Corporate Debt Maturity Matters For Monetary Policy*

Joachim Jungherr   Matthias Meier   Timo Reinelt   Immo Schott

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Abstract

We provide novel empirical evidence that firms' investment is more responsive to monetary policy when a higher fraction of their debt matures. In a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity, two channels explain this finding: (1.) Firms with more maturing debt have larger roll-over needs and are therefore more exposed to fluctuations in the real interest rate (*roll-over risk*). (2.) These firms also have higher default risk and therefore react more strongly to changes in the real burden of outstanding nominal debt (*debt overhang*). In comparison to existing models, we show that a model which accounts for the maturity of debt and its distribution across firms implies larger aggregate effects of monetary policy.

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

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

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

1 Introduction

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

We begin by providing novel empirical evidence that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. This result holds both across and within firms and is robust to a wide set of controls and specifications. After a tightening of monetary policy, investment, borrowing, sales, and employment all fall by more for firms with high shares of maturing debt.

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

The model generates the rich heterogeneity in firm financing choices found in the data, including the heterogeneity in debt maturity. Importantly, the model rationalizes the empirical evidence that firms with higher shares of maturing debt respond more strongly to monetary policy shocks. Given this ability to replicate key non-targeted micro moments, we study the model's macroeconomic implications. Compared to existing models, our model implies larger aggregate effects of monetary policy. The maturity of debt and its distribution across firms are key for this result.

In our empirical analysis, we combine balance sheet 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. The main result of our empirical analysis is that firms' investment is more responsive to monetary policy if a larger fraction of their debt matures at the time of a shock. This result is statistically and economically significant. After a typical contractionary monetary policy shock, firms with a one-standard deviation higher

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Figure 1: Share of debt maturing within the next year
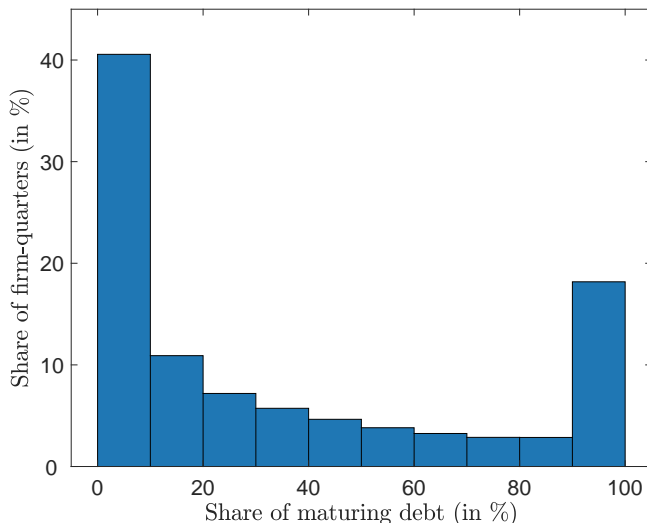
maturing bond share experience a persistent additional reduction of their capital stock which peaks at 0.2% eight quarters after the shock. Assuming an annual investment-to-capital ratio of 10%, this corresponds to a reduction of investment of 1%. A higher maturing bond share is also associated with similar-sized reductions in 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, leverage, and liquidity.

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

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

Importantly, the model explains our main empirical finding: a higher share of maturing debt at the time of a monetary policy shock is associated with a stronger response of firm capital. Both roll-over risk and debt overhang contribute to this result: (1.) Firms with more maturing debt roll over more debt and therefore experience a higher pass-through of interest rate changes to cash flow. This influences firms' need to raise costly outside financing and thereby affects the firm-specific costs of capital. (2.) Firms with more maturing debt have higher default risk and therefore react more strongly to fluctuations in the real burden of

outstanding nominal debt. For these firms, both default risk and investment respond more strongly to surprise changes in interest rates and inflation.

The model generates over two thirds of the peak empirical differential capital response associated with the maturing bond share. As in the data, the model produces a hump-shaped response: the initial effect is small and builds up over time. In addition, the model rationalizes the empirical role of the maturing bond share for the firm-level responses of debt, sales, and employment. We show that debt overhang is quantitatively more important in generating these results than roll-over risk.

Finally, we use our model to study the implications of these micro-level results for the macroeconomic effects of monetary policy. To this end, we compare our model to two alternative versions of our model. In the first one, we abstract from cross-sectional differences in debt maturity by assuming that all debt is short-term. This is the standard assumption in many quantitative macro models (e.g., Bernanke et al., 1999; Ottonello and Winberry, 2020). In the second alternative economy we allow firms to choose the maturity of their debt, but assume that all firms are ex-ante identical (as in Gomes et al., 2016). Our results show that both long-term debt and heterogeneity amplify the effects of monetary policy shocks on GDP, investment, and inflation. We conclude that the maturity of firm debt and its distribution are important for the aggregate effects of monetary policy.

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

First, our work contributes to empirical studies of how debt maturity shapes firms' investment response to aggregate shocks. Duchin et al. (2010) and Almeida et al. (2012) show that firms with more maturing debt at the onset of the Financial Crisis of 2007–2008 reduced investment by more.[1] Similarly, higher shares of maturing debt are associated with stronger investment declines during the Great Depression 1929–1933 (Benmelech et al., 2019) and during the 2010–2012 European sovereign debt crisis (Kalemli-Ozcan et al., 2018; Buera and Karmakar, 2021). We complement these event studies of financial crises by providing evidence on how debt maturity shapes the investment response to monetary policy shocks.

A second related group of empirical papers studies the role of firm financing in explaining heterogeneous effects of monetary policy across firms. Important empirical covariates of firms' response to monetary policy shocks are size (Gertler and Gilchrist, 1994), leverage (Anderson and Cesa-Bianchi, 2020; Ottonello and Winberry, 2020), age (Cloyne et al., 2020), liquidity (Jeenas, 2019; Greenwald et al., 2021), the share of floating-rate debt (Ippolito et al., 2018; Gurkaynak et al., 2021), and the share of bond financing (Darmouni et al., 2021). To this literature, we contribute the result that not only the *level* of debt (or leverage) is important, but also the precise *timing* of when this debt comes due.[2]

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[1]Chodorow-Reich and Falato (2021) highlight the role of covenant violations in determining the effective maturity of bank loans during the 2007–2008 Financial Crisis.

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

Third, the theoretical contribution of this paper is to develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. Existing quantitative models do not account for differences in debt maturity across firms. Gomes et al. (2016) study the role of nominal long-term debt for monetary policy using a representative firm setup with exogenous debt maturity. Our heterogeneous firm model accounts for the distribution of debt maturity across firms. In a short-term debt model without equity issuance, Ottonello and Winberry (2020) show that firms with low net worth and high leverage react less to monetary policy shocks. In our model the value of firm assets in place is a key determinant of leverage and investment as well. By allowing firms to choose both short-term debt and long-term debt, we study an additional dimension of firm heterogeneity and show its quantitative importance for monetary policy.

Starting with Bernanke et al. (1999), the theoretical literature on the role of financial frictions in generating cross-sectional differences in firm-level responses to aggregate shocks includes important contributions by Cooley and Quadrini (2006), Covas and Den Haan (2012), Khan and Thomas (2013), Gilchrist et al. (2014), Khan et al. (2016), Begenau and Salomao (2018), Crouzet (2018), Arellano et al. (2019), and Arellano et al. (2020). Because firms issue only one-period debt in these models, all firms have identical exposure to roll-over risk and no significant exposure to debt overhang.[3,4]

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

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.

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[3]Net worth is the only financial state variable in one-period debt models. If firms are allowed to issue long-term debt, the existing stock of previously issued debt enters the firm problem as additional state variable. For quantitative models which explore the implications of long-term debt for firm financing and investment, see also Crouzet (2017), Caggese et al. (2019), Perla et al. (2020), Poeschl (2020), Reiter and Zessner-Spitzenberg (2020), Xiang (2020), Gomes and Schmid (2021), Jermann and Xiang (2021), Jungherr and Schott (2021), Karabarbounis and Macnamara (2021), and Jungherr and Schott (2022). None of these models studies the role of debt maturity for monetary policy. 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 Admati et al. (2018), Crouzet and Tourre (2021), Dangl and Zechner (2021), or DeMarzo and He (2021). Also related is the sovereign debt literature on risky long-term debt (e.g., Arellano and Ramanarayanan, 2012; Chatterjee and Eyigungor, 2012; Hatchondo et al., 2016; Aguiar et al., 2019; Bocola and Dovis, 2019; Aguiar and Amador, 2020).

[4]A related quantitative literature explores the role of household heterogeneity for the transmission of monetary policy (e.g., Gornemann et al., 2016; Kaplan et al., 2018; Auclert, 2019; Bayer et al., 2019; Wong, 2019; Berger et al., 2021; Eichenbaum et al., 2022).

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-level 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.[5] Appendix A.1 provides further details on the bond-level data.

Firm-level data. We merge the FISD bond-level information with quarterly firm-level balance sheet data from Compustat. This is not a straightforward task. First, the 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 further details.

We exclude firms in the public administration, finance, insurance, real estate, and utilities sectors. We further exclude firm-quarters in which no bond is outstanding or maturing. This means that we are focusing on the subset of listed U.S. firms which 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 $t-4$.[6]

Monetary policy shocks. We use high-frequency changes in the prices of federal funds futures around FOMC meetings to identify monetary policy shocks. Our baseline shocks are based on the three-months ahead federal funds future within 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, 2020). Following Jarociński and Karadi (2020), we further use sign restrictions to separate information effects from

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[5]In Section 2.4, we discuss separate results for callable and variable-coupon bonds.

[6]We use the backward-looking four-quarter moving average of debt in the denominator to smooth out firm-specific seasonal factors and other transitory fluctuations. See Section 2.4 for a sensitivity analysis using alternative denominators for the maturing bond share.

Table 1: Descriptive statistics

	Mean	Sd	Min	Max	Obs
Capital growth *(in log points)*	0.78	3.94	-40.52	72.81	35,533
Maturing bond share $\mathcal{M}_{it}$ *(in % of debt)*	0.19	1.77	0.00	67.18	35,533
Leverage *(debt/assets in %)*	34.01	18.47	0.00	151.49	35,533
Liquidity *(cash/assets in %)*	7.59	8.41	0.00	72.64	35,532
Total assets *(in bln. 2005 US$)*	13.48	26.34	0.03	188.75	35,533
Sales growth *(in log points)*	0.76	17.75	-90.51	95.58	35,478
Average bond maturity *(in years)*	9.02	6.18	0.08	99.83	35,533
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.

conventional monetary policy shocks. Finally, we aggregate the daily shocks to quarterly frequency. Daily shocks are assigned fully to the current quarter if they occur on the first day of the quarter. If they occur within the quarter, they are partially assigned to the current and subsequent quarter (Gorodnichenko and Weber, 2016). The monetary policy shock series covers 1995Q2 through 2018Q3.[7]

Descriptive statistics. Table 1 reports descriptive statistics of key observables used in our empirical analysis. Our sample consists of 35,533 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.[8] 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 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 various firm-level control variables used in our analysis: leverage, liquidity, total assets, sales growth, and average bond maturity. Finally, Table 1 documents the distribution of the (baseline) monetary policy shock time series. The mean is approximately zero and the standard deviation 3.47 basis points. A one-standard deviation monetary policy shock leads to a 30 basis point increase in the federal funds rate (Meier and Reinelt, 2020).

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.

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[7]In addition to this baseline shock series, we consider various alternative series in Section 2.4.

[8]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, see Section 2.4.

