varepsilon';S')}{\partial b^{S'}}\varphi(\varepsilon'|z')d\varepsilon'=0. \tag{G.27}$$

The marginal debt issuance cost is:

$$\frac{\partial H(b^{S'},b^{L'},b^L/\pi)}{\partial b^{S'}}=2\eta\cdot\left(b^{S'}+\max\left\{0\,,\,b^{L'}-\frac{(1-\gamma)b^L}{\pi}\right\}\right). \tag{G.28}$$

Next period's value $V(x',\varepsilon';S')$ responds to an increase in $b^{S'}$ according to:

$$\frac{\partial V(x',\varepsilon';S')}{\partial b^{S'}}=\begin{cases}\frac{dq'(b^{S'},k')}{db^{S'}}\mathbb{E}_{z''|z'}\left[(1-\kappa)\frac{\partial W^C(x',\varepsilon',z'';S')}{\partial q'}+\kappa\frac{\partial W^X(x',\varepsilon',z'';S')}{\partial q'}\right] & \text{if } W(x',\varepsilon';S')\geq 0,\\ 0 & \text{otherwise.}\end{cases} \tag{G.29}$$

Next period's cash-on-hand q' depends directly on $b^{S'}$ and indirectly through the effect of $b^{S'}$ on capital k':

$$\frac{dq'(b^{S'},k')}{db^{S'}} = \frac{\partial q'(b^{S'},k')}{\partial b^{S'}} + \frac{\partial q'(b^{S'},k')}{\partial k'}\frac{\partial k'}{\partial b^{S'}}. \tag{G.30}$$

The direct effect of $b^{S'}$ on next period's cash-on-hand q' is:

$$\frac{\partial q'(b^{S'},k')}{\partial b^{S'}} = -\frac{1+(1-\tau)c}{\pi'}. \tag{G.31}$$

We already know that:

$$\frac{\partial q'(b^{S'},k')}{\partial k'} = Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon'-\delta)Q'\right]. \tag{G.32}$$

Furthermore, using implicit differentiation in the firm's cash flow constraint (G.2) yields:

$$\frac{\partial k'}{\partial b^{S'}} = \frac{p^S + b^{S'}\frac{\partial p^S(b^{S'},k')}{\partial b^{S'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L(b^{S'},k')}{\partial b^{S'}}}{Q - b^{S'}\frac{\partial p^S(b^{S'},k')}{\partial k'} - \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L(b^{S'},k')}{\partial k'}}. \tag{G.33}$$

To compute $\partial p^S/\partial b^{S'}$ and $\partial p^L/\partial b^{S'}$ in (G.33), we first derive how $b^{S'}$ affects the firm's default decision. Applying the implicit function theorem to (G.14), we derive:

$$\frac{\partial \bar{\varepsilon}'}{\partial b^{S'}} = -\frac{\frac{\partial q'}{\partial b^{S'}}}{\frac{\partial q'}{\partial \bar{\varepsilon}'}} = \frac{1+(1-\tau)c}{\pi'(1-\tau)Q'k'}. \tag{G.34}$$

Given $\partial\bar{\varepsilon}'/\partial b^{S'}$, the derivative of p^S with respect to $b^{S'}$ (holding k' constant) is:

$$\begin{aligned}\frac{\partial p^S(b^{S'},k')}{\partial b^{S'}} =& \mathbb{E}_{S'|S}\Lambda\Bigg[-\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{(b^{S'}+b^{L'})^2}\left[Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f\right]\right]\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \varphi(\bar{\varepsilon}'|z')\frac{\partial\bar{\varepsilon}'}{\partial b^{S'}}\left[-\frac{1+c}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg].\end{aligned} \tag{G.35}$$

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

$$\begin{aligned}\frac{\partial p^L(b^{S'},k')}{\partial b^{S'}} =& \mathbb{E}_{S'|S}\Lambda\Bigg[\int_{\bar{\varepsilon}'}^{\infty}\frac{1-\gamma}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial\tilde{g}(q',b',z'';S')}{\partial q'}\frac{\partial q'(b^{S'},k')}{\partial b^{S'}}\varphi(\varepsilon'|z')d\varepsilon' \\ &- \int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{(b^{S'}+b^{L'})^2}\left[Q'k' + (1-\tau)\left[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f\right]\right]\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \varphi(\bar{\varepsilon}'|z')\frac{\partial\bar{\varepsilon}'}{\partial b^{S'}}\left[-\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q',b',z'';S')}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg].\end{aligned} \tag{G.36}$$

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

$$-\frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^{L'}} + \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} \frac{\partial V(x', \varepsilon'; S')}{\partial b^{L'}} \varphi(\varepsilon'|z') d\varepsilon' = 0. \tag{G.37}$$

The marginal debt issuance cost is:

$$\frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^{L'}} = \begin{cases} 2\eta \left(b^{S'} + b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right) & \text{if} \quad b^{L'} > \frac{(1-\gamma)b^L}{\pi} \\ 0 & \text{if} \quad b^{L'} < \frac{(1-\gamma)b^L}{\pi} \end{cases}. \tag{G.38}$$

If default is avoided ($W(x', \varepsilon'; S') \geq 0$), next period's value $V(x', \varepsilon'; S')$ responds to an increase in $b^{L'}$ according to:

$$\begin{aligned} \frac{\partial V(x', \varepsilon'; S')}{\partial b^{L'}} =& \frac{dq'(b^{L'}, k')}{db^{L'}} \mathbb{E}_{z''|z'} \left[(1-\kappa)\frac{\partial \tilde{W}^C(q', b', z''; S')}{\partial q'} + \kappa \frac{\partial \tilde{W}^X(q', b', z''; S')}{\partial q'}\right] \\ &+ \frac{\partial b'}{\partial b^{L'}} \mathbb{E}_{z''|z'} \left[(1-\kappa)\frac{\partial \tilde{W}^C(q', b', z''; S')}{\partial b'} + \kappa \frac{\partial \tilde{W}^X(q', b', z''; S')}{\partial b'}\right]. \end{aligned} \tag{G.39}$$

Equation (G.39) uses the fact that $W^C(x', \bar{\varepsilon}', z''; S')$ and $W^X(x', \bar{\varepsilon}', z''; S')$ can be expressed as functions of the reduced state vector $(q', b', z''; S')$, as explained in Section 4.1: $\tilde{W}^C(q', b', z''; S')$ and $\tilde{W}^X(q', b', z''; S')$.

Next period's cash-on-hand q' depends directly on $b^{L'}$ and indirectly through the effect of $b^{L'}$ on capital k':

$$\frac{dq'(b^{L'}, k')}{db^{L'}} = \frac{\partial q'(b^{L'}, k')}{\partial b^{L'}} + \frac{\partial q'(b^{L'}, k')}{\partial k'} \frac{\partial k'}{\partial b^{L'}}. \tag{G.40}$$

The direct effect of $b^{L'}$ on next period's cash-on-hand q' is:

$$\frac{\partial q'(b^{L'}, k')}{\partial b^{L'}} = -\frac{\gamma + (1-\tau)c}{\pi'}. \tag{G.41}$$

We already know:

$$\frac{\partial q'(b^{L'}, k')}{\partial k'} = Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon' - \delta)Q'\right]. \tag{G.42}$$

It remains to find $\partial k'/\partial b^{L'}$. Using implicit differentiation in (G.2) yields:

$$\frac{\partial k'}{\partial b^{L'}} = \frac{b^{S'} \frac{\partial p^S(b^{L'}, k')}{\partial b^{L'}} + p^L + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right) \frac{\partial p^L(b^{L'}, k')}{\partial b^{L'}}}{Q - b^{S'} \frac{\partial p^S(b^{L'}, k')}{\partial k'} - \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right) \frac{\partial p^L(b^{L'}, k')}{\partial k'}}. \tag{G.43}$$

To compute $\partial p^S/\partial b^{L'}$ and $\partial p^L/\partial b^{L'}$ in (G.43), we first derive how $b^{L'}$ affects the firm's default decision. Applying the implicit function theorem to (G.14) yields:

$$\frac{\partial \bar{\varepsilon}'}{\partial b^{L'}} = -\frac{\frac{\partial q'(b^{L'},k')}{\partial b^{L'}}}{\frac{\partial q'(b^{L'},k')}{\partial \bar{\varepsilon}'}} - \frac{\frac{\partial b'}{\partial b^{L'}}}{\frac{\partial q'(b^{L'},k')}{\partial \bar{\varepsilon}'}} \frac{\mathbb{E}_{z''|z'}\left[(1-\kappa)\frac{\partial \tilde{W}^C(q',b',z'';S')}{\partial b'} + \kappa\frac{\partial \tilde{W}^X(q',b',z'';S')}{\partial b'}\right]}{\mathbb{E}_{z''|z'}\left[(1-\kappa)\frac{\partial \tilde{W}^C(q',b',z'';S')}{\partial q'} + \kappa\frac{\partial \tilde{W}^X(q',b',z'';S')}{\partial q'}\right]}. \tag{G.44}$$

Given $\partial \bar{\varepsilon}'/\partial b^{L'}$, the derivative of p^S with respect to $b^{L'}$ (holding k' constant) is

$$\begin{aligned}\frac{\partial p^S(b^{L'},k')}{\partial b^{L'}} =& \mathbb{E}_{S'|S}\Lambda\Bigg[-\int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{(b^{S'}+b^{L'})^2}\Big[Q'k' + (1-\tau)\Big[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f\Big]\Big]\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \varphi(\bar{\varepsilon}'|z')\frac{\partial \bar{\varepsilon}'}{\partial b^{L'}}\left[-\frac{1+c}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg].\end{aligned} \tag{G.45}$$

Similarly, we derive the derivative of p^L with respect to $b^{L'}$ (holding k' constant):

$$\begin{aligned}\frac{\partial p^L(b^{L'},k')}{\partial b^{L'}} =& \mathbb{E}_{S'|S}\Lambda\Bigg[\int_{\bar{\varepsilon}'}^{\infty}\frac{1-\gamma}{\pi'}\mathbb{E}_{z''|z'}\left(\frac{\partial \tilde{g}(q',b',z'';S')}{\partial q'}\frac{\partial q'(b^{L'},k')}{\partial b^{L'}} + \frac{\partial \tilde{g}(q',b',z'';S')}{\partial b'}\frac{\partial b'}{\partial b^{L'}}\right)\varphi(\varepsilon'|z')d\varepsilon' \\ &- \int_{\underline{\varepsilon}'}^{\bar{\varepsilon}'}\frac{1-\xi}{(b^{S'}+b^{L'})^2}\Big[Q'k' + (1-\tau)\Big[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f\Big]\Big]\varphi(\varepsilon'|z')d\varepsilon' \\ &+ \varphi(\bar{\varepsilon}'|z')\frac{\partial \bar{\varepsilon}'}{\partial b^{L'}}\left[-\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q',b',z'';S')}{\pi'} + \frac{(1-\xi)\underline{q}(\bar{\varepsilon}')}{b^{S'}+b^{L'}}\right]\Bigg].\end{aligned} \tag{G.46}$$

The derivative of the future amount of outstanding long-term debt b' with respect to $b^{L'}$ in (G.39), (G.44), and in (G.46) is simply:

$$\frac{\partial b'}{\partial b^{L'}} = 1-\gamma. \tag{G.47}$$

The marginal value of outstanding long-term debt $b' = (1-\gamma)b^{L'}$ in case of exogenous exit in (G.39) and in (G.44) is straightforward to derive using (3.9):

$$\frac{\partial \tilde{W}^X(q',b',z'';S')}{\partial b'} = -\frac{1}{\pi'}\tilde{g}(q',b',z'';S') - \frac{b'}{\pi'}\frac{\partial \tilde{g}(q',b',z'';S')}{\partial b'}. \tag{G.48}$$

To derive the marginal value of outstanding long-term debt $b' = (1-\gamma)b^{L'}$ for a continuing firm in (G.39) and in (G.44), we consider the effect of a marginal increase in b on (G.1) for given choices of e, $b^{S'}$, and $b^{L'}$. We derive:

$$\frac{\partial \tilde{W}^C(q,b,z';S)}{\partial b} = -\frac{\partial H(b^{S'},b^{L'},b^L/\pi)}{\partial b^L}\frac{\partial b^L}{\partial b} + \mathbb{E}_{S'|S}\Lambda\int_{\varepsilon'}\frac{\partial V(x',\varepsilon';S')}{\partial b}\varphi(\varepsilon'|z')d\varepsilon', \tag{G.49}$$

where the effect of long-term debt b^L on debt issuance costs is:

$$\frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^L} = \begin{cases} 2\eta \left(b^{S'} + b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\left(-\frac{1-\gamma}{\pi}\right) & \text{if} \quad b^{L'} > \frac{(1-\gamma)b^L}{\pi} \\ 0 & \text{if} \quad b^{L'} < \frac{(1-\gamma)b^L}{\pi} \end{cases}. \tag{G.50}$$

The derivative of long-term debt b^L with respect to $b = (1-\gamma)b^L$ is simply:

$$\frac{\partial b^L}{\partial b} = \frac{1}{1-\gamma}. \tag{G.51}$$

A marginal increase in outstanding long-term debt b affects future shareholder value according to:

$$\frac{\partial V(x', \varepsilon'; S')}{\partial b} = \begin{cases} \frac{\partial k'}{\partial b}\frac{\partial q'}{\partial k'}\mathbb{E}_{z''|z'}\left[(1-\kappa)\frac{\partial W^C(x',\varepsilon',z'';S')}{\partial q'} + \kappa\frac{\partial W^X(x',\varepsilon',z'';S')}{\partial q'}\right] & \text{if}\, W(x',\varepsilon';S') \geq 0, \\ 0 & \text{otherwise.} \end{cases} \tag{G.52}$$

Using (G.2), we find:

$$\frac{\partial k'}{\partial b} = -\frac{\frac{1}{\pi}p^L}{Q - b^{S'}\frac{\partial p^S}{\partial k'} - \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}} = -\frac{1}{\pi}p^L\frac{\partial k'}{\partial q}. \tag{G.53}$$