Baseline local projection. We start with a parsimonious baseline specification. Formally, we estimate

$$\Delta^{h+1} \log k_{it+h} = \beta_0^h \mathcal{M}_{it} + \beta_1^h \mathcal{M}_{it} \varepsilon_t^{\mathrm{mp}} + \beta_2^h \mathcal{M}_{it} \Delta \mathrm{gdp}_{t-1} + \delta_i^h + \delta_{st}^h + \nu_{it+h}^h, \qquad (2.2)$$

for $h = 0, \ldots, 16$ quarters. On the left-hand side, k_{it} denotes the real capital stock of firm i in quarter t and $\Delta^{h+1} \log k_{it+h} = \log k_{it+h} - \log k_{it-1}$ is the cumulative capital growth between $t-1$ and $t+h$. On the right-hand side, δ_i^h and δ_{st}^h are firm and sector-quarter fixed effects, $\varepsilon_t^{\mathrm{mp}}$ is the monetary policy shock, and $\Delta \mathrm{gdp}_{t-1}$ is lagged real GDP growth.[9]

Figure 2 presents the main empirical result of our paper. In panel (a), we show the estimated β_1^h coefficients. These capture the differential response of capital growth for firms which have a higher maturing bond share $\mathcal{M}_{it}$ at the time of a contractionary monetary policy shock. 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 shaded area is a 95% confidence band based on standard errors that are two-way clustered by firms and quarters. The differential response is statistically different from zero at the 5% significance level at horizons between six and eleven quarters after the shock. Given that the average capital growth response is negative, this means that firms with more maturing bonds are more responsive to monetary policy shocks.[10]

The estimated coefficients β_1^h in panel (a) of Figure 2 are standardized to reflect the differential response of firms which have a one standard deviation higher $\mathcal{M}_{it}$ at the time of a one standard deviation contractionary monetary policy shock. For instance, the estimate $\beta_1^8 = -0.21$ means an additional 0.21 percentage points reduction of capital growth over eight quarters ($\Delta^{8+1} \log k_{it+8}$). Given an annual investment-capital ratio of 10%, this translates into a reduction of investment by 1% between quarter $t-1$ and quarter $t+8$.[11]

Extended local projection. Debt maturity is endogenous and varies systematically across firms. Even within firms, the time series variation of debt maturity may be related to other firm observables. We next show that the results described above are highly robust to focusing on the within-firm variation in $\mathcal{M}_{it}$ over time, and to including a set of time-varying firm-level control variables. Formally, we estimate the extended specification

$$\Delta^{h+1} \log k_{it+h} = \beta_0^h \left(\mathcal{M}_{it} - \overline{\mathcal{M}}_i \right) + \beta_1^h \left(\mathcal{M}_{it} - \overline{\mathcal{M}}_i \right) \varepsilon_t^{\mathrm{mp}} + \beta_2^h \left(\mathcal{M}_{it} - \overline{\mathcal{M}}_i \right) \Delta \mathrm{gdp}_{t-1}$$
$$+ \Gamma_0^h Z_{it-1} + \Gamma_1^h Z_{it-1} \varepsilon_t^{\mathrm{mp}} + \Gamma_2^h Z_{it-1} \Delta \mathrm{gdp}_{t-1} + \delta_i^h + \delta_{st}^h + \nu_{it+h}^h, \qquad (2.3)$$

where $\mathcal{M}_{it} - \overline{\mathcal{M}}_i$ is the deviation of $\mathcal{M}_{it}$ from its firm-specific average $\overline{\mathcal{M}}_i$, and Z_{it-1} is a vector of control variables. Z_{it-1} includes leverage, liquidity, average maturity of outstanding

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[9]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 finding, including this interaction marginally lowers the standard errors of β_1^h but is not important for our conclusions.

[10]The average response of capital growth is shown in Figure B.1 in the Appendix.

[11]We use the law of motion of capital over a nine-quarter horizon: $K_{t+8} = (1-\delta)K_{t-1} + I_{t+8}$, where δ and I_{t+8} denote depreciation and investment between quarter $t-1$ and $t+8$. If capital growth increases relative to the stationary case ($\overline{I}_{t+8} = \delta K_{t-1}$), this implies an increase of investment by $(I_{t+8} - \overline{I}_{t+8})/\overline{I}_{t+8} = (K_{t+8} - K_{t-1})/\delta K_{t-1}$. Given $(K_{t+8} - K_{t-1})/K_{t-1} = 0.21$ and $\delta = 0.21$ (consistent with 10% annual depreciation), this implies: $(I_{t+8} - \overline{I}_{t+8})/\overline{I}_{t+8} = 1$.

Figure 2: Differential investment response associated with higher $\mathcal{M}_{it}$

(a) Baseline specification

(b) Extended specification
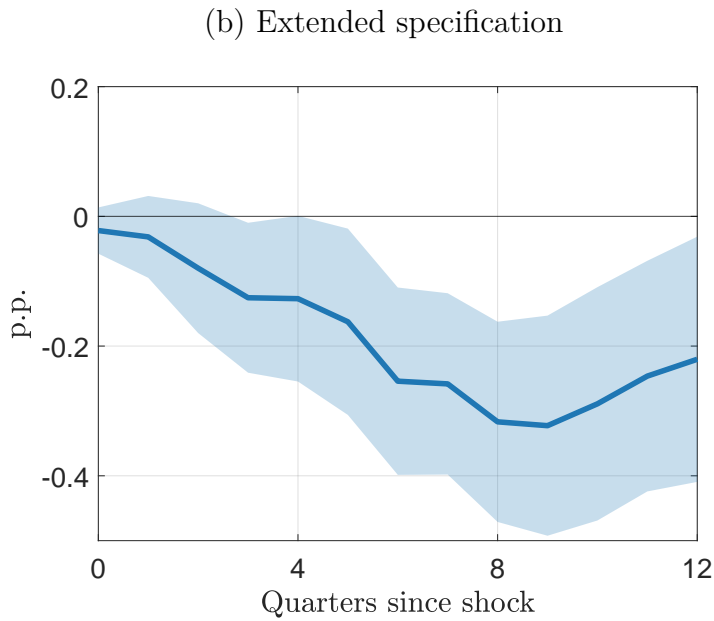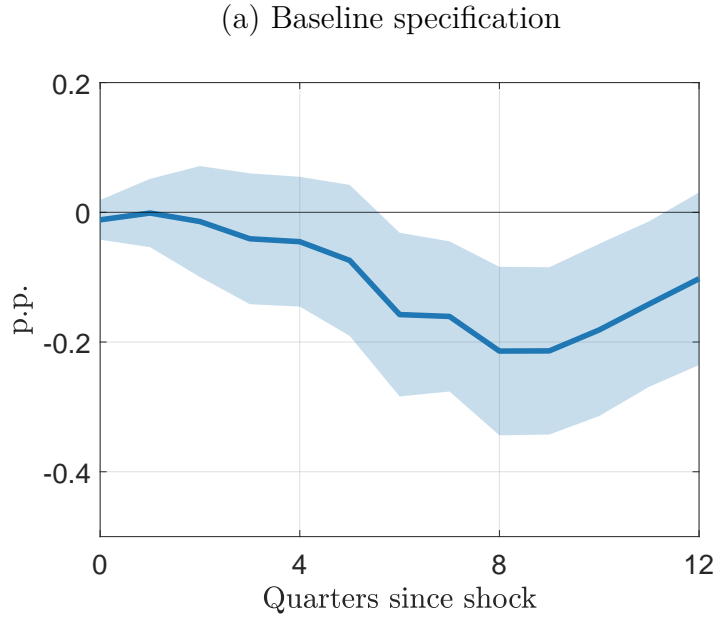
Note: Panel (a) shows the estimated β_1^h coefficients using the baseline specification in equation (2.2). Panel (b) shows the estimated β_1^h coefficients using the extended specification in equation (2.3), where Z_{it-1} includes leverage, liquidity, assets, sales growth, and average maturity (all demeaned). The β_1^h estimates are standardized to capture 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 $\mathcal{M}_{it}$ (in panel (a)) and a one standard deviation higher $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$ (in panel (b)). Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

bonds, real sales growth, and log real total assets (all in deviation from their respective firm-specific averages).

Panel (b) of Figure 2 shows the estimated β_1^h coefficients. The estimates conform with the finding in panel (a). The response of capital growth is more negative for firms that have a larger share of maturing bonds relative to the firm-level average share of maturing bonds, and conditional on other control variables. Compared to panel (a), the estimates shown in panel (b) tend to be larger (e.g., $\beta_1^8 = -0.32$) and more precisely estimated.[12]

2.3 Response of debt, sales, and other inputs

We next explore whether the share of maturing bonds is important for other firm responses besides investment. Specifically, we estimate the differential responses of firm-level debt, sales, employment, and cost of goods sold using the local projection in equation (2.3).[13] We focus on within-firm variation and use the same controls as in panel (b) of Figure 2.[14]

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

Panel (b) of Figure 3 shows that sales growth declines by more for firms with a larger maturing bond share. A caveat here is that the differential sales response is estimated relatively imprecisely. Panels (c) and (d) show the differential responses of employment and cost of goods sold, where the latter measures total expenses for materials, intermediate inputs, labor, and energy. Both employment and cost of goods sold decline by more if $\mathcal{M}_{it}$ is larger at the time of the monetary policy shock. These estimates are statistically different from zero at significance levels between five and ten percent around eight quarters after the shock. Overall, the evidence in Figure 3 shows that a high maturing bond share not only shapes the response of capital, but also that of other firm-level outcomes.

2.4 Additional results

We conclude the empirical analysis with additional results and robustness exercises.

Timing of maturity. Our empirical analysis uses detailed FISD bond-level information which allows us to measure the amount of maturing bonds in a given quarter. Figure B.3 in the Appendix shows the importance of measuring the precise timing of maturity relative to monetary policy shocks. In a quasi-Placebo exercise, we replace $\mathcal{M}_{it}$ with $\mathcal{M}_{it-1}$,

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[12]For a list of coefficients in the baseline and extended specification, see Appendix Tables B.1 and B.2.

[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.

[14]Figure B.2 in the Appendix provides the corresponding estimates for the baseline specification in (2.2).