It follows that:

$$\frac{\partial V(x', \varepsilon'; S')}{\partial b} = -\frac{1}{\pi}p^L\frac{\partial V(x', \varepsilon'; S')}{\partial e} \tag{G.54}$$

But from the first-order condition (G.8), we know that

$$\mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} \frac{\partial V(x', \varepsilon'; S')}{\partial e}\varphi(\varepsilon'|z')d\varepsilon' = 1 + \frac{\partial G(e)}{\partial e}. \tag{G.55}$$

Equation (G.49) becomes:

$$\frac{\partial \tilde{W}^C(q, b, z'; S)}{\partial b} = -\frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^L}\frac{\partial b^L}{\partial b} - \frac{1}{\pi}p^L\left(1 + \frac{\partial G(e)}{\partial e}\right). \tag{G.56}$$

Iterating forward one period yields:

$$\frac{\partial \tilde{W}^C(q', b', z''; S')}{\partial b'} = -\frac{\partial H(b^{S''}, b^{L''}, b^{L'}/\pi')}{\partial b^{L'}}\frac{\partial b^{L'}}{\partial b'} - \frac{1}{\pi'}\tilde{g}(q', b', z''; S')\left(1 + \frac{\partial G(e')}{\partial e'}\right). \tag{G.57}$$

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 (3.13). 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 (3.21) 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 (3.21) 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 (3.13) 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 a 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 grid 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:

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

The corresponding equilibrium conditions consist of

- the first-order conditions with respect to equity issuance (G.8) for a firm in a given state $s = (q, b, z')$,
- the first-order conditions with respect to short-term debt (G.27),
- the first-order conditions with respect to long-term debt (G.37),
- the equation for the continuation value W_{st}^C in (3.10),
- the condition for the long-term bond price p_{st}^L in (3.13),
- the stochastic discount factor: $\Lambda_{t,t+1} = \beta C_t / C_{t+1}$,
- 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: $L_t = \int_{\tilde{\mu}_{t-1}} l(z_{it}, \tilde{k}_{it}, \tilde{b}_{it}^S, \tilde{b}_{it}^L; S_t) d\tilde{\mu}_{t-1}$
- Fisher equation: $1/(1+i_t) = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1}/\pi_{t+1}$,
- 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: $Q_t = \left(\frac{I_t}{\delta K_t}\right)^{\frac{1}{\phi}}$,
- 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 Cross-sectional implications

Steady state firm policy functions. Figures H.1 and H.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 (3.21) 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'.

Stationary firm distribution. Figure H.3 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.

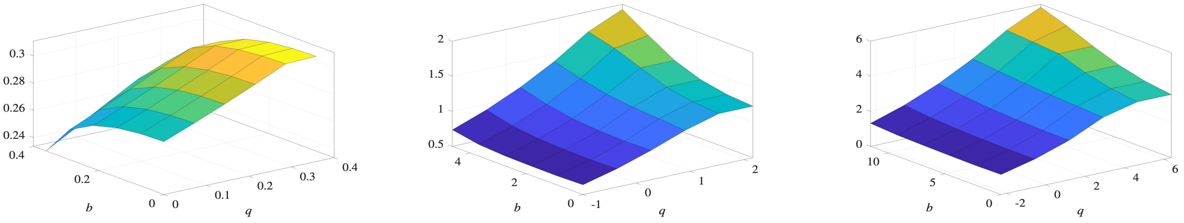
H.3 Heterogeneous effects of monetary policy shocks

Decomposing the transmission channels: Cash-flow effects of roll-over risk. In Section 4.5, we conduct a model experiment in which firms are paid cash transfers which compensate for the cash shortfall on credit markets due to changes in interest rates. Results are shown in Figure 10. The cash transfer $T(q, b, z', S)$ in (4.4) is 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. Figure H.4 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 roll-over risk, they receive higher compensating cash transfers.

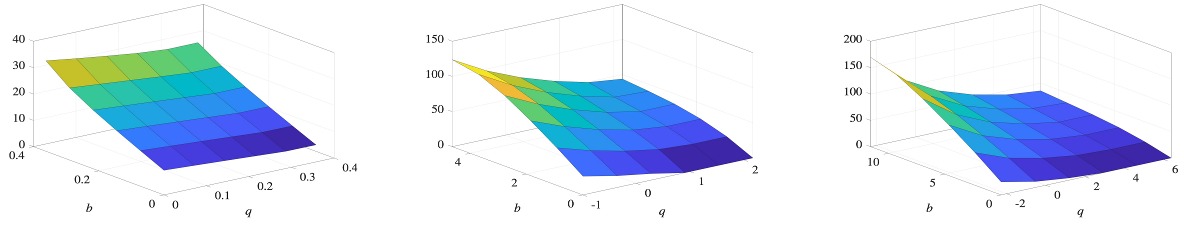
Decomposing the transmission channels: Cash-flow effects of debt deflation. In general, debt deflation operates in the model through debt overhang as well as through cash-flow effects. These cash-flow effects of debt deflation enter through firms' cash-on-hand (3.3), where a surprise fall in inflation π_t increases the real value of current debt payments and lowers firms' cash-on-hand q_{it}. Holding total debt constant, this effect is larger for firms with higher shares of short-term debt (because $\gamma < 1$), i.e., higher maturing debt shares. To assess the quantitative significance of this channel, we design a model experiment which eliminates debt deflation without eliminating this 'cash-flow channel of debt deflation'. In this experiment, we convert all nominal debt variables to real ones, but we also add a firm-specific cash transfer T_{it}^{dd} to q_{it} in (3.3), which is approximately equal to a firm's change in

Figure H.1: Steady state policy functions

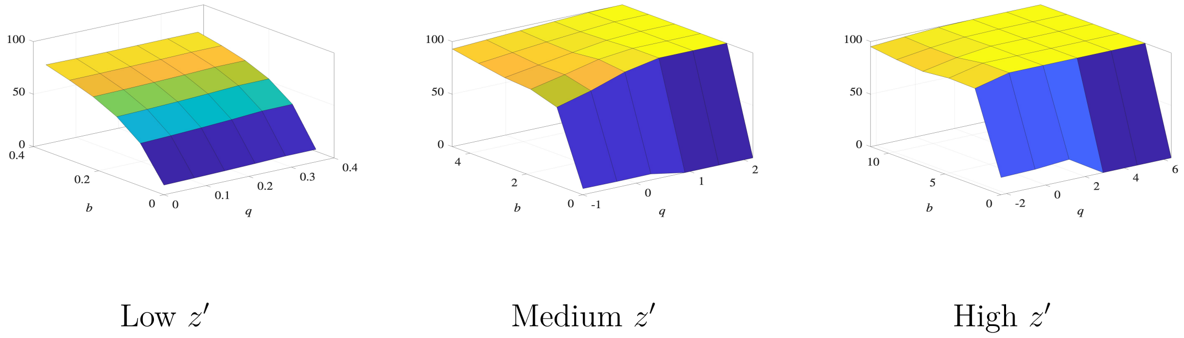
(a) Capital



(b) Leverage



(c) Long-term debt share



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 $b^{L'}/(b^{S'} + b^{L'})$.

q_{it} due to a change in inflation:

$$T^{dd}_{it} = b^S_{it,SS} - \frac{b^S_{it}}{\pi_t} + \gamma b^L_{it,SS} - \frac{\gamma b^L_{it}}{\pi_t} + (1 - \tau)\left[c(b^S_{it,SS} + b^L_{it,SS}) - \frac{c(b^S_{it} + b^L_{it})}{\pi_t}\right]. \tag{H.3}$$

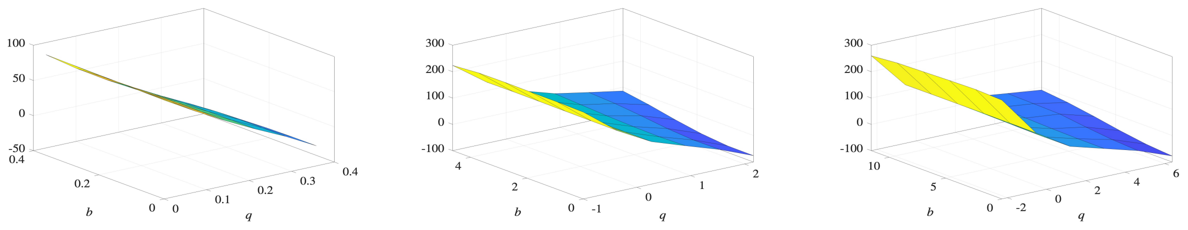
The values $b^S_{it,SS}$ and $b^L_{it,SS}$ are the firm choices in steady state. The values b^S_{it}, b^L_{it}, and inflation π_t are computed from the equilibrium dynamics in the benchmark model after a conventional monetary policy shock. This implies a negative transfer when (gross) inflation

π_t falls below its steady state value of 1. Through the transfer T_{it}^{dd}, the model experiment uses real debt but firms still experience the cash-flow channel of debt deflation. Figure H.5 shows the results of this experiment. The red and green lines are the same as in Figure 10. The blue dash-dotted line corresponds to the experiment where firm debt is real but firms are subject to the cash transfer T_{it}^{dd} described above. The main takeaway is that the cash-flow channel of debt deflation only plays a minor role. One reason for this result is that the size of the transfer T_{it}^{dd} is small. This is shown in Figure H.6. The cash flow effects of debt deflation account for 2 basis points of firm capital (for high-$\mathcal{M}$ firms) and less than 1 basis point (for low-$\mathcal{M}$ firms), respectively.

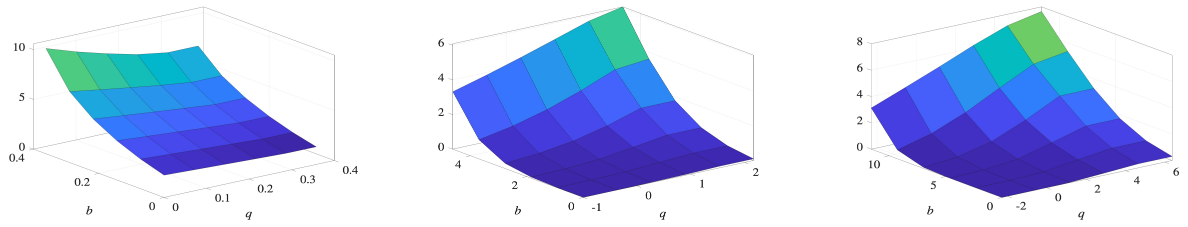
Exogenous variation in maturing bond share. In Section 4.5, we conduct a model experiment with exogenous variation in the maturing bond share. A representative sample of firms of zero mass is drawn from the benchmark economy. For the selected firm sample, we exogenously set $\mathcal{M}$ to a higher 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.7 shows that in this model experiment the average share of debt due in one year initially increases from about 30% to 100% for the selected firm sample and subsequently endogenously 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.2: Steady state policy functions (continued)

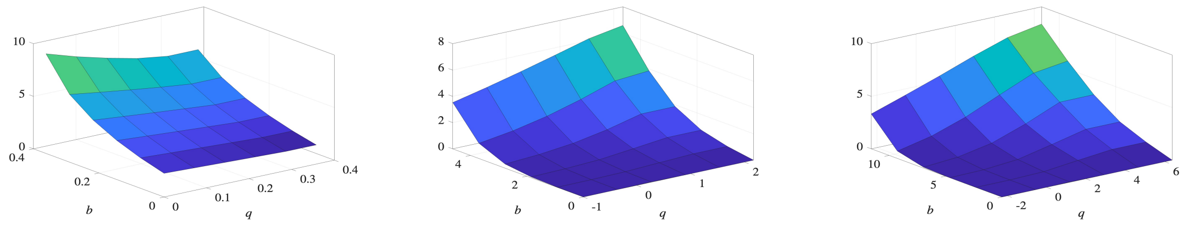
(a) Equity issuance



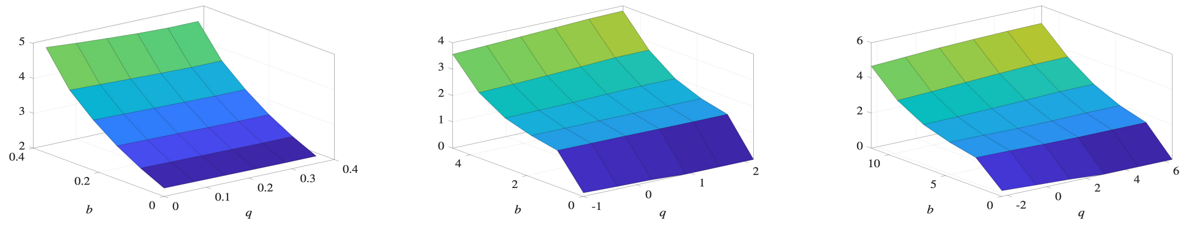
(b) Default risk



(c) Short-term credit spread



(d) Long-term credit spread



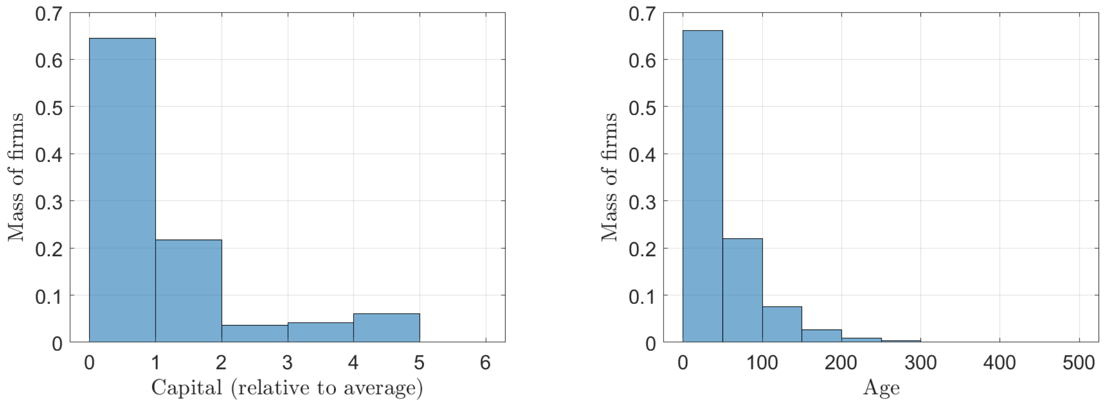
Low z' Medium z' High z'

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.

Figure H.3: Firm dynamics

(a) Stationary distribution of firm size

(b) Stationary distribution of firm age



(c) Stationary distribution of capital growth rates

(d) Average log capital over life cycle of firms

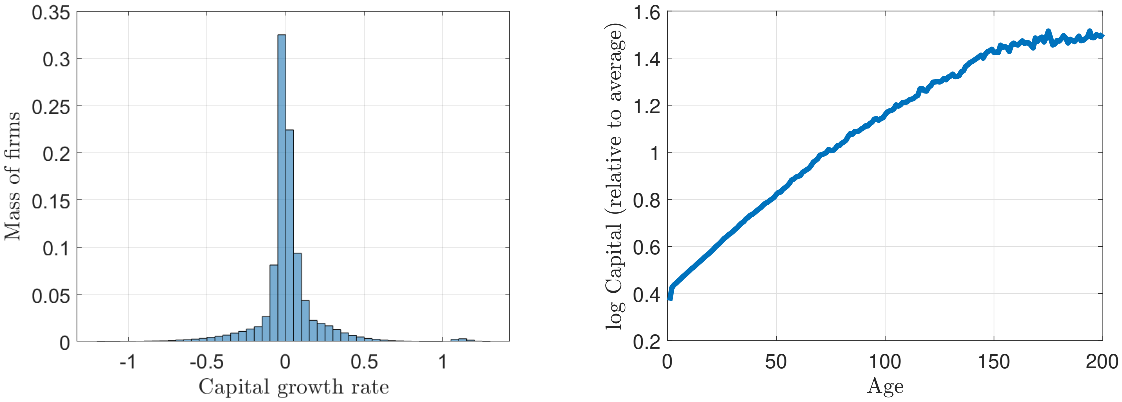
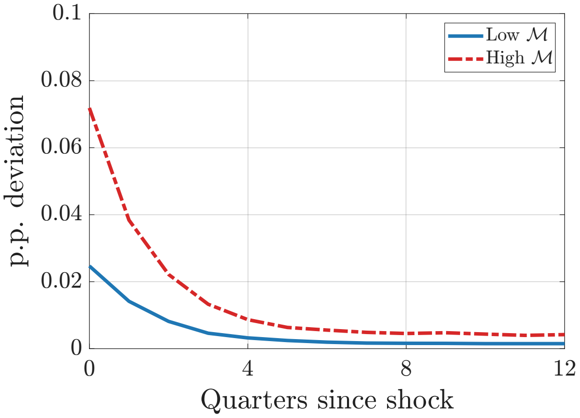
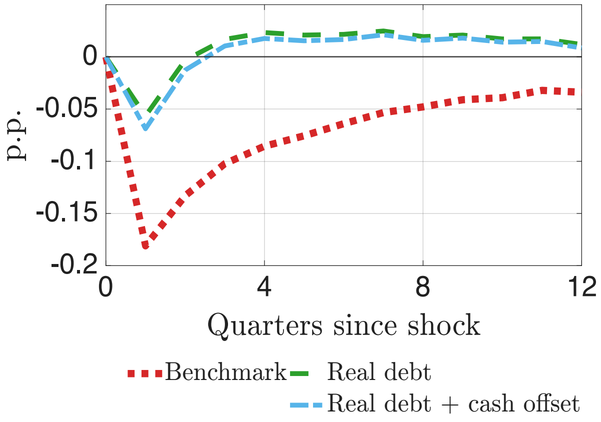


Figure H.4: Model experiment on cash-flow effects of roll-over risk - Cash transfer $T(q, b, z', S)$



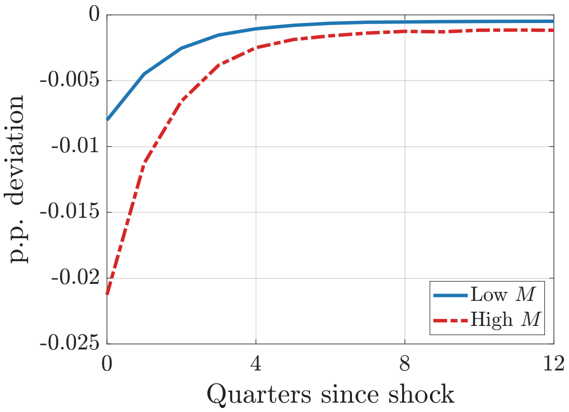
Note: The figure shows the average cash transfer (relative to pre-shock firm-level capital) paid in (4.4) after an unexpected one-standard deviation (30bp) increase in the nominal interest rate i for firms below (blue solid lines) and above (red dash-dotted lines) the median maturing bond share $\mathcal{M}$ at the time of the shock. See Figure 10 for the resulting differential investment response associated with $\mathcal{M}_{it}$.

Figure H.5: Model experiment on cash-flow effects of debt deflation - Differential investment response associated with $\mathcal{M}_{it}$



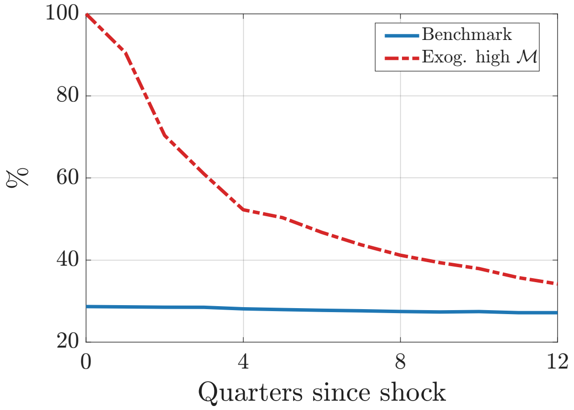
Note: The lines show estimated β_1^h coefficients based on equation (4.2) using simulated model data. The estimates are standardized to capture the differential cumulative capital growth response (in p.p.) to a one standard deviation (30bp) increase in the nominal interest rate i associated with a one standard deviation higher $\mathcal{M}_{it}$. The red dotted line shows the estimates in the benchmark model with nominal debt. The green dashed line shows the counterpart when all debt is real. The blue dash-dotted line shows the estimates when debt is real but firms are subject to the cash transfer T_{it}^{dd} in (H.3).

Figure H.6: Model experiment on cash-flow effects of debt deflation - Cash transfer T_{it}^{dd}



Note: The figure shows the average cash transfer T_{it}^{dd} in (H.3) (relative to pre-shock firm-level capital) after 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. See Figure H.5 for the resulting differential investment response associated with $\mathcal{M}_{it}$.

Figure H.7: 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 in Figure 11. 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.

H.4 Unconventional monetary policy and corporate debt maturity: Implementation

The effect of the UMP shock $\varepsilon_t^{\text{ump}}$ on the wedge η_t^{ump} between $\Lambda_{t,t+1}^S$ and $\Lambda_{t,t+1}^L$ in (4.5) can be implemented as an exogenous perturbation $\hat{\eta}_t^{\text{ump}}$ of the policy rule (D.16):

$$1 + \tilde{i}_t = \frac{1}{\beta} \pi_t^{\varphi^{\text{mp}}} e^{\hat{\eta}_t^{\text{ump}}}. \tag{H.4}$$

To show this, we re-write (D.17):

$$\tilde{i}_t = \frac{1+c}{\tilde{P}_{rt}^S} - 1 \quad \Leftrightarrow \quad \tilde{P}_{rt}^S = \frac{1+c}{1+\tilde{i}_t}. \tag{H.5}$$

Furthermore, we know from (D.17):

$$\tilde{P}_{rt}^S = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1}^L \frac{1+c}{\pi_{t+1}}. \tag{H.6}$$

Combining (H.5) and (H.6) yields a relation between the policy rate $\tilde{i}_t$ and $\Lambda_{t,t+1}^L$:

$$\frac{1+c}{1+\tilde{i}_t} = \mathbb{E}_{S_{t+1}|S_t} \Lambda_{t,t+1}^L \frac{1+c}{\pi_{t+1}} \quad \Leftrightarrow \quad \frac{1}{1+\tilde{i}_t} = \mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^L}{\pi_{t+1}}. \tag{H.7}$$

Applying (H.7) to the policy rule (H.4), we derive:

$$\mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^L}{\pi_{t+1}} = \frac{\beta}{\pi_t^{\varphi^{\text{mp}}} e^{\hat{\eta}_t^{\text{ump}}}}. \tag{H.8}$$

A perturbation $\hat{\eta}_t^{\text{ump}}$ of the policy rule therefore affects $\Lambda_{t,t+1}^L$. This is not the case for $\Lambda_{t,t+1}^S$, as follows from (D.15):

$$\left(\mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^S}{\pi_{t+1}} \right)^{-1} - 1 = \beta^{-1} - 1 \quad \Leftrightarrow \quad \mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^S}{\pi_{t+1}} = \beta. \tag{H.9}$$

Combining (H.8) and (H.9) yields:

$$\mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^L}{\pi_{t+1}} = \frac{1}{\pi_t^{\varphi^{\text{mp}}} e^{\hat{\eta}_t^{\text{ump}}}} \mathbb{E}_{S_{t+1}|S_t} \frac{\Lambda_{t,t+1}^S}{\pi_{t+1}}. \tag{H.10}$$

Finally, for any future state S_{t+1}, the wedge η_t^{ump} between $\Lambda_{t,t+1}^S$ and $\Lambda_{t,t+1}^L$ in (4.5) is:

$$\Lambda_{t,t+1}^L = (1 + \eta_t^{\text{ump}}) \Lambda_{t,t+1}^S \quad \Leftrightarrow \quad \frac{\Lambda_{t,t+1}^L}{\pi_{t+1}} = (1 + \eta_t^{\text{ump}}) \frac{\Lambda_{t,t+1}^S}{\pi_{t+1}}. \tag{H.11}$$

It follows that also in expectation it must hold:

$$\mathbb{E}_{S_{t+1}|S_t}\frac{\Lambda^L_{t,t+1}}{\pi_{t+1}} = \mathbb{E}_{S_{t+1}|S_t}(1+\eta^{\text{ump}}_t)\frac{\Lambda^S_{t,t+1}}{\pi_{t+1}} = (1+\eta^{\text{ump}}_t)\mathbb{E}_{S_{t+1}|S_t}\frac{\Lambda^S_{t,t+1}}{\pi_{t+1}}. \tag{H.12}$$

Combining (H.10) and (H.12) yields:

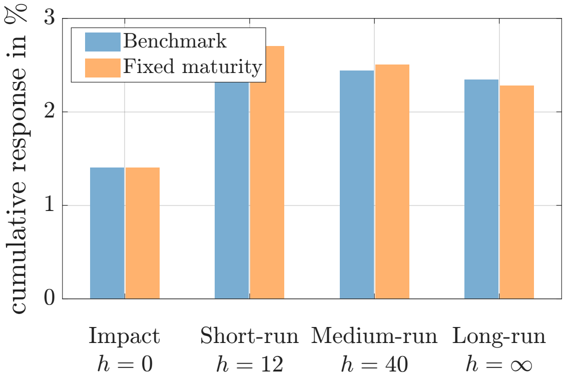
$$\frac{1}{\pi_t^{\varphi^{\text{mp}}} e^{\hat{\eta}^{\text{ump}}_t}} = 1+\eta^{\text{ump}}_t. \tag{H.13}$$

It follows that for any equilibrium dynamic triggered by a time path of the wedge η^{ump}_t in (4.5) we can find a time path of the exogenous perturbation $\hat{\eta}^{\text{ump}}_t$ of the policy rule (H.4) which generates an identical equilibrium allocation.

H.5 Unconventional monetary policy and corporate debt maturity: Additional results

The role of endogenous debt maturity for inflation. Analogously to Figure 14 (a) in the main text, Figure H.8 shows the cumulative inflation response to a UMP shock in the benchmark model with endogenous maturity (blue bars) and the alternative fixed-maturity model (orange bars). The cumulative effects of UMP on inflation are very similar with and without endogenous debt maturity.

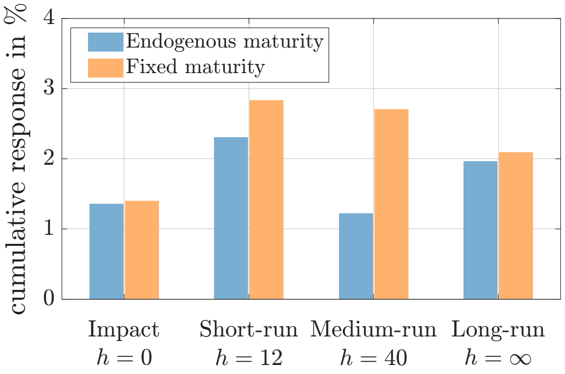
Figure H.8: The role of endogenous debt maturity for inflation



Note: The figure shows cumulative inflation responses following a UMP shock $\varepsilon^{\text{ump}}_t$ of identical size. Blue bars correspond to the benchmark economy with endogenous debt maturity. Orange bars correspond to the alternative fixed-maturity model.

Counterfactual calibration. Figure H.9 is the inflation counterpart to Figure 14 (b) in the main text. It uses the counterfactual calibration and shows the cumulative inflation response to a UMP shock with endogenous debt maturity (blue bars) and with fixed debt maturity (orange bars).

Figure H.9: The role of endogenous debt maturity for inflation under the counterfactual high-leverage calibration



Note: The figure shows cumulative inflation responses following an unconventional monetary policy shock. It uses the counterfactual calibration. Blue bars correspond to the benchmark model with endogenous debt maturity. Orange bars correspond to the alternative fixed-maturity model.