Figure 3: Differential response of other variables associated with higher $\mathcal{M}_{it}$
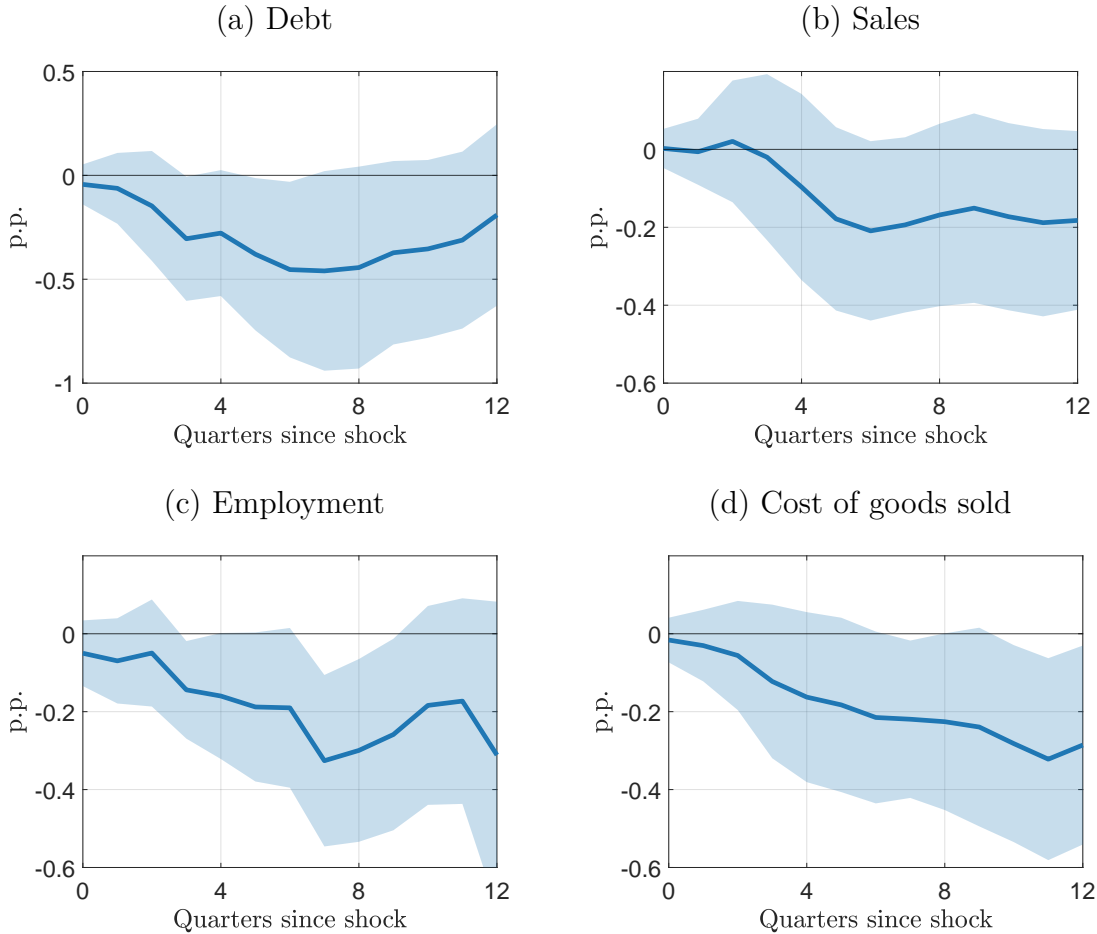
(a) Debt

(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 (2.3), but where the left-hand side is $\Delta^{h+1}\log(\text{debt})_{it+h}$ in panel (a), $\Delta^{h+1}\log(\text{sales})_{it+h}$ in panel (b), $\Delta^{h+1}\log(\text{employment})_{it+h}$ in panel (c), and $\Delta^{h+1}\log(\text{cost of goods sold})_{it+h}$ in panel (d). In all panels, Z_{it-1} includes leverage, liquidity, assets, sales growth, and average maturity (all demeaned). The β_1^h estimates are standardized to capture 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.

the maturing bond share in the quarter preceding the monetary policy shock. In the baseline specification, the differential investment response associated with $\mathcal{M}_{it-1}$ is small and insignificant. In the extended specification with additional control variables, the differential response even turns positive several quarters after the shock. These findings underline the importance of using precise information on the timing of maturity.

Maturing debt share in Compustat. In contrast to FISD data, Compustat only provides information on maturing debt within a twelve-month window and does not distinguish between bonds and bank loans. In Figure B.4, we replicate our empirical analysis using Compustat maturity data. Let $\widetilde{\mathcal{M}}_{it}$ denote the Compustat share of total maturing debt

within the next twelve months. We show that the differential investment response associated with $\widetilde{\mathcal{M}}_{it}$ (instead of $\mathcal{M}_{it}$) is very imprecisely estimated. This shows the benefit of using FISD data to precisely measure bond maturity.

Callable and variable-coupon bonds. Our main results are based on the maturity of non-callable fixed coupon bonds. A concern with callable bonds is that firm-level conditions which determine the decision to call a bond before maturity may affect the estimates associated to $\mathcal{M}_{it}$. Panel (a) of Figure B.5 shows the β_1^h estimates when constructing $\mathcal{M}_{it}$ using only the maturing amount of callable bonds. The estimated coefficients are insignificant. When combining the maturing amount of callable and non-callable bonds, the estimates are close to our baseline results, see panel (b). We also consider variable-coupon bonds. Panel (c) of Figure B.5 shows the estimated β_1^h coefficients when constructing $\mathcal{M}_{it}$ using only the maturing amount of variable-coupon bonds. The estimates are insignificant. A potential reason for this result is the relatively low number and value of variable-coupon bonds. We observe four times more fixed-coupon bonds than variable-coupon bonds in our sample. When combining the maturing amount of fixed-coupon and variable-coupon bonds, the estimates are close to our baseline results, see panel (d).

Denominators in $\mathcal{M}_{it}$. Equation (2.1) defines the maturing bond share $\mathcal{M}_{it}$ as the ratio of maturing bonds over the backward-looking four-quarter average of total debt. We consider three alternative measures, for which we replace total debt in the denominator with capital, sales, or assets. Panels (a)-(c) of Figure B.6 show the associated β_1^h estimates. In panel (d), we show the β_1^h estimates when using the simple lagged level of debt, capital, sales, and assets, respectively. Our main finding is robust to these alternative definitions of $\mathcal{M}_{it}$.

Unobserved firm characteristics. Our main empirical result is robust to controlling for permanent differences in the maturing bond share across firms and a broad set of other variables. To investigate the potential role of unobserved variables, we follow the approach in Cinelli and Hazlett (2020) which provides a necessary condition for an estimate to be purely spurious in the sense that the true coefficient is zero. If we consider $h = 8$ in Figure 2 (b) where $\beta_1^8 = -0.32$, unobserved variables would need to explain at least 36% of the residual variance in capital growth and in the interaction between $\mathcal{M}_{it}$ and $\varepsilon_t^{\mathrm{mp}}$. For comparison, all controls and fixed effects included in specification (2.3) explain 21% of the variance in the interaction between $\mathcal{M}_{it}$ and $\varepsilon_t^{\mathrm{mp}}$. Unobserved variables would thus need to explain more residual variance than all controls and fixed effects included in our extended specification.

Firm age. Recent research has highlighted the role of firm age for understanding the investment response to monetary policy shocks (e.g., Cloyne et al., 2020). Figure B.7 in the Appendix shows that our main finding is not affected by controlling for firm age.

Book value of capital. Our main finding in Figure 2 is based on firm-level capital stocks, constructed using a perpetual inventory method. If we instead measure capital by deflated net fixed assets, we obtain similarly significant, but larger, estimates of β_1^h, see Figure B.8.

Dummy specification. Our baseline specification includes a linear interaction between monetary policy shocks and the maturing bond share. Alternatively, we consider a modification of (2.2), 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.9 shows that this leads to similar conclusions.

Monetary policy shocks. Our main findings are robust to a variety of alternative monetary policy shock series. Our baseline shock series is based on changes in the three-months-ahead federal funds future around regular FOMC meetings, sign-restricted following Jarociński and Karadi (2020). Figure B.10 compares these baseline shocks with changes in the 2-quarter, 3-quarter, and 4-quarter ahead eurodollar futures, using either the observed future price changes or the sign-restricted price changes.

Great Recession and ZLB. We study the sensitivity of our results with respect to different time periods by excluding the Great Recession period or the post-Great Recession period, which is largely characterized by a binding effective zero lower bound on monetary policy. Figure B.11 shows the β_1^h estimates when using monetary policy shocks until the height of the Great Recession in 2008Q2, or when excluding 2008Q3–2009Q2 from the sample. The results show that our findings are robust to varying the time sample of our analysis.

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 implications of this result for the aggregate effects of monetary policy, we develop a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity.

At the heart of the model is a continuum of heterogeneous production firms which produce output using capital and labor. Capital is financed through equity and nominal debt. Debt has a tax advantage relative to equity but introduces the risk of costly default. Firms can choose a mix of short-term debt and long-term debt. Long-term debt saves roll-over costs but generates debt overhang which increases future leverage and default risk.

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

3.1 Production firms

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

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

Earnings before interest and taxes are

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

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

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

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

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

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

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

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

where the real face value of nominal short-term and long-term debt depends on (gross) inflation $\pi_t \equiv P_t/P_{t-1}$, and $A_{it} k_{it}^{\alpha} = \max_{l_{it}} \{ p_t y_{it} - w_t l_{it} \}$, with $A_{it} = A(z_{it}, p_t, w_t)$ and $\alpha \in (0,1)$ (see Appendix C.1 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 a firm's assets to creditors for liquidation. Default is costly. Creditors only recover a fraction $1 - \xi$ of firm assets.

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

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

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

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

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

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

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 $b_{it+1}^L < (1-\gamma)b_{it}^L/\pi_t$) is costless. Total debt issuance costs $H(b_{it+1}^S, b_{it+1}^L, b_{it}^L/\pi_t)$ are therefore

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

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 4. A firm enters period t with an idiosyncratic state $x_{it} \equiv (z_{it}, k_{it}, b_{it}^S, b_{it}^L)$. Given the aggregate state S_t (defined below), it chooses labor demand l_{it} and produces output y_{it}. After the idiosyncratic capital quality shock ε_{it} is realized, the firm decides whether to default. Negative realizations of ε_{it} can generate losses that absent default must be borne by shareholders through lower

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

Figure 4: Timing
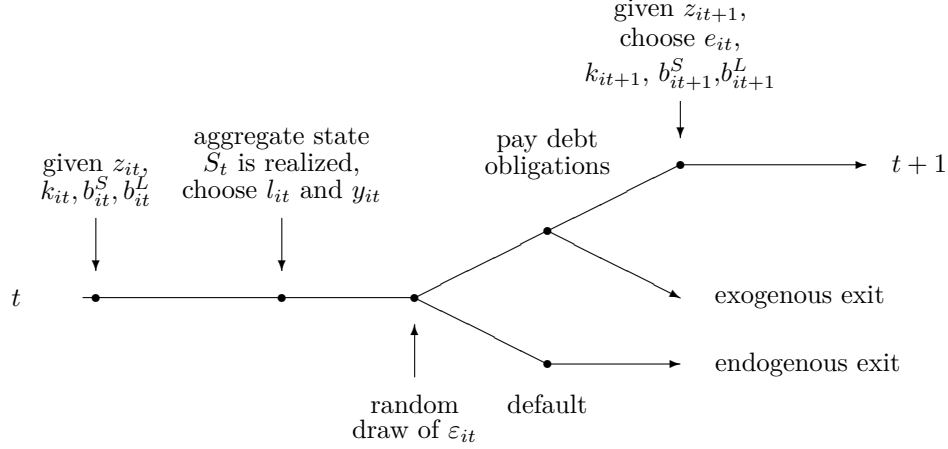
dividends or higher equity injections. Limited liability creates an upper bound on the losses that shareholders are willing to bear. Let $W_t(x_{it}, \varepsilon_{it}; S_t)$ denote shareholder value conditional on servicing all current debt obligations. Default is optimal if and only if $W_t(x_{it}, \varepsilon_{it}; S_t) < 0$. After the realization of ε_{it}, shareholder value is therefore given by

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

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

$$W_t(x_{it}, \varepsilon_{it}; S_t) = (1 - \kappa)\mathbb{E}_{z_{it+1}|z_{it}}W_t^C(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) + \kappa\left(q_{it} - \frac{(1-\gamma)b_{it}^L}{\pi_t}\mathbb{E}_{z_{it+1}|z_{it}}p_{it}^L\right) \tag{3.8}$$

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

$$W_t^C(x_{it}, \varepsilon_{it}, z_{it+1}; S_t) = \max_{\substack{e_{it} \geq \underline{e}, k_{it+1}, \\ b_{it+1}^S, b_{it+1}^L}} -e_{it} - G(e_{it}) - H\left(b_{it+1}^S, b_{it+1}^L, \frac{b_{it}^L}{\pi_t}\right) +$$

$$\mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\int_{\varepsilon_{it+1}} V_{t+1}(x_{it+1}, \varepsilon_{it+1}; S_{t+1})\varphi(\varepsilon_{it+1})d\varepsilon_{it+1} \tag{3.9}$$