Appendix I Two-period Model

The four *Implications* presented in Section 3.8 highlight key model mechanisms which are important for understanding the quantitative results described in Section 4. This section presents a simplified two-period version of the firm problem used in the main part of the paper. In this simplified setup, we derive formal propositions about firms' trade-off with respect to debt maturity, and about their response to monetary policy. These results clarify the economic mechanisms at play and provide additional context for the four *Implications* in Section 3.8.

The main deviations from the fully dynamic model presented in Section 3 are: (1) There are only two periods: 0 and 1. (2) Capital is chosen in period 0 and used for production in period 1. (3) Short-term debt issuance in period 0 is exogenous. (4) There is no long-term debt issuance. (5) The recovery value of creditors in case of default is zero: $\xi = 1$. (6) There is no aggregate uncertainty.

Roadmap: Propositions 1 and 2 characterize the benefits of long-term debt: lower debt issuance costs and insurance against fluctuations in bond prices. Propositions 3 and 4 show the downside of long-term debt: debt overhang and its relation to default risk (*Implication 1*). The remainder addresses the firm's response to monetary policy: Proposition 5 characterizes the role of the maturing debt share for roll-over risk (*Implication 2*). Propositions 6 and 7 show that the effects of debt deflation depend on the firm's maturing debt share (*Implication 3*) and on default risk (*Implication 4*).

I.1 Two-period model: Setup

Period 0: The firm begins period 0 with an exogenous amount of cash-on-hand $\tilde{q}_0$ and an exogenous amount of outstanding nominal debt $B > 0$. The real debt burden at time 0 is $b = B/P_0$. An exogenous fraction $m \in [0, 1]$ of this debt is already due in period 0 (mb) while the remainder ($(1 - m)b$) will come due in period 1. Accordingly, the parameter m denotes the firm's maturing debt share. A high m means that b mostly consists of debt with short remaining maturity; a low m means that most of b has long remaining maturity. Note that $\tilde{q}_0$ measures cash-on-hand before debt payments in period 0. After debt payments in period 0, cash-on-hand is $q_0 = \tilde{q}_0 - mb$.

The only firm choice in period 0 is how much capital k_1 to purchase for production in period 1. The market value of capital is given by the cash flow constraint

$$Q_0 k_1 = q_0 + b^S p^S + e = \tilde{q}_0 - mb + b^S p^S + e, \tag{I.1}$$

where Q_0 is the price of capital goods, $b^S \equiv B^S/P_0$ is the (exogenous) amount of short-term debt issued in period 0, p^S is the firm's short-term bond price, and e denotes equity issuance. We assume that short-term debt issuance b^S satisfies:

$$\frac{b^S}{\pi_1} = mb, \tag{I.2}$$

where $\pi_1 \equiv P_1/P_0$ is (gross) inflation between period 1 and period 0. This means that the real amount of newly issued short-term debt due in period 1, $B^S/P_1 = b^S/\pi_1$, equals the real amount due in period 0, mb. This is a natural assumption if inflation π_1 is known at time 0 and the firm wants to raise enough funds on the bond market to repay mb. Because b^S is exogenous, the marginal financing source of capital is equity. As in Section 3, equity issuance costs are given by

$$G(e) = \nu \left(\max\{e, 0\}\right)^2 . \tag{I.3}$$

Debt issuance costs are:

$$H\left(b^S\right) = \eta \left(b^S\right)^2 . \tag{I.4}$$

The equilibrium price of short-term debt depends on the firm's default risk:

$$p^S = \Lambda \int_{\varepsilon} (1 - \mathcal{D}) \frac{1+c}{\pi_1} \varphi(\varepsilon) d\varepsilon, \tag{I.5}$$

where the indicator function $\mathcal{D}$ is one if and only if the firm defaults in period 1. Λ is an exogenous discount factor.

Period 1: Earnings in period 1 before interest and taxes are

$$Ak_1^{\alpha} - Q_1 \delta k_1 + Q_1 \varepsilon k_1 - f, \tag{I.6}$$

where A is productivity, $\alpha \in (0, 1)$, Q_1 is the price of capital goods in period 1, δ is the depreciation rate, and f is a fixed cost of production. The firm-specific capital quality shock ε is realized in period 1 and is i.i.d. Normal with mean zero and probability density $\varphi(\varepsilon)$. In period 1, the firm owes a real amount b^S/π_1 of short-term debt issued in period 0 and a real amount $(1 - m)b/\pi_1$ of debt issued before period 0. After production, taxation, and payment of debt obligations, cash-on-hand in period 1 is therefore:

$$q_1 = Q_1 k_1 - \frac{b^S}{\pi_1} - \frac{(1-m)b}{\pi_1} + (1-\tau)\left[Ak_1^{\alpha} + (\varepsilon - \delta)Q_1 k_1 - f - \frac{c(b^S + (1-m)b)}{\pi_1}\right]. \tag{I.7}$$

I.2 Two-period model: Firm problem and choices

Period 1: Default decision. After the realization of ε in period 1, firm owners decide whether to default. Default is optimal for firm owners if and only if $q_1 < 0$. From (I.7) we derive the following default threshold $\bar{\varepsilon}$:

$$\bar{\varepsilon} = -\frac{Q_1 k_1 - mb - \frac{(1-m)b}{\pi_1} + (1-\tau)\left[Ak_1^{\alpha} - \delta Q_1 k_1 - f - cmb - \frac{c(1-m)b}{\pi_1}\right]}{(1-\tau)Q_1 k_1}, \tag{I.8}$$

where we have used (I.2) to substitute out b^S/π_1. The firm defaults in period 1 if and only if $\varepsilon < \bar{\varepsilon}$. This default threshold $\bar{\varepsilon}$ depends on the firm's choice of capital k_1:

$$\frac{\partial \bar{\varepsilon}}{\partial k_1} = \frac{(1-\alpha)A}{Q_1 k_1^{2-\alpha}} - \frac{mb[1 + (1-\tau)c] + \frac{(1-m)b}{\pi_1}[1 + (1-\tau)c] + (1-\tau)f}{(1-\tau)Q_1 k_1^2}. \tag{I.9}$$

This derivative can be positive or negative. However, the second term on the right-hand side of (I.9) is always negative. It captures the fact that an increase in capital financed through equity reduces firm leverage and thereby reduces the default threshold $\bar{\varepsilon}$. If α is sufficiently close to unity and firm debt b and the fixed cost f are sufficiently large, the second term on the right-hand side of (I.9) dominates and an increase in capital k_1 reduces the firm's default risk. In the following, we assume this to be the case.[43]

Assumption 1. The default threshold $\bar{\varepsilon}$ is decreasing in capital k_1:

$$\frac{\partial \bar{\varepsilon}}{\partial k_1} < 0 \tag{I.10}$$

Period 0: Capital choice. In period 0, the firm solves:

$$W(\tilde{q}_0, b, m) = \max_{k_1, \bar{\varepsilon}, e} -e - G(e) - H\left(mb\pi_1\right) + \Lambda \int_{\bar{\varepsilon}}^{\infty} q_1 \, d\varphi(\varepsilon) \tag{I.11}$$

subject to:

$$e = Q_0 k_1 - \tilde{q}_0 + mb - mb\pi_1 p^S \tag{I.12}$$

$$q_1 = Q_1 k_1 - mb - \frac{(1-m)b}{\pi_1} + (1-\tau)\left[Ak_1^{\alpha} + (\varepsilon - \delta)Q_1 k_1 - f - cmb - \frac{c(1-m)b}{\pi_1}\right] \tag{I.13}$$

$$\bar{\varepsilon} = -\frac{Q_1 k_1 - mb - \frac{(1-m)b}{\pi_1} + (1-\tau)\left[Ak_1^{\alpha} - \delta Q_1 k_1 - f - cmb - \frac{c(1-m)b}{\pi_1}\right]}{(1-\tau)Q_1 k_1} \tag{I.14}$$

$$p^S = \Lambda[1 - \Phi(\bar{\varepsilon})]\frac{1+c}{\pi_1} \tag{I.15}$$

Accordingly, the first-order condition with respect to k_1 is:

$$\begin{aligned} &-[1 + G'(e)]\left[Q_0 - mb\pi_1\left[\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]\right] \\ &\qquad + \Lambda \int_{\bar{\varepsilon}}^{\infty}\left[Q_1 + (1-\tau)\left[A\alpha k_1^{\alpha-1} + (\varepsilon - \delta)Q_1\right]\right] d\varphi(\varepsilon) = 0 \end{aligned} \tag{I.16}$$

This first-order condition is very similar to its counterpart (3.24) from the fully dynamic firm problem. A marginal increase in capital k_1 requires higher equity issuance e (or lower dividend payout if $e < 0$). The marginal cost of capital therefore depends on the price of capital Q_0 and the marginal equity issuance cost $G'(e)$. The marginal benefit of capital consists of two parts. The first one is direct. If the firm does not default in period 1 ($\varepsilon \geq \bar{\varepsilon}$), capital increases production which raises future cash-on-hand q_1 (second line of (I.16)). The second benefit is indirect. An increase in capital reduces default risk ($\partial \bar{\varepsilon}/\partial k_1 < 0$ in the first

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[43] Assumption 1 rules out the special case that the positive first term on the right-hand-side of (I.9) dominates. It captures the fact that the riskless component of cash-on-hand (I.7) increases in k_1 with diminishing returns (because $\alpha < 1$), whereas the risky component increases with constant returns (because the capital quality shock ε scales linearly with k_1). Through this channel, an increase in k_1 can, in principle, increase default risk (even if it is financed through equity).

line of (I.16), see Assumption 1) which increases the bond price p^S. In the following, we will refer to the left-hand side of (I.16) as the marginal *net* benefit of capital.

I.3 Two-period model: Debt maturity

We now study the effect of exogenous changes in the maturing debt share m on shareholder value. We consider an economy in which aggregate variables are in steady state, e.g., $\pi_1 = 1$, and conduct comparative statics in the neighborhood of a fixed firm state $(\tilde{q}_0^*, b^*, m^*)$. Let $\bar{\varepsilon}^* = f(\tilde{q}_0^*, b^*, m^*)$ be the firm's default threshold implied by its equilibrium choice of k_1 in the firm problem (I.11). We make the following assumption about the relation between $\bar{\varepsilon}^*$ and the debt coupon c:

Assumption 2. The exogenous and fixed debt coupon c satisfies:

$$\Lambda[1 - \Phi(\bar{\varepsilon}^*)](1 + c) = 1 \tag{I.17}$$

This assumption implies that the debt coupon c is just high enough to compensate for the degree of impatience embedded in the discount factor Λ as well as for the equilibrium value of default risk. It also implies that the equilibrium bond price p^S is high enough that the amount $b^S p^S$ raised on the bond market in period 0 is exactly equal to the amount required to service the maturing debt mb:

$$b^S p^S = mb\pi_1 p^S = mb\pi_1 \Lambda[1 - \Phi(\bar{\varepsilon}^*)]\frac{1 + c}{\pi_1} = mb\Lambda[1 - \Phi(\bar{\varepsilon}^*)](1 + c) = mb. \tag{I.18}$$

As long as $\bar{\varepsilon} = \bar{\varepsilon}^*$, a small variation in the firm's maturing debt share m therefore has no direct impact on its cash flow in period 0.

Benefits of long-term debt: Debt issuance costs and insurance. There are two benefits of having a small maturing debt share m in this model. The first is that debt roll-over in period 0 is low which saves debt issuance costs. This effect is captured by the following proposition.

Proposition 1. *Under Assumption 2 and for a given capital level k_1, a marginal increase in the maturing debt share m around the firm state $(\tilde{q}_0^*, b^*, m^*)$ reduces shareholder value $W(\tilde{q}_0^*, b^*, m)$ by increasing debt issuance costs.*

The proof is deferred to Appendix I.5.1 below. The second benefit of a small maturing debt share m is that it provides insurance against fluctuations in the bond price p^S. In order to characterize this insurance benefit of long-term debt, we assume that initial cash-on-hand $\tilde{q}_0$ is a random variable which can take on high and low values (in the neighborhood of $\tilde{q}_0^*$). A first auxiliary result is that exogenous fluctuations in $\tilde{q}_0$ are costly because of equity issuance costs.

Lemma 1. *Under Assumption 1, fluctuations in cash-on-hand $\tilde{q}_0$ reduce expected shareholder value $\mathbb{E}_{\tilde{q}_0} W(\tilde{q}_0, b^*, m^*)$ because shareholder value $W(\tilde{q}_0, b^*, m^*)$ is concave in cash-on-hand $\tilde{q}_0$: It is strictly concave for equity-issuing firms (with low values of $\tilde{q}_0^*$ and with $e > 0$) and linear for dividend payers (with high values of $\tilde{q}_0^*$ and with $e < 0$).*

See Appendix I.5.4 for the proof. Equity issuance costs effectively render the firm risk averse even if firm owners are perfectly risk-neutral with respect to firm-level outcomes (Cooley and Quadrini, 2001).

We now identify the insurance benefit of having a small maturing debt share m. Because fluctuations in cash-on-hand $\tilde{q}_0$ translate into fluctuations in the bond price p^S, the firm is more exposed to these fluctuations if it has a high maturing debt share and high debt roll-over in period 0. As shown below in Appendix I.5.5, a sufficient condition for this result is that the firm's bond price p^S is concave in capital k_1. Assumption 1 and the following Assumption 3 together imply this concavity.

Assumption 3. Given the firm state $(\tilde{q}_0^*, b^*, m^*)$ and the corresponding default threshold $\bar{\varepsilon}^*$, the probability density $\varphi(\bar{\varepsilon}^*)$ is increasing in $\bar{\varepsilon}^*$:

$$\varphi'(\bar{\varepsilon}^*) > 0 \tag{I.19}$$

Note that this assumption is very mild. Since ε follows a Normal distribution, its density is increasing as long as default risk is less than 1/2 per period (a mild constraint given empirical default probabilities).