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

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[16]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 the entire asset value of the firm as dividend: $e_{it} = -q_{it}$. In

3.2 Creditors

A firm's choice of capital k_{it+1}, short-term debt b_{it+1}^S, and long-term debt b_{it+1}^L 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 $(1+c)b_{it+1}^S/\pi_{t+1}$, and long-term creditors are paid $(\gamma+c)b_{it+1}^L/\pi_{t+1}$. In case of default, the value of firm assets is

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

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

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

$$p_{it}^S = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1} \int_{\varepsilon_{it+1}} \left[(1-\mathcal{D}_{it+1})\frac{1+c}{\pi_{t+1}} + \mathcal{D}_{it+1}\frac{(1-\xi)\underline{q}_{it+1}}{b_{it+1}^S + b_{it+1}^L}\right]\varphi(\varepsilon_{it+1})d\varepsilon_{it+1}, \qquad (3.11)$$

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

$$p_{it}^L = \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1} \int_{\varepsilon_{it+1}} \left[(1-\mathcal{D}_{it+1})\frac{\gamma+c+(1-\gamma)\mathbb{E}_{z_{it+2}|z_{it+1}}g_{t+1}(x_{it+1},\varepsilon_{it+1},z_{it+2};S_{t+1})}{\pi_{t+1}}\right.$$
$$\left. + \mathcal{D}_{it+1}\frac{(1-\xi)\underline{q}_{it+1}}{b_{it+1}^S + b_{it+1}^L}\right]\varphi(\varepsilon_{it+1})d\varepsilon_{it+1}. \qquad (3.12)$$

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

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

$$1 - \rho(1-p_t) - \lambda\pi_t(\pi_t-1) + \mathbb{E}_{S_{t+1}|S_t}\Lambda_{t,t+1}\lambda\frac{Y_{t+1}}{Y_t}\pi_{t+1}(\pi_{t+1}-1) = 0, \qquad (3.13)$$

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.

where $\rho > 1$ is the elasticity of substitution over differentiated varieties, and λ is a price adjustment cost parameter (see Appendix C.1 for a detailed derivation). Equation (3.13) 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 (3.13). A higher value of the price adjustment cost parameter λ dampens the contemporary response of inflation.

3.4   Capital producers

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

$$K_{t+1} = \Phi\left(\frac{I_t}{K_t}\right) K_t + (1 - \delta)K_t, \quad \text{where} \quad \Phi\left(\frac{I_t}{K_t}\right) = \frac{\delta^{\frac{1}{\phi}}}{1 - \frac{1}{\phi}}\left(\frac{I_t}{K_t}\right)^{1 - \frac{1}{\phi}} - \frac{\delta}{\phi - 1}. \quad (3.14)$$

Profit maximization pins down the price of capital goods:

$$Q_t = \left(\frac{\frac{I_t}{K_t}}{\delta}\right)^{\frac{1}{\phi}} \quad (3.15)$$

3.5   Government and monetary policy

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

$$1 + i_t = \frac{1}{\beta}\pi_t^{\varphi^{\mathrm{mp}}} e^{\eta_t^{\mathrm{mp}}}, \quad (3.16)$$

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

$$\eta_t^{\mathrm{mp}} = \rho^{\mathrm{mp}}\eta_{t-1}^{\mathrm{mp}} + \varepsilon_t^{\mathrm{mp}}, \quad \text{with} \quad \varepsilon_t^{\mathrm{mp}} \sim N(0, \sigma_{\mathrm{mp}}^2). \quad (3.17)$$

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

$$\log(C_t) - \frac{L_t^{1+\theta}}{1+\theta}, \quad \text{with} \quad \theta > 0. \tag{3.18}$$

The stochastic discount factor of the representative household is

$$\Lambda_{t,t+1} = \beta \frac{C_t}{C_{t+1}}. \tag{3.19}$$

3.7 General equilibrium

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

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

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

$$\tag{3.20}$$

subject to:

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

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

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

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

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

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

$$\tag{3.21}$$

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

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

1. *Production firms:* The value functions $V(x, \varepsilon; S)$, $W(x, \varepsilon; S)$, $W^C(x, \varepsilon, z'; S)$, and policy functions $\phi(x, \varepsilon, z'; S) = \{e, k', b^{S'}, b^{L'}\}$ solve the firm problem (3.20).

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

3. *Retail firms:* p and π follow the New Keynesian Phillips curve (3.13).

4. *Capital producers:* The price of capital Q is given by (3.15).

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 (3.16).

7. *Firm distribution:* $\mu(x') = \Gamma(\mu(x); S)$ as in (3.21).

8. *Market clearing:* The labor market, the final goods market, and the market for capital goods clear (see Appendix C.1 for details).

4 Characterization

In this section, we first describe how production firms choose capital, leverage, and debt maturity. We then explain how firms' investment responses to monetary policy shocks depend on debt maturity.

4.1 First-order conditions

The problem of a production firm (3.20) can be expressed in terms of three choice variables: the scale of production k' and the amounts of short-term debt $b^{S'}$ and long-term debt $b^{L'}$. We characterize the equilibrium behavior of firms in terms of the three associated first-order conditions. For simplicity, we discuss these optimality conditions assuming that there is no exogenous exit ($\kappa = 0$). See Appendix C.2 for the general case and detailed derivations.

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

$$\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[-Q + b^{S'}\frac{\partial p^S}{\partial k'} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}\right]$$

$$+ \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'}[1 - \mathcal{D}(x', \varepsilon'; S')]\frac{\partial q(x', \varepsilon'; S')}{\partial k'}\mathbb{E}_{z''|z'}\left(1 + \frac{\partial G(e')}{\partial e'}\right)\varphi(\varepsilon')d\varepsilon' = 0. \qquad (4.1)$$

This equation can be decomposed into the costs and benefits of capital. For given choices of $b^{S'}$ and $b^{L'}$, an increase in capital k' must be financed through an equity injection into the firm (see equation 3.4). The marginal cost of capital therefore depends on the price of capital Q and the marginal equity issuance cost $\partial G(e)/\partial e$, shown on the first line of (4.1). The marginal benefit of capital consists of two parts. The first one is direct: capital increases production and raises future assets $q(x', \varepsilon'; S')$, as shown on the second line of (4.1). If default is avoided, higher assets reduce the need for future equity issuance or increase future dividends. The second benefit is indirect. If capital reduces default risk, it increases bond prices and bond market revenue, $\partial p^S/\partial k' > 0$ and $\partial p^L/\partial k' > 0$ on the first line of (4.1).

A firm's past choices of debt issuance and debt maturity are important for this indirect benefit of capital. As shown on the first line of (4.1), the benefit is falling in the amount of previously issued long-term debt $(1-\gamma)b^L/\pi$. A higher long-term bond price p^L benefits shareholders only to the extent that it increases the firm's revenue from selling new long-term debt. The fact that a lower default risk also increases the market value of existing long-term debt is not internalized by the firm. In this way, a larger existing stock of debt can reduce firm investment. This is the classic *debt overhang* effect described in Myers (1977).

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

$$\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[p^S + b^{S'}\frac{\partial p^S}{\partial b^{S'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{S'}}\right] - \frac{\partial H(b^{S'}, b^{L'}, \frac{b^L}{\pi})}{\partial b^{S'}}$$

$$+ \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'}[1 - \mathcal{D}(x', \varepsilon'; S')]\frac{\partial q(x', \varepsilon'; S')}{\partial b^{S'}}\mathbb{E}_{z''|z'}\left(1 + \frac{\partial G(e')}{\partial e'}\right)\varphi(\varepsilon')d\varepsilon' = 0. \qquad (4.2)$$

For given choices of k' and $b^{L'}$, selling additional short-term debt is beneficial because it reduces the need for costly equity issuance by $[1 + \partial G(e)/\partial e] \cdot p^S$. This is shown on the first line of (4.2). The costs of short-term debt consist of debt issuance costs $H(\cdot)$ and higher default risk which reduces bond market revenue, i.e., $\partial p^S/\partial b^{S'} < 0$ and $\partial p^L/\partial b^{S'} < 0$. For each short-term bond sold, the firm promises a payment of $(1 + c)/\pi'$ which reduces future assets, captured by $\partial q(x', \varepsilon'; S')/\partial b^{S'} < 0$ on the second line of (4.2). The bond price p^S fully reflects the coupon c promised to creditors, but because it is tax deductible it only reduces $q(x', \varepsilon'; S')$ by $(1 - \tau)c$. This is the tax benefit of debt.

A larger stock of previously issued long-term debt $(1-\gamma)b^L/\pi$ lowers bond market revenue. As can be seen from the first line of (4.2), this reduces the impact of changes in p^L caused by additional short-term debt $b^{S'}$. The firm disregards the fact that an increase in default risk lowers the market value of existing long-term debt. In this way, debt overhang increases firms' incentive to issue additional debt.[17]

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[17] In the sovereign debt literature (e.g., Hatchondo et al., 2016) this incentive to increase indebtedness

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

$$\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[p^L + b^{S'}\frac{\partial p^S}{\partial b^{L'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{L'}}\right] - \frac{\partial H(b^{S'}, b^{L'}, \frac{b^L}{\pi})}{\partial b^{L'}}$$

$$+ \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'}[1 - \mathcal{D}(x', \varepsilon'; S')]$$

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

$$(4.3)$$

Similar to short-term debt, selling additional long-term debt reduces the need for costly equity issuance by $[1 + \partial G(e)/\partial e] \cdot p^L$. At the same time, it increases a firm's default risk and lowers bond market revenue, $\partial p^S/\partial b^{L'} < 0$ and $\partial p^L/\partial b^{L'} < 0$. In addition, the firm incurs the marginal debt issuance cost $\partial H(b^{S'}, b^{L'}, b^L/\pi)/\partial b^{L'} > 0$. This is shown on the first line of (4.3). Different from short-term debt, a long-term bond only promises a payment of $(\gamma + c)/\pi'$ next period, a fraction γ of the principal plus a coupon. The associated reduction of future assets $q(x', \varepsilon'; S')$ on the third line of (4.3) is therefore smaller. However, the fact that a fraction $1 - \gamma$ of long-term debt remains outstanding lowers future bond market revenue by $(1 - \gamma)/\pi' \cdot g(x', \varepsilon', z''; S')$.

The main benefit of issuing long-term debt is that it reduces future debt issuance costs, shown as $\partial H(b^{S''}, b^{L''}, b^{L'}/\pi')/\partial b^{L'} < 0$ on the third line of (4.3). The downside is that it creates debt overhang. Whereas an increase in $b^{S'}$ affects p^L only through next period's default risk, an increase in $b^{L'}$ also affects p^L through its effect on future choices of capital k'', short-term debt $b^{S''}$, and long-term debt $b^{L''}$. As discussed above, a higher future stock of outstanding long-term debt generates debt overhang which can lead to reduced investment and higher borrowing. This increases future leverage and default risk and thereby has an additional negative effect on today's bond price p^L.

Debt overhang is a commitment problem. When selling long-term debt, shareholders would like to promise low future values of leverage and default risk because this would increase today's bond price p^L. However, this promise is not credible. After long-term debt is sold, the firm continues to internalize the benefits of higher leverage. Yet a part of the associated costs is borne by existing creditors. As creditors have rational expectations, p^L correctly anticipates the effects of debt overhang on future firm behavior. Shareholders therefore face a commitment problem: leverage is higher ex-post than optimal ex-ante (see Jungherr and Schott, 2021).[18]

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at the expense of existing creditors is known as *debt dilution*. In corporate finance, the term *debt dilution* is sometimes used to describe the specific situation that a larger number of creditors must share a given liquidation value of a bankrupt firm. The mechanism described above is at work even if the liquidation value is zero or if existing debt is fully prioritized (as in Bizer and DeMarzo, 1992).

[18]A large literature documents the empirical use and effects of seniority structures, secured assets, and debt covenants aimed at mitigating conflicts of interest between existing creditors and shareholders (e.g., Green, 2018; Drechsel, 2019; Greenwald, 2019; Adler, 2020; Benmelech et al., 2020; Ivashina and Vallee, 2020; Chodorow-Reich and Falato, 2021; Lian and Ma, 2021). Empirically, these contracting features are less common for bonds than they are for bank loans, and their usage is increasing with default risk.

4.2   Debt maturity and the investment effects of monetary policy

We now return to the question that lies at the heart of this paper: How does debt maturity affect the firm-level investment response to monetary policy shocks? This section explains that in our model debt maturity matters because of two channels: *roll-over risk* and *debt overhang*. Ceteris paribus, roll-over risk generates larger investment responses for firms which borrow at shorter maturities whereas debt overhang implies the opposite.

Consider a contractionary monetary policy shock which raises the real interest rate. While this increases the cost of capital for all firms, differences in debt maturity generate heterogeneous investment responses. In the model, the maturing bond share is

$$\mathcal{M} = \frac{b^S + \gamma b^L}{b^S + b^L}. \tag{4.4}$$

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. For a given amount of total debt, firms with lower $\mathcal{M}$ borrow at longer maturities, roll over less debt per period, and choose next period's capital k' in the presence of a higher amount of outstanding long-term debt $(1 - \gamma)b^L/\pi$. Outstanding long-term debt enters the firm problem through equity issuance e, i.e., the cash flow from shareholders to the firm:

$$e = Qk' - q - \underbrace{\left(b^{S'}p^S + \left(b^{L'} - \frac{(1 - \gamma)b^L}{\pi} \right) p^L \right)}_{\text{bond market revenue}}. \tag{4.5}$$

The role of $\mathcal{M}$ in generating heterogeneity in firms' investment responses can be decomposed into two channels, roll-over risk and debt overhang. These channels are illustrated in Figure 5.

Roll-over risk.   Panel (a) of Figure 5 shows that a contractionary monetary policy shock increases equity issuance costs by more for firms with a higher maturing bond share $\mathcal{M}$. Because these firms have higher roll-over needs, they face a larger reduction in bond market revenue. Ceteris paribus, this requires higher equity issuance which increases the cost of capital. Roll-over risk can therefore generate a larger investment reduction for high-$\mathcal{M}$ firms.

More precisely, the figure shows equity issuance costs, $G(e)$, as a function of capital k'. The red solid line plots $G(e)$ for a high-$\mathcal{M}$ firm, the blue line is drawn for a firm with low $\mathcal{M}$. Firm assets q and leverage are identical across firms and held constant as k' increases. Because an increase in capital is partly financed through additional equity, equity issuance costs are increasing in capital for both firms.[19]

The dashed lines show the effect of an increase in the real interest rate r. A higher real rate implies a lower stochastic discount factor Λ and lower bond prices p^S and p^L for both firms. Because the high-$\mathcal{M}$ firm rolls over more debt per period, the pass-through of bond price changes to bond market revenue and cash flow is higher. For a given choice of capital,

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[19]Equity issuance costs are higher for the low-$\mathcal{M}$ firm. Because this firm has the same amount of assets q but a higher amount of outstanding debt $(1 - \gamma)b^L/\pi$, its bond market revenue is lower. To obtain a given amount of capital k' it therefore needs to issue more equity.

Figure 5: Debt maturity and the effects of a contractionary monetary policy shock

(a) Roll-over risk

(b) Debt overhang
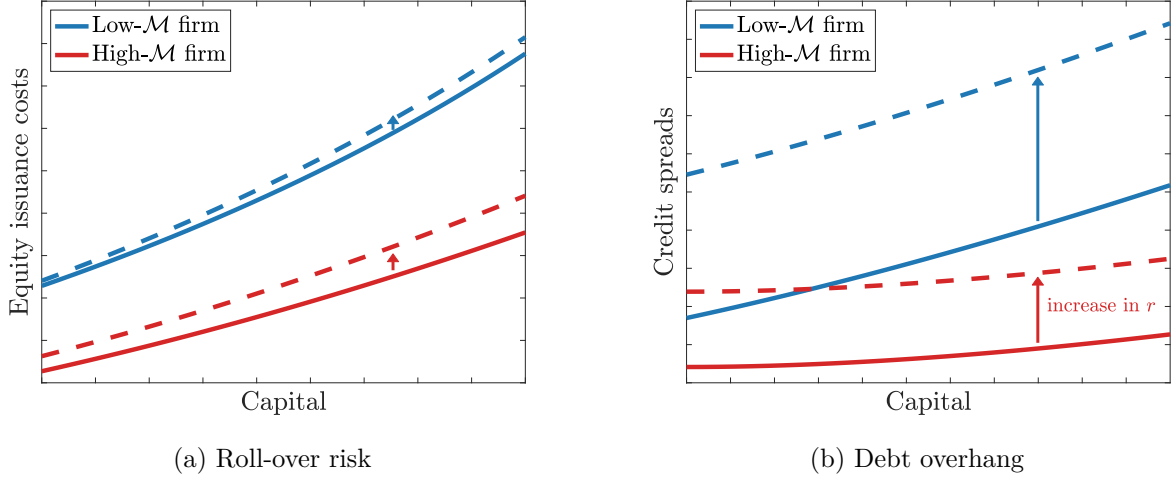
Note: Panel (a) shows equity issuance costs $G(e)$ as a function of capital k', panel (b) shows firm-specific credit spreads. Credit spreads are a maturity-weighted average over the short-term spread and long-term spread, see Appendix D.1. Solid lines represent the steady state, dashed lines show values after an unexpected increase in the real interest rate r. Blue lines show a firm with a low maturing bond share $\mathcal{M}$ (i.e., high $(1-\gamma)b^L/\pi$ and low $\mathcal{M}' = (b^{S'} + \gamma b^{L'})/(b^{S'} + b^{L'})$), red lines show a high-$\mathcal{M}$ firm. Both firms have identical productivity z and assets q. Leverage $(b^{S'} + b^{L'})/k'$ is identical across firms and held constant as k' increases. For the blue dashed line in panel (b), both leverage and r are increased for the low-$\mathcal{M}$ firm.

this implies a larger increase in equity issuance. With increasing equity issuance costs, this raises $\partial G(e)/\partial e$ and thereby the marginal cost of capital in first-order condition (4.1). Through this mechanism, a higher $\mathcal{M}$ exposes firms to roll-over risk and generates a larger investment response to changes in the real rate. Long-term debt lowers $\mathcal{M}$ and thereby provides insurance against roll-over risk.

Increasing marginal equity issuance costs are a necessary condition for roll-over risk to have an effect on investment. If equity issuance costs were linear or zero, current cash flow and existing assets q would not appear in firms' first-order condition for capital. Differences in $\mathcal{M}$ would still imply different effects of interest rate changes on cash flow and dividends, but those differences would not affect the marginal cost of capital.

In addition to increasing the real interest rate, a contractionary monetary policy shock also reduces inflation π and thereby increases the real value of outstanding nominal long-term debt $(1-\gamma)b^L/\pi$. This effect is known as *Fisherian debt deflation*. In our model, this effect further reduces the roll-over needs of low-$\mathcal{M}$ firms and therefore amplifies firms' heterogeneous exposure to roll-over risk.

Debt overhang. Panel (b) of Figure 5 shows that a contractionary monetary policy shock leads to a larger increase in credit spreads for firms with a low maturing bond share $\mathcal{M}$. Because these firms have higher amounts of previously issued long-term debt $(1-\gamma)b^L/\pi$, debt overhang generates a larger increase in default risk and credit spreads in response to the shock. This increase in default risk and credit spreads lowers investment. In this way,

debt overhang can generate a larger investment response for low-$\mathcal{M}$ firms.

The figure shows credit spreads as a function of capital k'. For the high-$\mathcal{M}$ firm, credit spreads display little variation in k'. This is because the high-$\mathcal{M}$ firm mainly relies on short-term debt whose credit spread only depends on next period's default risk. As leverage is held constant in Figure 5, next period's default risk varies very little in k'. Credit spreads increase more rapidly in k' for the low-$\mathcal{M}$ firm. This firm has a higher share of long-term debt whose credit spread also depends on default risk in future periods. Future default risk increases in k' because a higher value of k' implies a higher future stock of outstanding long-term debt $(1-\gamma)b^{L'}/\pi'$. Through debt overhang, this increases future leverage and default risk and thereby already raises the long-term credit spread today.

The dashed lines show the effect of an increase in the real interest rate r. The discounted net present value of future firm earnings falls, while the amount of previously issued long-term debt $(1-\gamma)b^L/\pi$ remains unchanged (or even rises if inflation π falls). Firms' incentive to increase leverage at the expense of existing creditors becomes stronger. This debt overhang effect is larger for the low-$\mathcal{M}$ firm with a higher amount of outstanding long-term debt $(1-\gamma)b^L/\pi$. In panel (b), this is illustrated through a larger relative increase in leverage for the low-$\mathcal{M}$ firm. Its default risk and credit spreads increase by more, which drives up the firm's cost of capital. Through this mechanism, a lower $\mathcal{M}$ exposes firms to debt overhang and generates a bigger investment response to changes in the real rate.[20]

Inflation π falls after a contractionary monetary policy shock. This raises the real burden of outstanding nominal long-term debt $(1-\gamma)b^L/\pi$. Low-$\mathcal{M}$ firms have higher amounts of outstanding long-term debt and are therefore more strongly affected by the increase in the real value of their nominal debt. Through debt overhang, this generates larger increases in default risk and credit spreads. In this way, Fisherian debt deflation amplifies firms' heterogeneous exposure to debt overhang.

5 Quantitative Analysis

The previous section showed that the role of debt maturity for firms' investment response is theoretically ambiguous. We therefore proceed with a quantitative analysis. Our calibrated model replicates several targeted and non-targeted moments that characterize financing choices of U.S. listed firms. The model also rationalizes the empirical result that firms with higher shares of maturing debt react more strongly to monetary policy shocks. At the aggregate level, we show that both long-term debt and heterogeneity amplify the effects of monetary policy.

5.1 Solution method

We use value function iteration and interpolation to compute the Markov perfect equilibrium of our model. There are three key challenges. The first is the dimensionality of the state space. The variables (z, k, b^S, b^L) describe the firm's idiosyncratic state at the beginning of the period. Together with S and ε, they determine a firm's default decision. Firms decide

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

about investment and financing at the end of the period after the realization of z'. The state in (3.20) is therefore given by $(z, k, b^S, b^L, \varepsilon, z'; S)$. To solve the model, we exploit the fact that this information can be summarized in the reduced state vector $(q, b, z'; S)$ which includes firm assets $q = q(z, k, b^S, b^L, \varepsilon; S)$ and outstanding long-term debt $b = (1 - \gamma)b^L$.

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

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

5.2 Calibration

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

Externally set parameters. The model period is one quarter. We set $\beta = 0.99$ which implies a quarterly steady state real interest rate of $r^* = 1.01\%$. In the steady state of the model, inflation is zero and the nominal interest rate i is equal to the real rate. The debt coupon is fixed at $c = r^*$ which implies that the steady state equilibrium prices of riskless short-term and long-term bonds are both equal to one. The preference parameter θ is chosen to match a Frisch elasticity of 2 as in Arellano et al. (2019).