Proposition 2. *Under Assumptions 1, 2, and 3, a higher maturing debt share m increases the concavity of shareholder value $W(\tilde{q}_0, b^*, m^*)$ in cash-on-hand $\tilde{q}_0$ for equity-issuing firms and thereby amplifies the costs of fluctuations in $\tilde{q}_0$.*

The proof is deferred to Appendix I.5.5. The intuition is as follows. Low realizations of $\tilde{q}_0$ increase equity issuance. This increases the marginal equity issuance cost and thereby drives up the marginal cost of capital. This reduces the firm's capital choice and increases default risk (see Assumption 1). But increased default risk lowers the bond price p^S and bond market revenue, making cash even scarcer for the firm and requiring even higher equity issuance. The pass-through of these fluctuations in the bond price p^S to firm cash flow crucially depends on the maturing debt share. A higher maturing debt share m increases debt roll-over and thereby amplifies the pass-through of fluctuations in p^S to firm cash flow. This increases the overall costs of fluctuations in $\tilde{q}_0$. Long-term debt reduces the maturing debt share m and thereby provides insurance against fluctuations in cash-on-hand $\tilde{q}_0$ and the bond price p^S.

Cost of long-term debt: Debt overhang. While Proposition 1 and Proposition 2 characterize the downsides of a high maturing debt share m, an increase in m has the benefit of reducing debt overhang and increasing investment.

Proposition 3. *Under Assumptions 1 and 2, a marginal increase in the maturing debt share m around the firm state $(\tilde{q}_0^*, b^*, m^*)$ increases the optimal capital choice k_1.*

See Appendix I.5.6 for the proof. The intuition is as follows. Part of the benefit of increasing capital is that default risk is reduced which increases the bond price p^S. If the firm's maturing debt share m is larger, the amount of debt roll-over in period 0 is higher which amplifies the firm's benefit of an increased bond price. As a consequence, the optimal capital choice k_1 increases in m. On the other hand, a firm with a lot of long-term debt has a low maturing debt share and little roll-over. For this firm, most of the benefit of the increase in the bond price is captured by the owners of outstanding long-term debt. The lower the maturing debt share m, the higher the share of the investment benefits captured by the owners of outstanding long-term debt and the smaller the marginal benefit of capital that remains for shareholders. In this way, long-term debt increases debt overhang and weakens investment incentives (Myers, 1977).

Through debt overhang, a lower maturing debt share m reduces the firm's capital choice k_1 and increases default risk. However, the effect of debt overhang on shareholder value is not fully captured by the two-period model considered here. In a fully dynamic model with long-term debt issuance (like the one presented in Section 3), creditors anticipate that a firm that sells additional long-term debt today will suffer from increased debt overhang in the future (i.e., lower capital and higher default risk). Accordingly, creditors are only willing to buy the firm's long-term debt at a reduced bond price. It is through the reduced long-term bond price that debt overhang reduces shareholder value. This effect is absent in this two-period model without long-term debt issuance.

Debt overhang and default risk. We conclude this analysis of exogenous changes in debt maturity by highlighting the interplay between default risk and debt overhang. This discussion provides context for *Implication 1* in Section 3.8.

By increasing debt roll-over, a higher maturing debt share mitigates debt overhang and thereby strengthens the firm's investment incentives. Importantly, debt overhang has a stronger effect on investment when default risk is high. Since an increase in firm productivity lowers default risk, it dampens the effect of debt overhang on investment and thereby weakens the positive effect of the maturing debt share on capital. The following proposition formalizes this result.

Proposition 4. *Under Assumptions 1, 2, and 3, the positive effect of an increase in the maturing debt share m around the state $(\tilde{q}_0^*, b^*, m^*)$ on the firm's marginal net benefit of capital in (I.16) is decreasing in firm productivity A, because higher productivity lowers default risk.*

The proof is deferred to Appendix I.5.7. For a firm with low default risk, default is a tail event. An increase in capital therefore affects the firm's default decision only in low-probability states. As a result, the firm's bond price p^S does not respond by much to changes in capital. Accordingly, variations in debt roll-over matter little for the firm's investment incentives. By contrast, when default risk is high, capital influences default in states with substantial probability mass. This means that the bond price p^S is highly sensitive to capital. Variations in debt roll-over strongly affect the firm's investment incentives in this case because debt overhang is strong. Firms with low productivity A have high default risk and their bond price p^S is highly sensitive to their capital choice. Increasing debt maturity and reducing debt roll-over therefore substantially increases debt overhang and weakens their investment incentives.

Because firms do not issue long-term debt in this two-period model, debt overhang does not reduce shareholder value even though it distorts the firm's capital choice. This is different in the fully dynamic model with long-term debt issuance studied in the main part of the paper. If debt overhang is severe and the firm's capital choice therefore highly responsive to the amount of outstanding long-term debt (e.g., because default risk is high), the firm can sell additional long-term debt only at a low bond price. Higher default risk therefore generates a larger cost of long-term debt. This underlies *Implication 1* in the main text of the paper.

I.4 Two-period model: Debt maturity and the investment response to monetary policy

So far, we have studied the impact of exogenous changes in the firm's maturing debt share on shareholder value and on its capital choice. In the following, we investigate the effects of changes in monetary policy. In particular, we study exogenous variations of the real interest rate r and inflation π_1. We will show that the firm's capital response to these changes depends on its maturing debt share. This provides context for *Implications* 2-4 in Section 3.8.

Roll-over risk. The first result on monetary policy relates to *Implication* 2 in the main part of the paper. If monetary policy changes the real interest rate r, this affects the valuation of future cash flows as captured by the discount factor Λ:

$$\frac{1}{1+r} = \Lambda \tag{I.20}$$

A lower real interest rate raises the discount factor Λ and the firm's bond price p^S. This increases the firm's optimal capital choice. A larger share of maturing debt m increases the firm's exposure to changes in the bond price p^S. This amplifies the transmission of changes in the real rate to the firm's capital choice. As discussed below, the only exception can arise for an equity-issuing firm if the equity issuance cost parameter ν is high and the amount of debt roll-over substantially exceeds equity issuance. The following assumption rules out this special case.

Assumption 4. We assume:

$$2\nu(m^*b - e)\mathbb{1}_{e>0} < 1 \tag{I.21}$$

Proposition 5. *Under Assumptions 1, 2, and 4, an increase in the maturing debt share m amplifies the effect of the real interest rate r on the firm's marginal net benefit of capital in* (I.16) *by increasing the firm's sensitivity to changes in its bond price p^S.*

See Appendix I.5.8 for the proof. The intuition for this result is straightforward. First, a reduction in the real rate r implies an increase in the discount factor Λ which raises the bond price p^S and lowers the firm's need for equity issuance. This lowers the marginal equity issuance cost and thereby the marginal cost of capital of an equity-issuing firm. Through this cash-flow channel, a higher bond price increases investment. Second, the indirect benefit of capital in (I.16) is that it reduces default risk. This increases expected future payments to creditors and raises the bond price p^S. If creditors' discount factor increases, their valuation of future payments rises. As a result, a given reduction in default risk raises the bond price by more. This amplifies the indirect benefit of capital in (I.16). Importantly, both effects are stronger for firms with a larger share of maturing debt as they roll over more debt at the increased bond price p^S. This underlies *Implication 2* provided in the main text. Long-term debt insulates firms against this roll-over risk by reducing the maturing debt share.[44]

Debt deflation. Contractionary monetary policy lowers inflation and thereby increases the real burden of outstanding nominal debt and raises default risk. By strengthening debt overhang, this can depress investment and thereby amplify firms' response to monetary policy.

The first result on this debt deflation mechanism relates to *Implication 3* in the main text. A higher maturing debt share reduces firms' exposure to debt deflation. This can dampen the effect of inflation on firms' capital response. As discussed below, exceptions may arise when the maturing debt share is very high or, for equity-issuers, if the equity issuance cost parameter ν is large relative to the marginal cost of equity issuance $2\nu e$. The following assumption rules out these special cases.

Assumption 5. We assume

$$m^* < \frac{1}{2} \quad \text{and} \quad \frac{2\nu}{1+2\nu e}\mathbb{1}_{e>0} \to 0 \tag{I.23}$$

Proposition 6. *Under Assumptions 1, 2, 3, and 5, an increase in the maturing debt share m reduces the effect of inflation π_1 on the firm's marginal net benefit of capital in* (I.16) *by reducing the firm's exposure to debt deflation.*

The proof is deferred to Appendix I.5.9. Inflation π_1 (which, in this two-period model, is fully anticipated in period 0) changes the real debt burden only for debt issued *before* period 0. The nominal amount of debt newly issued in period 0 is adjusted in proportion to the change in π_1, leaving the real debt burden of newly issued debt unchanged. A larger share of maturing debt increases debt roll-over in period 0 and thereby reduces the share of period-1 debt whose real value is affected by inflation π_1. This reduces the firm's exposure

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[44] Assumption 4 rules out a special case in which Proposition 5 does not necessarily hold. As discussed above, two effects of Λ are important here: (1.) The cash-flow channel, that is, the negative impact of Λ on e. This channel becomes stronger when debt roll-over is higher, because the increase in p^S applies to a greater amount of newly issued debt. (2.) The amplification of the indirect benefit of capital through its positive effect on p^S. This channel reduces the net equity requirement NER of an additional unit of capital:

$$NER \equiv Q_0 + mb\pi_1\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}. \tag{I.22}$$

Since $\partial\bar{\varepsilon}/\partial k_1 < 0$ (Assumption 1), an increase in Λ lowers the NER. This second channel has a larger positive effect on the marginal benefit of capital if the marginal cost of equity issuance $2\nu e$ is high. Intuitively, if issuing equity is costly, any reduction in the NER becomes more valuable.

An increase in the maturing debt share m strengthens the second channel (by further reducing the NER), but this may simultaneously weaken the impact of the first channel (reduction of e). When the NER falls, each additional unit of capital requires less equity issuance, making the cash-flow channel of Λ less relevant for the marginal net benefit of capital. Therefore, if the first channel is initially strong (that is, debt roll-over is sufficiently high) while the second channel is initially weak (that is, marginal equity issuance costs are sufficiently low), then increasing the maturing debt share m can, in principle, reduce the overall positive effect of Λ on the marginal benefit of capital.

to debt deflation. Conversely, a smaller share of maturing debt increases the share of debt whose real value is affected by π_1, amplifying the impact of inflation on the firm's marginal net benefit of capital. This mechanism underlies *Implication 3* in the main text.[45,46]

The final result of this analysis relates to *Implication 4* in the main text. A higher default risk not only increases the probability of future states in which the firm prefers to default on its debt. It also increases the probability of states in which the firm is indifferent between defaulting and repaying. A given increase in inflation is therefore more likely to change the firm's default decision and the marginal net benefit of capital if the firm's default risk is higher. Since firm productivity lowers default risk, it can dampen the role of debt deflation for firm investment. As discussed below, the only exception can arise if the share of maturing debt is very high. The following assumption is sufficient to rule out this special case.

Assumption 6. We assume that $m^* \to 0$.

Proposition 7. *Under Assumptions 1, 3, and 6, an increase in firm productivity A reduces the effect of inflation π_1 on the firm's marginal net benefit of capital in* (I.16) *by reducing the firm's default risk and debt overhang.*

See Appendix I.5.10 for the proof. Proposition 7 clarifies how low productivity can make firms more responsive to changes in inflation. Default risk is higher for low-productivity firms and more responsive to changes in inflation π_1. A given increase in inflation reduces default risk by more for these firms. As a result, debt overhang declines more strongly, which explains the larger positive response of capital. This mechanism underlies *Implication 4* presented in the main text of the paper.[47]

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[45] In this two-period model, there is no aggregate uncertainty. As a result, nominal debt issuance at time 0 can adjust in response to period-1 inflation π_1. This differs from the fully dynamic model with aggregate shocks studied in the main part of the paper, where debt issued at time $t-1$ cannot respond to a surprise change in inflation π_t. However, even with aggregate shocks, nominal debt issuance at time t can (and will) adjust in response to the contemporaneous inflation surprise π_t. By contrast, outstanding nominal long-term debt issued prior to period t cannot adjust to π_t and is therefore subject to debt deflation effects. Higher debt roll-over therefore reduces firms' exposure to debt deflation, even in the fully dynamic setting.

[46] Assumption 5 is sufficient, but not necessary, for a dampening role of the maturing debt share for debt deflation. Even if the assumption does not hold, a higher m may still reduce the sensitivity of capital to inflation π_1. Two effects of π_1 are important here: (1.) By lowering default risk and increasing the bond price p^S, higher inflation reduces costly equity issuance e. Since a larger m implies more debt is rolled over at the higher bond price p^S, this positive cash-flow effect of π_1 becomes stronger as m increases. If capital is highly responsive to cash flow (i.e., if the equity issuance cost parameter ν is large while the marginal equity issuance cost $2\nu e$ is not), this cash-flow channel of inflation can, in principle, overturn the dampening role of m. (2.) Higher inflation π_1 reduces default risk and thereby makes the bond price p^S less responsive to capital k_1. This weakens the indirect benefit of capital in (I.16). By reducing exposure to debt deflation, a higher m dampens this negative effect of inflation on the marginal net benefit of capital. If m^* is sufficiently large (i.e., $m^* > 1/2$), this can likewise overturn the dampening role of m for debt deflation.

[47] Assumption 6 is sufficient, but not necessary, for firm productivity A to dampen the effect of debt deflation. Even when $m^* > 0$, higher productivity may still reduce the sensitivity of capital to inflation. Two forces can overturn this result when the maturing debt share is sufficiently large. (1.) Higher firm productivity A lowers default risk. This lowers the responsiveness of the bond price p^S to k_1 and thereby increases the NER in (I.22), especially if m^* is high. In this way, a higher A can, in principle, amplify the cash-flow effect of inflation on the marginal benefit of capital. (2.) By lowering the responsiveness of p^S to k_1, a higher A reduces the indirect benefit of capital in (I.16), especially if m^* is high. This means that the negative effect of inflation on the indirect benefit of capital becomes less important.