The production technology parameters ζ and ψ are taken from Bloom et al. (2018). The quarterly depreciation rate δ is 2.5%. We follow Gomes et al. (2016) in setting the tax rate $\tau = 0.4$ and the repayment rate of long-term debt $\gamma = 0.05$.[21] The choice of γ implies a Macaulay duration of $(1 + r^*)/(\gamma + r^*) = 16.8$ quarters or 4.2 years. This is a conservative choice relative to the average duration of 6.5 years calculated by Gilchrist and Zakrajšek (2012) for a sample of U.S. corporate bonds with remaining term to maturity above one year.

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

Table 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

As in Kaplan et al. (2018), we set the elasticity of substitution for retail good varieties to $\rho = 10$ (implying a steady state markup of 11 percent) and the Taylor rule parameters to $\varphi^{\mathrm{mp}} = 1.25$ 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 et al., 2005). All externally set parameters are summarized in Table 2.

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

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

Once a firm has reached the highest productivity level Z_J, it remains there until it defaults or exits the economy exogenously. This productivity process has two desirable features. First, it captures the positive skewness of empirical firm growth (Decker et al., 2014). Second, it facilitates the computation of the Markov perfect equilibrium.[22]

We internally calibrate eight parameters: σ_ε, ξ, η, ν, ρ_z, $\bar{z}$, κ, and f. Their values are chosen to match key empirical moments which are informative about the financing and investment behavior of firms. Firm-level data on leverage, equity issuance, and capital growth comes from Compustat. Credit spreads are calculated by combining firm-level credit ratings with rating-specific corporate bond spreads, following Arellano et al. (2019). To discipline firms' maturity choices in the model, we use Compustat information on the share of total debt (bonds and loans) due within a year (*cf.* Figure 1). 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 internal calibration is summarized in Table 3. While the model is highly non-linear and all parameters are jointly identified, we provide some intuition for their identification. Average leverage depends on the standard deviation of the capital quality shock σ_ε because

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[22]If a firm's amount of outstanding long-term debt $(1 - \gamma)b^L/\pi$ is sufficiently high, large negative shocks to z' would cause the dividend payout constraint $e \geq \underline{e}$ in (3.20) to bind for any value of $\underline{e}$. The productivity process described above avoids this problem.

Table 3: Internally calibrated parameters

Parameter	Value	Target	Data	Model
σ_ε	0.66	Average firm leverage *(in %)*	34.4	29.3
ξ	0.90	Average credit spread on long-term debt *(in %)*	3.1	3.3
η	0.0045	Average share of debt due within a year *(in %)*	30.5	30.7
ν	0.0005	Average equity issuance *(in %)*	11.4	14.6
ρ_z	0.983	Average firm capital growth *(in %)*	1.0	1.2
$\bar{z}$	0.184	Std. of firm capital growth *(in %)*	8.3	9.7
κ	0.0151	Firm exit rate *(in %)*	2.2	2.3
f	0.274	Steady state value of firm entry	-	0

Note: The data sample is 1995-2017. Firm-level data on leverage (debt/assets), the share of debt due within a year, equity issuance (relative to assets), and capital growth 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.

higher earnings volatility induces firms to reduce leverage in order to contain the risk of default. The average credit spread is directly affected by the default cost ξ. The average maturing debt share pins down the debt issuance cost parameter η because higher debt issuance costs make short-term debt less attractive. The equity issuance cost parameter ν targets equity issuance relative to firm assets. The parameters ρ_z and $\bar{z}$ are important for matching the empirical moments of firm-level capital growth. The probability of exogenous exit κ affects the total rate of exit (endogenous and exogenous). Finally, the fixed cost of production f is chosen such that the steady state value of firm entry is zero.
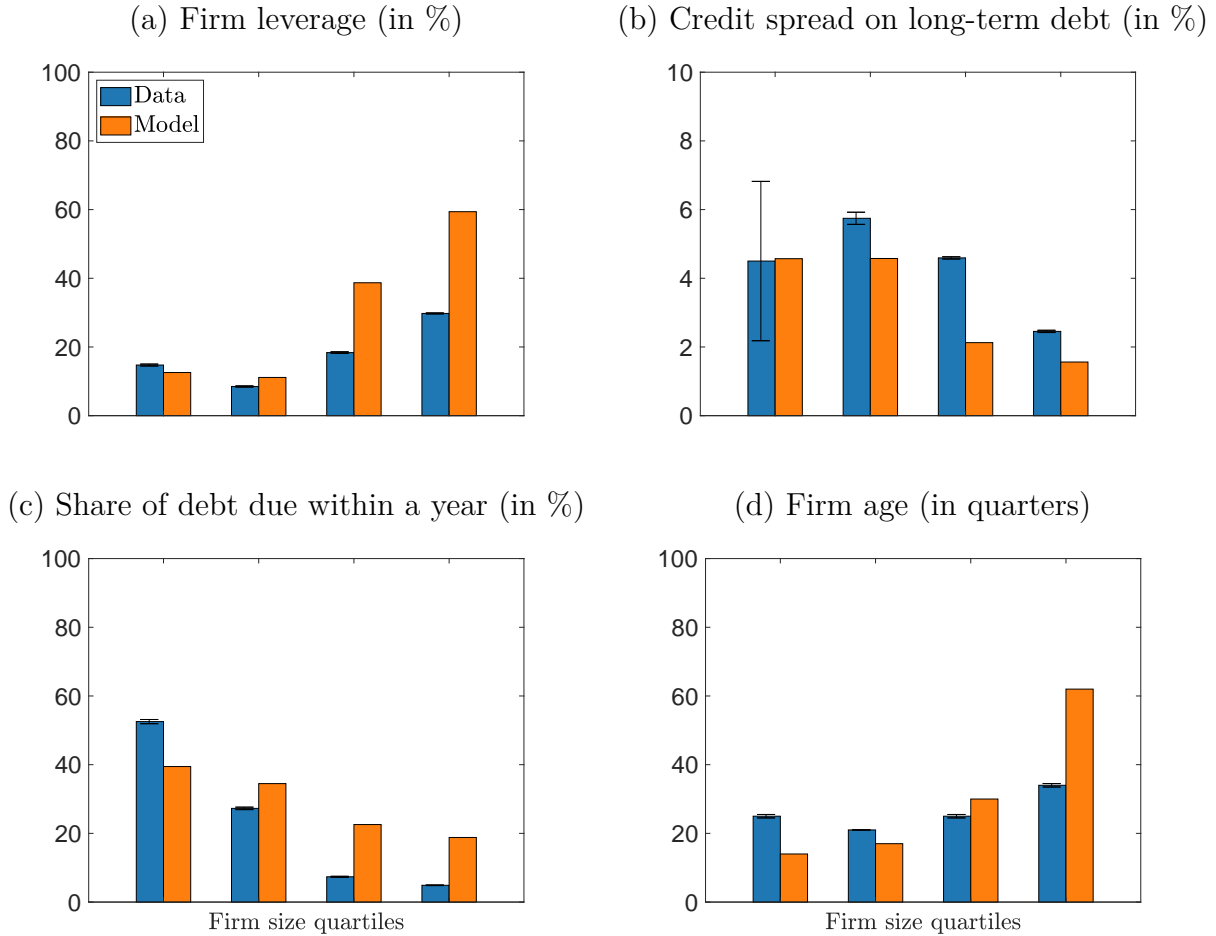
Table 3 shows that the model matches the data well. Average firm leverage and the maturing debt share are both about 30%. The average annual credit spread on long-term debt is close to 3 percent. Even though the value of the equity issuance cost parameter ν is smaller than the debt issuance cost parameter η, aggregate equity issuance costs exceed aggregate debt issuance costs (0.12% vs. 0.05% of GDP). The model generates a quarterly default rate of 0.8%. Although untargeted, the default rate is very close to the corresponding values of 0.8% in Bernanke et al. (1999) and the 1.0% in Moody's expected default frequency across rated and unrated Compustat firms reported by Hovakimian et al. (2011).

5.3 Steady state results

As we show in this section, the steady state of the calibrated model replicates how empirical firm financing choices vary by size and by age. One important fact in the data is that smaller and younger firms pay higher credit spreads and have larger shares of maturing debt. The model generates this result. It will play an important role for the cross-sectional effects of monetary policy in Section 5.4 below.

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

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 (in quarters)

Note: For each variable, median values are shown by size quartile. The data sample is 1995–2017. Firm-level data on size (total assets), leverage, the share of debt due within a year, and age (quarters since initial public offering) is from Compustat. Firm-level credit spreads are computed using data from Compustat and FISD. Empirical median values are shown with 95% confidence intervals. Confidence intervals are large for the bottom quartile in panel (b) because small firms are often unrated which means that we are unable to assign credit spreads to them. Model moments are computed from the stationary distribution of the model. See Appendix D.1 and D.2 for details.

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

The model replicates these empirical patterns. Differences in firm productivity are key for this result. Low productivity firms choose a smaller scale of production. The fixed cost of production f implies that smaller firms are less profitable and therefore have higher default risk for given amounts of leverage. As a consequence, smaller firms pay higher credit spreads and choose lower amounts of leverage (see Appendix D.3 for the policy functions of the calibrated model).

Panel (c) shows that the model also replicates the fact that the maturing debt share is higher for smaller firms. An advantage of long-term debt common to all firms is that it reduces future debt issuance costs. A disadvantage of issuing long-term debt is that it lowers

today's long-term bond price because debt overhang will lead to higher future leverage and default risk (*cf.* Section 4.1). This negative effect of long-term debt on today's long-term bond price $\partial p^L / \partial b^{L'} < 0$ is stronger for smaller firms. Smaller firms have a higher default risk, which implies that their long-term bond price is more sensitive to changes in future firm behavior (see Figure D.14 in Appendix D.3). As a consequence, the costs of debt overhang are higher for them. Through this mechanism, the model can explain why smaller firms borrow at shorter maturities and therefore have higher shares of maturing debt.

A brief comparison with Figure 5 in Section 4.2 is in order here. In Figure 5, we compared two firms with exogenous differences in maturing debt shares. Debt overhang was larger for the firm with a lower maturing debt share. In the quantitative model, debt maturity is endogenous. As Figure 6 shows, firms' maturity choice responds to differences in the costs of debt overhang. Debt overhang is a larger problem for firms with higher default risk. As a consequence, high-default risk firms choose to borrow at shorter maturities and therefore have higher maturing debt shares. This result will play an important role for the cross-sectional effects of monetary policy discussed below.

Finally, panel (d) of Figure 6 shows that the model also replicates the positive empirical relationship between firm age and size. Average firm productivity increases with age in the model. Older firms therefore choose higher values of capital and are larger. Additional results on the co-movement of age with leverage, credit spreads, and debt maturity are shown in Figure D.15 in the Appendix. In the data, leverage is increasing in age whereas credit spreads and the maturing debt share are falling. The model replicates these untargeted patterns.

## 5.4   Aggregate effects of monetary policy shocks

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

Figure 7 shows the aggregate effects of an unexpected one-standard deviation (30bp) increase in the nominal interest rate i caused by a monetary policy shock ($\varepsilon_t^{\mathrm{mp}}$ in equation (3.17)). GDP, consumption, and investment all fall in response to the shock. The real interest rate r increases by more than the nominal rate because inflation π falls. The associated decline in aggregate demand causes a reduction in the price of undifferentiated output p. This reduces firms' demand for capital and labor and decreases the wage w and the price of capital goods Q.

The second row of Figure 7 shows key financial variables. The increase in the real interest rate reduces firm value while lower inflation π increases the real burden of outstanding nominal long-term debt $(1 - \gamma)b^L / \pi$. As a result, firms accept an increase in leverage and default risk. Short-term credit spreads respond more strongly than long-term spreads because the price of short-term debt only depends on next period's default risk while the long-term bond price depends on default risk in all future periods.[23]

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[23]The model result that credit spreads rise after a contractionary monetary policy shock is consistent with empirical results in Gertler and Karadi (2015).

Figure 7: Aggregate response to a contractionary monetary policy shock
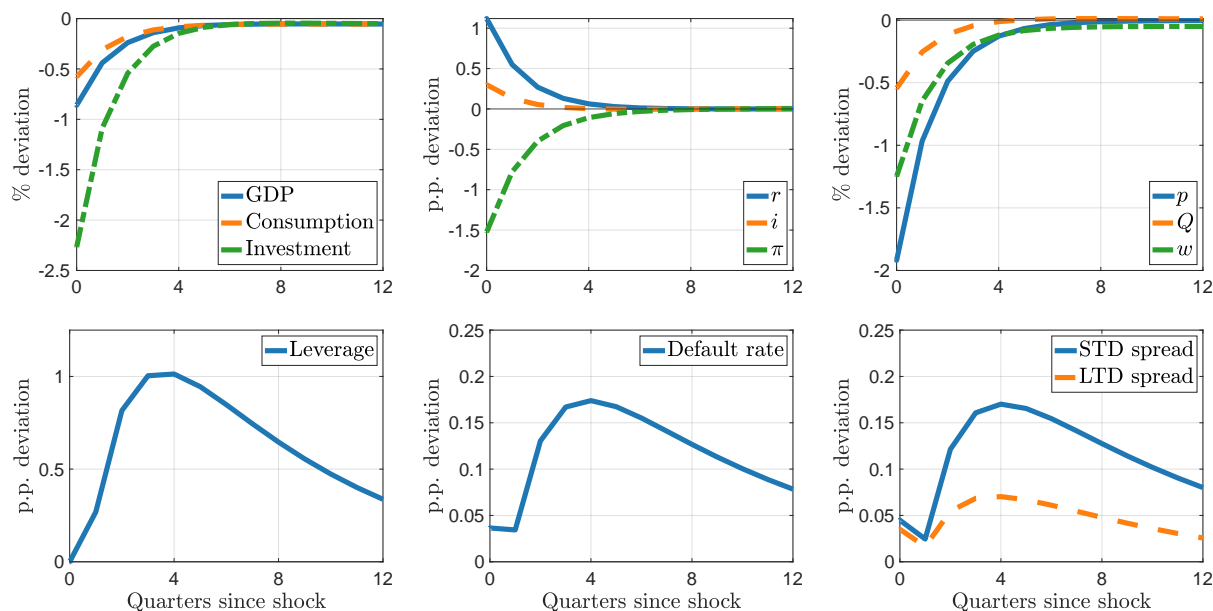
Note: The real interest rate r, the nominal rate i, and inflation π are annualized. Leverage is aggregate firm debt over aggregate firm capital. The default rate is annual. The short-term credit spread (*STD spread*) and the long-term credit spread (*LTD spread*) are cross-sectional averages. See Appendix D.1 for details.

5.5 Heterogenous effects of monetary policy shocks

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

Local projection on simulated model data. To compare the model with the empirical evidence, we run the model counterpart of the baseline local projection (2.2) on simulated data generated by our model. We estimate:

$$\Delta^{h+1} \log k_{it+h} = \beta_0^h \mathcal{M}_{it} + \beta_1^h \mathcal{M}_{it} \varepsilon_t^{\mathrm{mp}} + \delta_i^h + \delta_t^h + \nu_{it+h}^h, \tag{5.2}$$

where δ_i^h and δ_t^h are firm- and quarter-fixed effects, and $\mathcal{M}_{it}$ is the maturing bond share as defined in (4.4).[24] 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(a)). The estimates in Figure 8 are standardized to measure the differential response associated with a one standard deviation higher $\mathcal{M}_{it}$ at the time of an unexpected one standard deviation (30bp) increase in the nominal interest rate i.

As in the data, β_1^h is negative at all time horizons: A higher $\mathcal{M}_{it}$ implies a larger negative capital response. The model accounts for 69% of the peak empirical effect. Similar to the

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[24]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 the denominator instead.

Figure 8: Differential capital growth response associated with $\mathcal{M}_{it}$
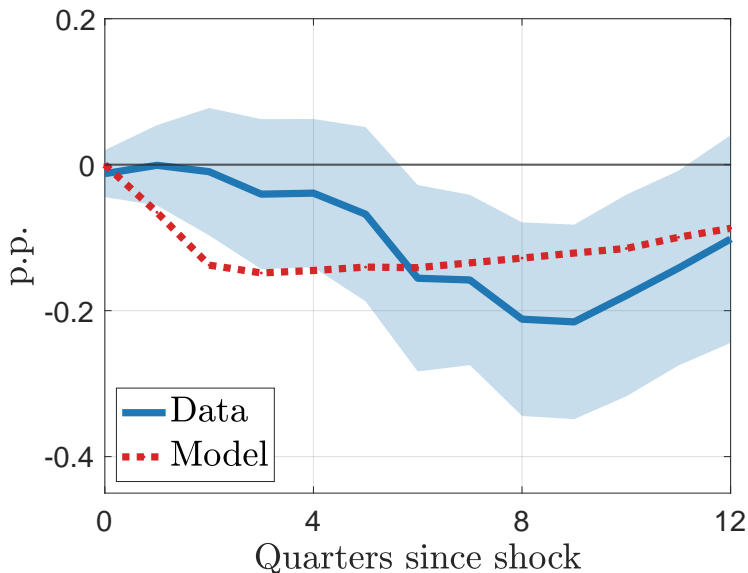
Note: The red dotted line shows the estimated β_1^h coefficients based on equation (5.2) using simulated model data. The β_1^h estimates are standardized to capture the differential cumulative capital growth response (in p.p.) to a one standard deviation (30bp) increase in the nominal interest rate i associated with a one standard deviation higher $\mathcal{M}_{it}$. The blue solid line shows the empirical estimates from Figure 2(a) together with 95% confidence bands.

empirical results, the differential effect on firm investment is initially small and builds up over time, reaching its peak three quarters after the shock. The persistence generated by the model is high: Twelve quarters after the shock, 59% of the peak differential effect is still present.

The model also replicates the empirical role of $\mathcal{M}_{it}$ for the response of other firm variables. Figure D.16 in the Appendix shows that a higher $\mathcal{M}_{it}$ at the time of the shock is associated with larger reductions in sales, employment, and debt relative to pre-shock capital. These model results are in line with the empirical findings of Figure 3.

Monetary transmission and $\mathcal{M}_{it}$. 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 effect on firm investment. Figure 9 shows that both roll-over risk and debt overhang contribute to this result.

The figure shows average responses of firms whose maturing bond share is above or below the median at the time of the shock. Panel (a) shows that high-$\mathcal{M}$ firms sharply reduce investment after the contractionary monetary policy shock. In contrast, low-$\mathcal{M}$ firms slightly increase capital as they benefit from lower factor prices w and Q. As in Figure 8, the difference between the two firm groups builds up over time and peaks several quarters quarters after the shock.

Roll-over risk: Panel (b) shows that equity issuance costs fall for both groups of firms after the contractionary shock. However, the decline is smaller for high-$\mathcal{M}$ firms. As explained in

Figure 9: Heterogeneous responses to a contractionary monetary policy shock

(a) $\Delta \log$ capital (b) Equity issuance costs (c) Credit spreads
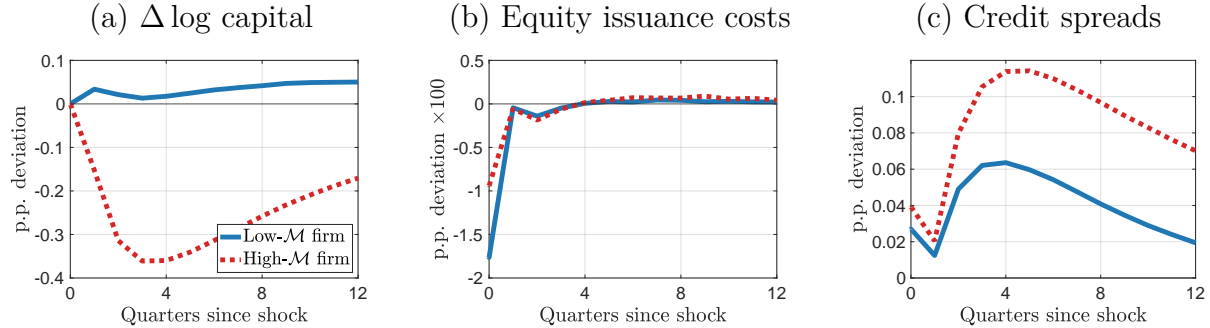
Note: The panels show the effect of an unexpected one-standard deviation (30bp) increase in the nominal interest rate i for firms below and above the median maturing bond share $\mathcal{M}$ at the time of the shock. Panel (a) shows average firm-level changes in log capital. Panel (b) shows average equity issuance costs (relative to steady state capital). Panel (c) shows average credit spreads.

Section 4.2, high-$\mathcal{M}$ firms have higher roll-over needs which generates a higher pass-through of lower bond prices to bond market revenue and cash flow. This cash shortfall requires higher equity issuance compared to low-$\mathcal{M}$ firms. Equity issuance costs therefore fall by less for high-$\mathcal{M}$ firms which increases their cost of capital relative to low-$\mathcal{M}$ firms and contributes to a larger reduction in investment. However, the differential impact on equity issuance is short-lived.

Debt overhang: Panel (c) shows credit spreads by firm group. Different from Figure 5 in Section 4.2, credit spreads increase by more for high-$\mathcal{M}$ firms. The reason for this seeming contradiction is that debt maturity is an endogenous response to the firm-specific costs of debt overhang. Because debt overhang is more severe for firms with higher default risk, they choose to borrow at shorter maturities and therefore have higher maturing bond shares $\mathcal{M}$.

After a contractionary monetary policy shock, many firms reduce capital while the real burden of outstanding nominal long-term debt $(1-\gamma)b^L/\pi$ grows through debt deflation. It is feasible to keep leverage, default risk, and credit spreads constant after a reduction in capital but this would require repurchasing some of the now outsized stock of previously issued long-term debt. And while these repurchases would need to be financed by shareholders, they would to a large extent benefit existing creditors. The size of this externality is larger for firms with higher default risk because the market value of their debt is more sensitive to firm behavior. As a result, debt overhang drives up default risk and credit spreads by more for high-default risk firms despite their higher $\mathcal{M}$.[25]

The differential impact on credit spreads is long-lived, peaking four quarters after the shock. Debt deflation is an important reason for this persistence. The decline in inflation leads to a gradual build-up in the real burden of outstanding nominal debt. This amplifies firms' heterogeneous exposure to debt overhang and is key for the high degrees of persistence displayed in both panel (a) of Figure 9 and in Figure 8.

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[25]Because high-$\mathcal{M}$ firms face a higher default risk, a given increase in leverage causes a larger increase in their default risk compared to low-$\mathcal{M}$ firms. This explains why credit spreads grow by more for high-$\mathcal{M}$ firms even though debt increases by less, as shown in Figure D.16.