I.5 Two-period model: Proofs and derivations

I.5.1 Proof of Proposition 1

Proof. For a given level of k_1, shareholder value (I.11) is affected by the increase in m through changes in debt issuance costs $H(\cdot)$, as well as through potential changes in q_1, $\bar{\varepsilon}$, and e. Consider the first channel: a higher m increases exogenous debt roll-over in period 0 and thereby increases debt issuance costs. This reduces shareholder value. The remaining three channels are all zero: For a given level of k_1, future cash-on-hand q_1 is independent of m because $\pi_1 = 1$ and therefore:

$$mb + \frac{(1-m)b}{\pi_1} = b \tag{I.24}$$

Also the default threshold $\bar{\varepsilon}$ is independent of m since future cash-on-hand q_1 is independent of m for any given realization of ε. Finally, because of Assumption 2 (that is, $\Lambda[1-\Phi(\bar{\varepsilon}^*)](1+c) = 1$), we have $p^S = 1/\pi_1$ and equity issuance $e = Q_0 k_1 - \tilde{q}_0$ is independent of m. It follows:

$$\frac{\partial W(\tilde{q}_0^*, b^*, m)}{\partial m} = -\frac{\partial H(mb\pi_1)}{\partial m} = -2\eta m \left(b\pi_1\right)^2 \tag{I.25}$$

The derivative is strictly negative for any $m > 0$. □

I.5.2 Lemma 2: The effect of cash-on-hand on capital

Lemma 2. *Under Assumption 1, optimal capital k_1 depends on cash-on-hand $\tilde{q}_0$ as follows: For an equity-issuing firm ($e > 0$), k_1 is increasing in $\tilde{q}_0$. For a dividend payer ($e < 0$), k_1 does not depend on $\tilde{q}_0$.*

Proof. Consider the firm's first-order condition with respect to k_1 in (I.16). For a dividend payer ($e < 0$), the marginal equity issuance cost $G'(e)$ is zero. The value of $\tilde{q}_0$ does therefore not enter (I.16). It follows that k_1 is independent of cash-on-hand $\tilde{q}_0$ for dividend payers (with $e < 0$).

Now consider an equity-issuing firm ($e > 0$). For a given value of k_1, an increase in cash-on-hand $\tilde{q}_0$ reduces e and affects the marginal net benefit of capital, given by the left hand-side of (I.16), according to:

$$G''(e)\left[Q_0 - mb\pi_1\left[\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]\right] \tag{I.26}$$

Because equity issuance costs are convex ($G''(e) = 2\nu > 0$), the increase in $\tilde{q}_0$ raises the marginal net benefit of capital if and only if the term in the outer squared brackets in (I.26) is positive. We can characterize the sign of (I.26) by considering the firm's objective in (I.11). For shareholder value (I.11) to be positive for an equity-issuing firm (with $e > 0$), it must be that the expected value of future cash-on-hand (after production, taxation, and payment of debt obligations) is positive:

$$\int_{\bar{\varepsilon}}^{\infty} q_1 \, d\varphi(\varepsilon) > 0 \tag{I.27}$$

It follows:

$$\int_{\bar{\varepsilon}}^{\infty}\left[Q_1 k_1 - mb - \frac{(1-m)b}{\pi_1} + (1-\tau)\left[Ak_1^{\alpha} + (\varepsilon-\delta)Q_1 k_1 - f - cmb - \frac{c(1-m)b}{\pi_1}\right]\right] d\varphi(\varepsilon) > 0 \tag{I.28}$$

Assumption 1 implies:

$$\frac{\partial\bar{\varepsilon}}{\partial k_1} < 0 \quad \Leftrightarrow \quad \frac{(1-\alpha)A}{Q_1 k_1^{2-\alpha}} < \frac{mb[1+(1-\tau)c] + \frac{(1-m)b}{\pi_1}[1+(1-\tau)c] + (1-\tau)f}{(1-\tau)Q_1 k_1^2} \tag{I.29}$$

Multiplying this inequality by $(1-\tau)Q_1 k_1^2$ yields:

$$(1-\tau)(1-\alpha)Ak^{\alpha} < mb[1+(1-\tau)c] + \frac{(1-m)b}{\pi_1}[1+(1-\tau)c] + (1-\tau)f \tag{I.30}$$

It follows:

$$(1-\tau)Ak^{\alpha} < (1-\tau)\alpha Ak^{\alpha} + mb[1+(1-\tau)c] + \frac{(1-m)b}{\pi_1}[1+(1-\tau)c] + (1-\tau)f \tag{I.31}$$

We use this expression to substitute out the term $(1-\tau)Ak_1^{\alpha}$ in (I.28). Because of (I.31), it follows:

$$\int_{\bar{\varepsilon}}^{\infty}\left[Q_1 k_1 + (1-\tau)\left[A\alpha k_1^{\alpha} + (\varepsilon-\delta)Q_1 k_1\right]\right] d\varphi(\varepsilon) > 0 \tag{I.32}$$

Dividing by k_1 yields:

$$\int_{\bar{\varepsilon}}^{\infty}\left[Q_1 + (1-\tau)\left[A\alpha k_1^{\alpha-1} + (\varepsilon-\delta)Q_1\right]\right] d\varphi(\varepsilon) > 0 \tag{I.33}$$

This term enters the first-order condition (I.16). Since it is positive, it follows that (I.16) can only hold if the term in the outer squared brackets in (I.26) is positive as well:

$$Q_0 - mb\pi_1\left[\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right] > 0 \tag{I.34}$$

The marginal cost of buying one additional unit of capital Q_0 outweighs the marginal increase in bond market revenue due to the fall in $\bar{\varepsilon}$ (and the resulting increase in p^S). Otherwise the optimal capital choice would not have an interior solution. It follows that a marginal increase in k_1 requires an increase in equity issuance e. In turn, this means that the reduction in the marginal cost of equity issuance $G'(e)$ caused by an increase in $\tilde{q}_0$ reduces the marginal cost of capital. For the first-order condition (I.16) to continue to hold after the increase in $\tilde{q}_0$, the optimal choice of k_1 must increase. □

I.5.3 Lemma 3: The positive effect of cash-on-hand on capital is bounded

Lemma 3. *Under Assumption 1, the increase in optimal capital k_1 of an equity-issuing firm ($e > 0$) in response to a marginal increase in cash-on-hand $\tilde{q}_0$ is bounded above:*

$$\frac{\partial k_1}{\partial\tilde{q}_0} < \frac{1}{Q_0 - b^S\frac{\partial p^S}{\partial k_1}} = \frac{1}{Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)}$$

Proof. The increase in $\tilde{q}_0$ slackens the firm's cash flow constraint (I.1). If, in response to that, k_1 increases, every additional unit of capital requires Q_0 units of cash. But higher k_1 also generates additional cash by reducing default risk and increasing the bond price p^S. Consider the limit given in Lemma 3. If $\partial k_1/\partial \tilde{q}_0$ was equal to this limit, e would stay constant after the increase in $\tilde{q}_0$. Now consider the first-order condition (I.16). Assume that it holds for given values $\tilde{q}_0^O$, e^O, and k_1^O. Given a higher value of cash-on-hand $\tilde{q}_0^N > \tilde{q}_0^O$, capital increases for an equity-issuing firm: $k_1^N > k_1^O$ (see Lemma 2). Given an interior solution, the firm objective is strictly concave in k_1 which means that the marginal net benefit of capital is decreasing in k_1. With $e = e^O$ constant but $k_1^N > k_1^O$, the first-order condition (I.16) cannot continue to hold, because the marginal net benefit of capital must be strictly negative now. The only way that (I.16) can continue to hold for $\tilde{q}_0^N > \tilde{q}_0^O$ and $k_1^N > k_1^O$ is that equity issuance decreases: $e^N < e^O$. This limits by how much k_1 can rise in response to an increase in $\tilde{q}_0$. □

I.5.4 Proof of Lemma 1

Proof. Consider an increase in $\tilde{q}_0$. For dividend payers (with high values of $\tilde{q}_0^*$ and with $e < 0$), this increases the dividend in period 0 and shareholder value one-for-one:

$$e < 0: \quad \frac{\partial W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0} = 1 \tag{I.35}$$

For equity-issuing firms (with low values of $\tilde{q}_0^*$ and with $e > 0$), this reduces both equity issuance e and the equity issuance cost $G(e)$:

$$e > 0: \quad \frac{\partial W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0} = 1 + G'(e) + \frac{\partial W(\tilde{q}_0, b, m)}{\partial k_1}\frac{\partial k_1}{\partial \tilde{q}_0} = 1 + G'(e), \tag{I.36}$$

where the last equality follows from optimality of k_1: $\partial W(\tilde{q}_0, b, m)/\partial k_1 = 0$. Because $G'(e) > 0$, the gain in shareholder value after the increase in cash-on-hand $\tilde{q}_0$ is larger for equity-issuing firms. Furthermore:

$$e > 0: \quad \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2} = -G''(e) + \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial k_1 \partial \tilde{q}_0}\frac{\partial k_1}{\partial \tilde{q}_0} + \frac{\partial W(\tilde{q}_0, b, m)}{\partial k_1}\frac{\partial^2 k_1}{\partial \tilde{q}_0^2} \tag{I.37}$$

Again, it follows from optimality of k_1:

$$e > 0: \quad \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2} = -G''(e) + \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial k_1 \partial \tilde{q}_0}\frac{\partial k_1}{\partial \tilde{q}_0} \tag{I.38}$$

Using (I.26), we can write:

$$e > 0: \quad \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2} = -G''(e) + G''(e)\left[Q_0 - mb\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]\frac{\partial k_1}{\partial \tilde{q}_0} \tag{I.39}$$

It follows:

$$e > 0: \quad \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2} = G''(e)\left[-1 + \left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]\frac{\partial k_1}{\partial \tilde{q}_0}\right] \tag{I.40}$$

We know from Lemma 3:

$$\frac{\partial k_1}{\partial \tilde{q}_0} < \frac{1}{Q_0 - b^S \frac{\partial p^S}{\partial k_1}} = \frac{1}{Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)} \tag{I.41}$$

It follows:

$$\frac{\partial k_1}{\partial \tilde{q}_0}\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right] < 1 \tag{I.42}$$

We conclude for (I.40):

$$e > 0: \quad \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2} < 0 \tag{I.43}$$

Shareholder value $W(\tilde{q}_0, b, m)$ is concave in $\tilde{q}_0$: strictly concave for equity-issuing firms and linear for dividend payers. From Jensen's inequality it follows that expected shareholder value $\mathbb{E}_{\tilde{q}_0} W(\tilde{q}_0, b, m)$ is decreasing after any mean-preserving spread in the probability distribution of $\tilde{q}_0$: the effect is strictly negative for equity-issuing firms and zero for dividend payers. □

I.5.5 Proof of Proposition 2

Proof. Fluctuations in $\tilde{q}_0$ are costly for equity-issuing firms because shareholder value $W(\tilde{q}_0, b, m)$ is strictly concave in $\tilde{q}_0$ if $e > 0$. The degree of concavity is given by the second derivative of $W(\tilde{q}_0, b, m)$ with respect to $\tilde{q}_0$ in (I.40):

$$e > 0: \quad \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2} = G''(e)\left[-1 + \left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]\frac{\partial k_1}{\partial \tilde{q}_0}\right] \tag{I.44}$$

From Lemma 1 we know that (I.44) is strictly negative. How does it respond to changes in the maturing debt share m? From (I.3) we know that $G''(e)$ is independent of m: $G''(e) = 2\nu$. Furthermore, given that $\pi_1 = 1$, a change in the maturing debt share m has no direct effect on $\bar{\varepsilon}$ or on $\partial\bar{\varepsilon}/\partial k_1$. It follows for the derivative of (I.44) with respect to m:

$$e > 0: \quad \frac{\partial \frac{\partial^2 W(\tilde{q}_0, b, m)}{\partial \tilde{q}_0^2}}{\partial m} = G''(e)\left[b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\frac{\partial k_1}{\partial \tilde{q}_0} + \left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]\frac{\partial^2 k_1}{\partial \tilde{q}_0 \partial m}\right] \tag{I.45}$$

Given that $G''(e) > 0$, we only need to identify the sign of the following term:

$$\Omega \equiv b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\frac{\partial k_1}{\partial \tilde{q}_0} + \left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]\frac{\partial^2 k_1}{\partial \tilde{q}_0 \partial m} \tag{I.46}$$

Given Assumption 1 ($\partial\bar{\varepsilon}/\partial k_1 < 0$) and Lemma 2 ($\partial k_1/\partial \tilde{q}_0 > 0$), the first term on the right-hand-side of (I.46) is negative. When k_1 rises, it increases the bond price p^S by lowering $\bar{\varepsilon}$. A higher maturing debt share m amplifies the associated increase in bond market revenue because it increases debt roll-over. Furthermore, we know from the proof of Lemma 2 that the term in squared brackets in (I.46) is positive. It follows that (I.46) is negative if and only if $\partial^2 k_1/\partial \tilde{q}_0 \partial m$ is not sufficiently positive to outweigh the cash relief captured by the first term in (I.46):

$$\Omega < 0 \Leftrightarrow \frac{\partial^2 k_1}{\partial \tilde{q}_0 \partial m} < -b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\frac{\partial k_1}{\partial \tilde{q}_0}\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]^{-1} \tag{I.47}$$

The derivative of k_1 with respect to $\tilde{q}_0$ is implicitly defined by the first-order condition (I.16):

$$d\tilde{q}_0\left[-G''(e)(-1)\right]\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right] + dk_1 SOC = 0, \tag{I.48}$$

where SOC is the second derivative of (I.11) with respect to k_1:

$$\begin{aligned} SOC \equiv & -G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]^2 - [1+G'(e)]mb\Lambda\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial \bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2 \bar{\varepsilon}}{\partial k_1^2}\right](1+c) \\ & + \Lambda\int_{\bar{\varepsilon}}^{\infty}(1-\tau)A\alpha(\alpha-1)k_1^{\alpha-2}d\varphi(\varepsilon) + \Lambda\frac{\partial \bar{\varepsilon}}{\partial k_1}[-\varphi(\bar{\varepsilon})]\left[Q_1 + (1-\tau)\left[A\alpha k_1^{\alpha-1} + (\bar{\varepsilon}-\delta)Q_1\right]\right] \end{aligned} \tag{I.49}$$

The second-order condition for an interior solution of k_1 is $SOC < 0$. From (I.48) it follows:

$$\frac{dk_1}{d\tilde{q}_0} = -G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]SOC^{-1} \tag{I.50}$$

Since the term in squared brackets is positive (see the proof of Lemma 2) and SOC is negative (because shareholder value is concave in k_1 around any interior solution), (I.50) is positive (as also follows from Lemma 2). Now we can rewrite the term on the right hand side of the second inequality in (I.47):

$$-b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\frac{\partial k_1}{\partial \tilde{q}_0}\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]^{-1} = \left[-b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right][-G''(e)]SOC^{-1} \tag{I.51}$$

Furthermore, we can compute the left hand side of the second inequality in (I.47) by taking the partial derivative of (I.50) with respect to m. We apply the product rule to (I.50) and derive:

$$\begin{aligned} \frac{\partial^2 k_1}{\partial \tilde{q}_0 \partial m} = & -G''(e)b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)SOC^{-1} \\ & -G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right] \\ & (-1)SOC^{-2}\Bigg\{-G''(e)2\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]b\Lambda\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c) \\ & -[1+G'(e)]b\Lambda\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial \bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2 \bar{\varepsilon}}{\partial k_1^2}\right](1+c)\Bigg\} \end{aligned} \tag{I.52}$$

Note that variations in m have no impact on e because of Assumption 2 and because we consider small variations of $\tilde{q}_0$ and m in the neighbourhood of the firm state $(\tilde{q}_0^*, b^*, m^*)$.

Now we can re-write inequality (I.47):

$$\begin{aligned}\Omega < 0 \Leftrightarrow & - G''(e)b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)SOC^{-1}\\ & - G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\\ & \quad (-1)SOC^{-2}\Big\{ - G''(e)2\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right] b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\\ & \qquad - [1+G'(e)]b\Lambda\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right](1+c)\Big\}\\ & < \left[-b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\left[-G''(e)\right]SOC^{-1} \end{aligned} \tag{I.53}$$

We multiply both sides by SOC. Note that the inequality flips sign because SOC is negative:

$$\begin{aligned} & - G''(e)b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\\ & - G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\\ & \quad (-1)SOC^{-1}\Big\{ - G''(e)2\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right] b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\\ & \qquad - [1+G'(e)]b\Lambda\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right](1+c)\Big\}\\ & > \left[-b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\left[-G''(e)\right] \end{aligned} \tag{I.54}$$

We divide by $G''(e)$ and add the first term to both sides of the inequality:

$$\begin{aligned} \left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]SOC^{-1}\Big\{ & - 2G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right] b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\\ & - [1+G'(e)]b\Lambda\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right](1+c)\Big\}\\ & > 2b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c) \end{aligned} \tag{I.55}$$

We re-arrange terms on the left-hand-side:

$$\begin{aligned} SOC^{-1}\Big\{ & - 2G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]^2 b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\\ & - [1+G'(e)]b\Lambda\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right](1+c)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\Big\}\\ > & \; 2b\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c) \end{aligned} \tag{I.56}$$

We divide by the term on the right-hand-side (which is negative by Assumption 1). Note that the sign of the inequality flips again because we divide by a negative term:

$$\begin{aligned} SOC^{-1}\Bigg\{ &-G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]^2 \\ &-[1+G'(e)]\frac{\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right]}{2\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}}\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\Bigg\} < 1 \end{aligned} \tag{I.57}$$

Now we multiply both sides by SOC. The inequality flips sign one more time because we multiply by a negative term:

$$\begin{aligned} &-G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]^2 \\ &-[1+G'(e)]\frac{\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right]}{2\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}}\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right] > SOC \end{aligned} \tag{I.58}$$

But we know from Lemma 3 that:

$$\frac{\partial k_1}{\partial\tilde{q}_0} < \frac{1}{Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)} \quad\Leftrightarrow\quad \left(\frac{\partial k_1}{\partial\tilde{q}_0}\right)^{-1} > Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c) \tag{I.59}$$

Using (I.50), Lemma 3 becomes:

$$-\frac{SOC}{G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]} > Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c) \tag{I.60}$$

Or, equivalently:

$$-SOC > G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]^2 \tag{I.61}$$

Multiplying this inequality by -1 yields:

$$-G''(e)\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]^2 > SOC \tag{I.62}$$

The left hand side corresponds to the first term on the left hand side of (I.58). Furthermore, the right hand side is the right hand side of (I.58). It therefore follows from Lemma 3 that the inequality (I.58) holds if:

$$-[1+G'(e)]\frac{\left[\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2 + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}\right]}{2\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}}\left[Q_0 + mb\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right] > 0 \tag{I.63}$$

Because the default threshold $\bar{\varepsilon}$ is falling in capital k_1 (Assumption 1) and because the last term in squared brackets is positive (see proof of Lemma 2), condition (I.63) holds if and only if:

$$\varphi'(\bar{\varepsilon})\left(\frac{\partial\bar{\varepsilon}}{\partial k_1}\right)^2+\varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}>0 \tag{I.64}$$

This is the condition for concavity of the bond price p^S in (I.15) with respect to k_1. By Assumption 3, the first term of the sum on the left-hand-side is positive. Furthermore:

$$\frac{\partial^2\bar{\varepsilon}}{\partial k_1^2}=\frac{(1-\alpha)A}{Q_1}\left(\frac{\alpha-2}{k_1^{3-\alpha}}\right)-\frac{mb[1+(1-\tau)c]+\frac{(1-m)b}{\pi_1}[1+(1-\tau)c]+(1-\tau)f}{(1-\tau)Q_1}\left(\frac{-2}{k_1^3}\right) \tag{I.65}$$

We know from Assumption 1:

$$\frac{\partial\bar{\varepsilon}}{\partial k_1}=\frac{(1-\alpha)A}{Q_1k_1^{2-\alpha}}-\frac{mb[1+(1-\tau)c]+\frac{(1-m)b}{\pi_1}[1+(1-\tau)c]+(1-\tau)f}{(1-\tau)Q_1k_1^2}<0 \tag{I.66}$$

Multiplying the inequality above by the negative term $(\alpha-2)/k_1$ yields:

$$\frac{(1-\alpha)A}{Q_1}\left(\frac{\alpha-2}{k_1^{3-\alpha}}\right)-\frac{mb[1+(1-\tau)c]+\frac{(1-m)b}{\pi_1}[1+(1-\tau)c]+(1-\tau)f}{(1-\tau)Q_1}\left(\frac{\alpha-2}{k_1^3}\right)>0 \tag{I.67}$$

But if the above is true, it follows *a fortiori*:

$$\frac{(1-\alpha)A}{Q_1}\left(\frac{\alpha-2}{k_1^{3-\alpha}}\right)-\frac{mb[1+(1-\tau)c]+\frac{(1-m)b}{\pi_1}[1+(1-\tau)c]+(1-\tau)f}{(1-\tau)Q_1}\left(\frac{-2}{k_1^3}\right)>0 \tag{I.68}$$

It follows that $\partial^2\bar{\varepsilon}/\partial k_1^2>0$ in (I.65). This implies that (I.64) is positive and the inequalities (I.47) and (I.58) hold. From (I.47) it follows that the concavity of shareholder value $W(\tilde{q}_0,b,m)$ with respect to cash-on-hand $\tilde{q}_0$ is strengthened by an increase in the maturing debt share m. This concludes the proof of Proposition 2. ☐

I.5.6 Proof of Proposition 3

Proof. The derivative of k_1 with respect to m is implicitly defined by the first-order condition (I.16):

$$dm(-1)[1+G'(e)]b\pi_1\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}+dk_1SOC=0, \tag{I.69}$$

where SOC is defined in (I.49) above. It is the second derivative of (I.11) with respect to k_1. Variations in m around the firm state $(\tilde{q}_0^*,b^*,m^*)$ have no impact on e because of Assumption 2 and no impact on $\bar{\varepsilon}$ and $\partial\bar{\varepsilon}/\partial k_1$ because $\pi_1=1$. Using (I.69), we can write the derivative of k_1 with respect to m as:

$$\frac{dk_1}{dm}=\frac{1}{SOC}[1+G'(e)]b\pi_1\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1} \tag{I.70}$$

We know that SOC is negative because the firm objective is concave in k_1 in the neighborhood of any interior solution for k_1. Furthermore, we know that $\partial\bar{\varepsilon}/\partial k_1 < 0$ (Assumption 1). The product of the two terms is positive. We conclude that a higher maturing debt share m increases the optimal capital choice k_1. $\square$

I.5.7 Proof of Proposition 4

Proof. The effect of an increase in the maturing debt share m on the firm's marginal net benefit of capital is given by the partial derivative of the left hand side of (I.16) with respect to m:

$$\frac{\partial^2 W(\tilde{q}_0^*, b^*, m^*)}{\partial k_1 \partial m} = (-1)[1 + G'(e)]b\pi_1\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1} \tag{I.71}$$

It is positive (by Assumption 1). It responds to changes in firm productivity A according to:

$$\begin{aligned}\frac{\partial^3 W(\tilde{q}_0^*, b^*, m^*)}{\partial k_1 \partial m \partial A} =& (-1)G''(e)\left[-mb\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial A}\frac{1+c}{\pi_1}\right] b\pi_1\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\\ &- [1+G'(e)]b\pi_1\Lambda\frac{\partial}{\partial A}\left[\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\right]\frac{1+c}{\pi_1}\end{aligned} \tag{I.72}$$

It follows from (I.8):

$$\frac{\partial\bar{\varepsilon}}{\partial A} = -\frac{1}{Q_1 k_1^{1-\alpha}} < 0 \tag{I.73}$$

We conclude that the right hand side of the first line of (I.72) is negative. Furthermore:

$$\frac{\partial}{\partial A}\left[\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\right] = \varphi'(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial A}\frac{\partial\bar{\varepsilon}}{\partial k_1} + \varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1\partial A}, \quad \text{where:} \quad \frac{\partial^2\bar{\varepsilon}}{\partial k_1 \partial A} = \frac{1-\alpha}{Q_1 k_1^{2-\alpha}} \tag{I.74}$$

From Assumptions 1 and 3 it follows that the second line of (I.72) is negative as well. Accordingly, (I.72) is negative. This concludes the proof. $\square$

I.5.8 Proof of Proposition 5

Proof. The marginal net benefit of capital is given by the left hand side of the first-order condition (I.16). It responds to the discount factor Λ according to:

$$\begin{aligned}\frac{\partial^2 W(\tilde{q}_0^*, b^*, m^*)}{\partial k_1 \partial \Lambda} =& -G''(e)\left[-mb\pi_1[1-\Phi(\bar{\varepsilon})]\frac{1+c}{\pi_1}\right]\left[Q_0 - mb\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]\\ &- [1+G'(e)]\left[-mb\pi_1[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right] + \int_{\bar{\varepsilon}}^{\infty}\left[Q_1 + (1-\tau)[A\alpha k_1^{\alpha-1} + (\varepsilon-\delta)Q_1]\right]d\varphi(\varepsilon)\end{aligned} \tag{I.75}$$

The first line on the right-hand side of (I.75) is positive (because the last term in squared brackets is positive, see the proof of Lemma 2). It captures the cash-flow effects of a higher discount factor Λ. The increase in Λ raises the bond price p^S and bond market revenue. For a given choice of capital, the firm requires less equity issuance now. This lowers the marginal cost of equity issuance $G'(e)$ and thereby the marginal cost of capital. Note that the effect of Λ on equity issuance increases with the maturing debt share m (because roll-over increases in m). The first term on the second line of (I.75) is positive as well (by Assumption 1). It captures how the discount factor Λ affects the indirect benefit of capital from lowering the default threshold $\bar{\varepsilon}$. If Λ increases, this amplifies the impact of a given reduction in default risk on the bond price p^S. This strengthens the indirect benefit of capital. Again, this effect increases with the maturing debt share m (because roll-over increases in m). Finally, also the second term on the second line of (I.75) is positive (see the proof of Lemma 2). It follows that (I.75) is positive.

It remains to show that (I.75) increases in m. We derive:

$$
\begin{aligned}
\frac{\partial^3 W(\tilde{q}_0^*, b^*, m^*)}{\partial k_1 \partial \Lambda \partial m} = &- G''(e)\left[-b\pi_1[1-\Phi(\bar{\varepsilon})]\frac{1+c}{\pi_1}\right]\left[Q_0 - mb\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right] \\
&- G''(e)\left[-mb\pi_1[1-\Phi(\bar{\varepsilon})]\frac{1+c}{\pi_1}\right]\left[-b\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right] \\
&- [1+G'(e)]\left[-b\pi_1[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]
\end{aligned}
\tag{I.76}
$$

Under Assumption 2 (that is, $\Lambda[1-\Phi(\bar{\varepsilon}^*)](1+c) = 1$), a change in m has no effect on e. Since $\pi_1 = 1$, m also does not directly affect the default threshold $\bar{\varepsilon}$ in (I.8). The first line of the right hand side of (I.76) is positive. Given Assumption 1, the second line is negative and the third line is positive again. We can re-write the second and third line:

$$
\begin{aligned}
&- G''(e)\left[-mb\pi_1[1-\Phi(\bar{\varepsilon})]\frac{1+c}{\pi_1}\right]\left[-b\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right] \\
&\quad - [1+G'(e)]\left[-b\pi_1[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right] \\
&= \left[-b[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right]\left[2\nu \mathbb{1}_{e>0} mb\Lambda[1-\Phi(\bar{\varepsilon})](1+c) - 1 - 2\nu\mathbb{1}_{e>0} e\right] \\
&= b\varphi(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\left[2\nu\mathbb{1}_{e>0} mb - 1 - 2\nu\mathbb{1}_{e>0} e\right],
\end{aligned}
\tag{I.77}
$$

where the last equation follows from Assumption 2 (that is, $\Lambda[1-\Phi(\bar{\varepsilon}^*)](1+c) = 1$). Expression (I.77) is positive if and only if:

$$
2\nu\mathbb{1}_{e>0}(mb - e) < 1 \tag{I.78}
$$

Given Assumption 4, the inequality above holds and (I.76) is positive. This concludes the proof. □

I.5.9 Proof of Proposition 6

Proof. The marginal net benefit of capital, on the left hand side of the first-order condition (I.16), responds to inflation π_1 according to:

$$\begin{aligned}\frac{\partial^2 W(\tilde{q}_0^*, b^*, m^*)}{\partial k_1 \partial \pi_1} = & - G''(e)\left[-mb\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial \pi_1}(1+c)\right]\left[Q_0 - mb\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial k_1}(1+c)\right] \\ & - [1+G'(e)]\left[-mb\Lambda\left[-\varphi'(\bar{\varepsilon})\frac{\partial \bar{\varepsilon}}{\partial \pi_1}\frac{\partial \bar{\varepsilon}}{\partial k_1} - \varphi(\bar{\varepsilon})\frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial \pi_1}\right](1+c)\right] \\ & + \Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial \bar{\varepsilon}}{\partial \pi_1}\left[Q_1 + (1-\tau)[A\alpha k_1^{\alpha-1} + (\bar{\varepsilon}-\delta)Q_1]\right] \end{aligned} \tag{I.79}$$

From (I.8) we derive:

$$\frac{\partial \bar{\varepsilon}}{\partial \pi_1} = -\frac{(1-m)b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1}\frac{1}{\pi_1^2} < 0 \tag{I.80}$$

Higher inflation reduces default risk by decreasing the real burden of nominal debt b. Since the last term in squared brackets in the first line of (I.79) is positive (see the proof of Lemma 2), it follows from (I.80) that the right hand side of the first line is positive. By reducing default risk and increasing p^S, higher inflation increases cash-flow and reduces the marginal cost of equity issuance. Furthermore, from (I.9) we derive:

$$\frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial \pi_1} = \frac{(1-m)b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1^2}\frac{1}{\pi_1^2} > 0 \tag{I.81}$$

It follows from Assumptions 1 and 3 that the second line of (I.79) is negative. By reducing default risk, higher inflation lowers the indirect benefit of capital. Finally, we have the term in squared brackets in the third line of (I.79):

$$\begin{aligned} & Q_1 + (1-\tau)[A\alpha k_1^{\alpha-1} + (\bar{\varepsilon}-\delta)Q_1] \\ = & Q_1 + (1-\tau)\Bigg[A\alpha k_1^{\alpha-1} - \delta Q_1 \\ & + Q_1\left(-\frac{Q_1 k_1 - mb - \frac{(1-m)b}{\pi_1} + (1-\tau)\left[A k_1^{\alpha} - \delta Q_1 k_1 - f - cmb - \frac{c(1-m)b}{\pi_1}\right]}{(1-\tau)Q_1 k_1}\right)\Bigg], \end{aligned} \tag{I.82}$$

where we have used (I.8) to substitute out $\bar{\varepsilon}$. This can be simplified:

$$\begin{aligned} & Q_1 + (1-\tau)A\alpha k_1^{\alpha-1} - (1-\tau)\delta Q_1 - Q_1 + \frac{mb[1+(1-\tau)c] + \frac{(1-m)b[1+(1-\tau)c]}{\pi_1} + (1-\tau)f}{k_1} \\ & \qquad - (1-\tau)A k_1^{\alpha-1} + (1-\tau)\delta Q_1 \\ & = -(1-\tau)A(1-\alpha)k_1^{\alpha-1} + \frac{mb[1+(1-\tau)c] + \frac{(1-m)b[1+(1-\tau)c]}{\pi_1} + (1-\tau)f}{k_1} \end{aligned} \tag{I.83}$$

Expression (I.83) is positive if and only if:

$$-(1-\tau)A(1-\alpha)k_1^{\alpha}+mb[1+(1-\tau)c]+\frac{(1-m)b[1+(1-\tau)c]}{\pi_1}+(1-\tau)f>0 \tag{I.84}$$

But we know from (I.30) in the proof of Lemma 2 that Assumption 1 is equivalent to the inequality above. It follows that the third line of (I.79) is positive. By reducing default risk, inflation reduces debt overhang and increases the marginal net benefit of capital. If m is sufficiently small, the third line of (I.79) dominates the second line and the overall effect of inflation on the marginal net benefit of capital is necessarily positive.

It remains to show that (I.79) decreases in m. We derive:

$$\begin{aligned}\frac{\partial^3 W(\tilde{q}_0^*,b^*,m^*)}{\partial k_1\partial\pi_1\partial m}=&-G''(e)\left[-b\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial\pi_1}(1+c)\right]\left[Q_0-mb\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]\\&-G''(e)\left[-mb\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial^2\bar{\varepsilon}}{\partial\pi_1\partial m}(1+c)\right]\left[Q_0-mb\pi_1\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}\frac{1+c}{\pi_1}\right]\\&-G''(e)\left[-mb\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial\pi_1}(1+c)\right]\left[-b\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial k_1}(1+c)\right]\\&-[1+G'(e)]\left[b\Lambda\left[\varphi'(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial\pi_1}\frac{\partial\bar{\varepsilon}}{\partial k_1}+\varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1\partial\pi_1}\right](1+c)\right]\\&-[1+G'(e)]\left[mb\Lambda\left[\varphi'(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial\pi_1\partial m}\frac{\partial\bar{\varepsilon}}{\partial k_1}+\varphi(\bar{\varepsilon})\frac{\partial^3\bar{\varepsilon}}{\partial k_1\partial\pi_1\partial m}\right](1+c)\right]\\&+\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial^2\bar{\varepsilon}}{\partial\pi_1\partial m}\left[Q_1+(1-\tau)[A\alpha k_1^{\alpha-1}+(\bar{\varepsilon}-\delta)Q_1]\right]\Bigg]\end{aligned} \tag{I.85}$$

Under Assumption 2 (that is, $\Lambda[1-\Phi(\bar{\varepsilon}^*)](1+c)=1$), a change in m has no effect on e. Since we consider variations in inflation close to the steady state ($\pi_1=1$), m also does not affect the default threshold $\bar{\varepsilon}$ in (I.8). The right hand side of the first line of (I.85) is positive. It follows from (I.80):

$$\frac{\partial^2\bar{\varepsilon}}{\partial\pi_1\partial m}=\frac{b[1+(1-\tau)c]}{(1-\tau)Q_1k_1}\frac{1}{\pi_1^2}>0 \tag{I.86}$$

A higher maturing debt share reduces exposure to debt deflation and thereby dampens the reduction in default risk due to higher inflation. It follows that the second line of (I.85) is negative. The third line is negative as well. The fourth and the fifth lines of (I.85) can be simplified to:

$$\begin{aligned}&-[1+G'(e)]\left[b\Lambda\left[\varphi'(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial\pi_1}\frac{\partial\bar{\varepsilon}}{\partial k_1}+\varphi(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial k_1\partial\pi_1}\right](1+c)\right]\\&-[1+G'(e)]\left[mb\Lambda\left[\varphi'(\bar{\varepsilon})\frac{\partial^2\bar{\varepsilon}}{\partial\pi_1\partial m}\frac{\partial\bar{\varepsilon}}{\partial k_1}+\varphi(\bar{\varepsilon})\frac{\partial^3\bar{\varepsilon}}{\partial k_1\partial\pi_1\partial m}\right](1+c)\right]\\=&-[1+G'(e)]\,b\Lambda(1+c)\left[\varphi'(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial k_1}\left(\frac{\partial\bar{\varepsilon}}{\partial\pi_1}+m\frac{\partial^2\bar{\varepsilon}}{\partial\pi_1\partial m}\right)+\varphi(\bar{\varepsilon})\left(\frac{\partial^2\bar{\varepsilon}}{\partial k_1\partial\pi_1}+m\frac{\partial^3\bar{\varepsilon}}{\partial k_1\partial\pi_1\partial m}\right)\right]\end{aligned} \tag{I.87}$$

We derive:

$$\begin{aligned}\frac{\partial \bar{\varepsilon}}{\partial \pi_1} + m \frac{\partial^2 \bar{\varepsilon}}{\partial \pi_1 \partial m} = &- \frac{(1-m)b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1} \frac{1}{\pi_1^2} + m \frac{b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1} \frac{1}{\pi_1^2} \\ &- \frac{(1-2m)b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1} \frac{1}{\pi_1^2} \end{aligned} \tag{I.88}$$

Under Assumption 5, the expression (I.88) is negative. Furthermore:

$$\begin{aligned}\frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial \pi_1} + m \frac{\partial^3 \bar{\varepsilon}}{\partial k_1 \partial \pi_1 \partial m} = &\frac{(1-m)b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1^2} \frac{1}{\pi_1^2} + m \left(- \frac{b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1^2} \frac{1}{\pi_1^2} \right) \\ &\frac{(1-2m)b[1+(1-\tau)c]}{(1-\tau)Q_1 k_1^2} \frac{1}{\pi_1^2} \end{aligned} \tag{I.89}$$

Under Assumption 5, the expression (I.89) is positive. Given Assumptions 1 and 3, it follows that (I.87) is negative. Finally, the sixth line of (I.85) is negative as well. Dividing (I.85) by the term $[1+G'(e)]$, we conclude that Assumption 5 implies that the first three lines of (I.85) are quantitatively dominated by the fourth, fifth, and sixth line. It follows that (I.85) is negative. □

I.5.10 Proof of Proposition 7

Proof. From (I.79) we derive:

$$\begin{aligned}&\frac{\partial^3 W(\tilde{q}_0^*, b^*, m^*)}{\partial k_1 \partial \pi_1 \partial A} \\ &= -G''(e) \left[-mb\Lambda[-\varphi'(\bar{\varepsilon})] \frac{\partial \bar{\varepsilon}}{\partial A} \frac{\partial \bar{\varepsilon}}{\partial \pi_1} (1+c) \right] \left[Q_0 - mb\Lambda[-\varphi(\bar{\varepsilon})] \frac{\partial \bar{\varepsilon}}{\partial k_1} (1+c) \right] \\ &- G''(e) \left[-mb\Lambda[-\varphi(\bar{\varepsilon})] \frac{\partial \bar{\varepsilon}}{\partial \pi_1} (1+c) \right] \left[mb\Lambda \left(\varphi'(\bar{\varepsilon}) \frac{\partial \bar{\varepsilon}}{\partial A} \frac{\partial \bar{\varepsilon}}{\partial k_1} + \varphi(\bar{\varepsilon}) \frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial A} \right) (1+c) \right] \\ &- G''(e) \left[-mb\Lambda[-\varphi(\bar{\varepsilon})] \frac{\partial \bar{\varepsilon}}{\partial A} (1+c) \right] \left[-mb\Lambda \left[-\varphi'(\bar{\varepsilon}) \frac{\partial \bar{\varepsilon}}{\partial \pi_1} \frac{\partial \bar{\varepsilon}}{\partial k_1} - \varphi(\bar{\varepsilon}) \frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial \pi_1} \right] (1+c) \right] \\ &- [1+G'(e)] \left[-mb\Lambda \left[-\varphi''(\bar{\varepsilon}) \frac{\partial \bar{\varepsilon}}{\partial A} \frac{\partial \bar{\varepsilon}}{\partial \pi_1} \frac{\partial \bar{\varepsilon}}{\partial k_1} - \varphi'(\bar{\varepsilon}) \frac{\partial \bar{\varepsilon}}{\partial \pi_1} \frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial A} - \varphi'(\bar{\varepsilon}) \frac{\partial \bar{\varepsilon}}{\partial A} \frac{\partial^2 \bar{\varepsilon}}{\partial k_1 \partial \pi_1} \right] (1+c) \right] \\ &+ \Lambda[-\varphi'(\bar{\varepsilon})] \frac{\partial \bar{\varepsilon}}{\partial A} \frac{\partial \bar{\varepsilon}}{\partial \pi_1} \left[Q_1 + (1-\tau)[A\alpha k_1^{\alpha-1} + (\bar{\varepsilon} - \delta) Q_1] \right] \\ &+ \Lambda[-\varphi(\bar{\varepsilon})] \frac{\partial \bar{\varepsilon}}{\partial \pi_1} (1-\tau) \left[\alpha k_1^{\alpha-1} + \frac{\partial \bar{\varepsilon}}{\partial A} Q_1 \right] \end{aligned} \tag{I.90}$$

Under Assumption 3 and given (I.73) and (I.80), the right hand side of the first line of (I.90) is negative. Under Assumptions 1 and 3 and given (I.74), the second line is positive. Under Assumptions 1 and 3 and given (I.81), the third line is positive as well. Under Assumptions 1 and 3, and given (I.74) and (I.81), also the fourth line is positive if $\varphi''(\bar{\varepsilon}) > 0$. Under

Assumption 3, the fifth line is negative. Using (I.73), the sixth line can be re-written as:

$$\begin{aligned}\Lambda[-\varphi(\bar{\varepsilon})]\frac{\partial\bar{\varepsilon}}{\partial\pi_1}(1-\tau)\left[\alpha k_1^{\alpha-1}+\frac{\partial\bar{\varepsilon}}{\partial A}Q_1\right]=&-\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial\pi_1}(1-\tau)\left[\alpha k_1^{\alpha-1}-\frac{1}{Q_1k_1^{1-\alpha}}Q_1\right]\\=&-\Lambda\varphi(\bar{\varepsilon})\frac{\partial\bar{\varepsilon}}{\partial\pi_1}(1-\tau)k_1^{\alpha-1}(\alpha-1)<0\end{aligned}\tag{I.91}$$

Under Assumption 6, the first four lines on the right hand side of (I.90) are dominated quantitatively by the last two lines which are negative. This concludes the proof. □

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