Figure 10: Counterfactuals: Differential capital growth response associated with $\mathcal{M}_{it}$
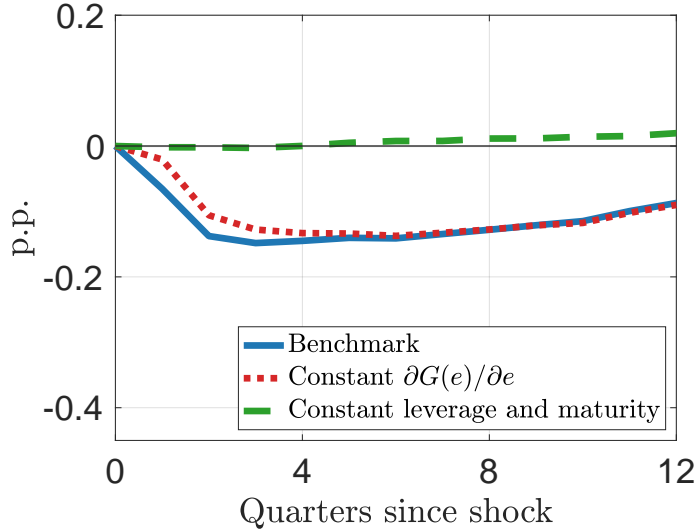
Note: The blue solid line shows the estimated β_1^h coefficients based on equation (5.2) using simulated model data (*cf.* Figure 8). The β_1^h estimates are standardized to capture the differential cumulative capital growth response (in p.p.) to a one standard deviation (30bp) increase in the nominal interest rate i associated with a one standard deviation higher $\mathcal{M}_{it}$. The red dotted line shows the corresponding value in a counterfactual economy with fixed marginal equity issuance costs. The green dashed line shows the corresponding value in a counterfactual economy with fixed leverage and debt maturity.

Decomposing the transmission channels. Roll-over risk and debt overhang both contribute to the result that investment falls by more for high-$\mathcal{M}$ firms after a contractionary monetary policy shock. To assess the two channels' relative quantitative importance, we simulate two counterfactual economies. We find that debt overhang is more important than roll-over risk for explaining the persistent differential investment effect associated with $\mathcal{M}$.

Constant marginal equity issuance costs: In the first counterfactual economy, for every firm state we hold marginal equity issuance costs $\partial G(e)/\partial e$ fixed at steady state values. This exercise is motivated by our analysis in Section 4.2, where we showed that roll-over risk only affects investment through changes in marginal equity issuance costs. By keeping marginal equity issuance costs at their steady state levels, we eliminate relative changes in the cost of capital that stem from different responses in equity issuance across firm groups.

Figure 10 compares the results from the local projection (5.2) using data from our benchmark model and the two counterfactual economies. The blue solid line reprints the estimates from the benchmark model. The red dotted line shows the β_1^h coefficients from the model with constant marginal equity issuance costs. The difference to our benchmark model is modest and short-lived. One reason for this result is that the cash flow effect stemming from different exposure to interest rate changes is small and does not generate much heterogeneity across firms. A simple back-of-the-envelope calculation shows that a 30bp increase in the nominal interest rate only produces differences in cash flow of less than 0.04% of firm capital. Because interest rates revert back to their long-run mean quickly after the monetary policy

shock, this effect is short-lived.[26]

Constant leverage and debt maturity: In the second counterfactual economy, we remove the effects of debt overhang on firms' investment response to monetary policy shocks. To do so, for every firm state we fix leverage $(b^{S'} + b^{L'})/k'$ and debt maturity $b^{L'}/(b^{S'} + b^{L'})$ at the respective steady state value. This is motivated by Section 4.2, where we described that debt overhang affects investment through the impact of firms' financing choices on default risk. In the counterfactual economy, firms cannot adjust their leverage and maturity choices in response to a monetary policy shock. As debt deflation increases the real burden of outstanding nominal debt, firms must keep leverage constant by raising outside equity or by reducing dividends.

The green dashed line in Figure 10 shows the β_1^h coefficients estimated using data from this counterfactual economy. The difference between high- and low-$\mathcal{M}$ firms' capital response disappears at all time horizons. Once firms' financing structure is held fixed, default risk increases homogeneously across firms. This prevents credit spreads and the cost of capital from increasing more for high-$\mathcal{M}$ firms, as shown in Figure D.17 in the Appendix. We conclude that debt overhang is the key channel for explaining persistent differences in the response of capital and credit spreads across firms.

5.6 Aggregate implications of heterogeneous debt maturity

In this section, we study the importance of heterogeneous debt maturity for the aggregate effects of monetary policy. We find that both long-term debt and heterogeneity amplify the aggregate effects of monetary policy shocks.

Model without long-term debt. To highlight the role of debt maturity for the aggregate effects of monetary policy, we first compare our benchmark model to an alternative economy in which firms can only issue short-term debt, but not long-term debt. This is the case in most macro models with firm-level financial frictions (e.g., Bernanke et al., 1999; Ottonello and Winberry, 2020). Because firms are only allowed to issue short-term debt, there is no heterogeneity in debt maturity in this economy. In all other respects, the setup is identical to the benchmark model with endogenous debt maturity described above.[27]

Figure 11 compares the aggregate effects of a contractionary monetary policy shock in our benchmark model (blue, solid lines) to two alternative economies. The green dashed lines show results for the short-term debt model. Although on impact the nominal interest rate increases by 30bp in all economies, the effects are very different. The negative GDP response is about 27% smaller in the short-term debt model (-0.63 p.p., compared to -0.86 p.p. in the benchmark economy). Investment and inflation also respond by less in the alternative model without long-term debt.

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[26]The standard deviation of the maturing bond share across firms is 13.1%. Assuming a leverage ratio of 30% and a real interest rate increase of one percentage point (as in Figure 7), a one-standard deviation higher value of $\mathcal{M}_{it}$ increases the fall in bond market revenue by $13.1\% \times 30\% \times 1\% = 0.039\%$ relative to firm capital. This calculation abstracts from changes in credit spreads caused by the monetary policy shock.

[27]To parameterize the short-term debt model, we set $\gamma = 1$ and re-calibrate model parameters to match the same empirical targets as above (*cf.* Table 3). Details are provided in Appendix D.5.

Figure 11: Aggregate response to monetary policy shock: Model comparison

(a) GDP   (b) Investment   (c) Real interest rate

(d) Inflation   (e) Default rate   (f) Firm leverage
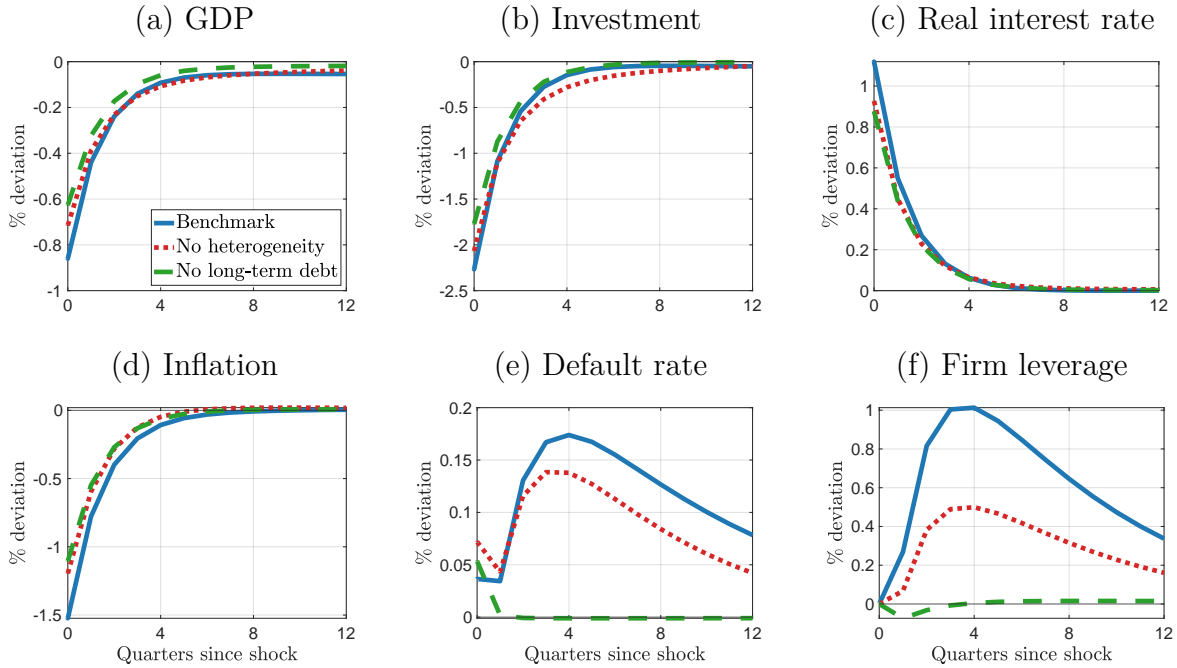
Note: The real interest rate r, inflation π, and default rates are annualized. Leverage is aggregate firm debt over aggregate firm capital. The blue solid lines are identical to those in Figure 7. The green dashed lines come from an alternative economy without long-term debt. The red dotted lines are from an alternative economy in which firms are ex-ante identical at the start of each period.

The reason for these dampened aggregate effects is that leverage and the default rate hardly react to the contractionary shock, as shown by the green dashed lines in panels (e) and (f). In the absence of long-term debt, there is no debt overhang. When firms decide on their leverage and default risk, no existing stock of previously issued long-term debt distorts their incentives. Because default risk and credit spreads move very little in the short-term debt model, the cost of capital increases by less compared to the benchmark economy which results in lower financial amplification.[28]

Model without heterogeneity. Different from existing models of long-term debt (e.g., Gomes et al., 2016), our model generates a realistic degree of debt heterogeneity across firms. In our second alternative economy, we study the quantitative importance of this heterogeneity. To do so, we solve an alternative model in which all firms are ex-ante identical every period. The setup is otherwise identical to the benchmark model with firm heterogeneity. In particular, both models include a debt maturity choice.[29]

The red dotted lines in Figure 11 show the response of the model without heterogeneity to

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[28] As a matter of fact, the model without long-term debt displays financial dampening relative to a model without financial frictions, as shown in Figure D.18 in the Appendix. In the benchmark model, the effects of monetary policy are amplified relative to the frictionless case through strongly counter-cyclical default rates and credit spreads.

[29] We calibrate the model without heterogeneity to the same empirical targets as above (*cf.* Table 3). Details are provided in Appendix D.5.

the contractionary monetary policy shock. Compared to the benchmark model, the negative GDP response is about 16% smaller (-0.72 p.p.). The initial responses of investment and inflation are dampened as well. Even though debt overhang is present in both economies and the steady state averages of leverage, credit spreads, and debt maturity are the same, an identical increase in the nominal rate causes very different model responses with and without firm heterogeneity.

An important reason for these distinct outcomes is the difference in persistence generated by the two models. While on impact GDP and investment respond by more in the benchmark model, they also revert back more quickly to their unconditional long-run averages. The persistence is lower in the benchmark model because it has an endogenous firm distribution: As default rates increase after a contractionary shock, defaulting firms are replaced by new firms that enter without existing debt. This reduces the average stock of outstanding long-term debt in the benchmark economy and lowers the negative impact of debt overhang, speeding up the recovery. This effect is absent in the economy without heterogeneity because all firms are ex-ante identical and the (degenerate) firm distribution is not time-varying.

Differences in persistence are important because of intertemporal substitution. The shorter-lived reduction of wages in the benchmark economy strengthens the substitution effect on labor supply and allocates labor away from periods of low wages (King and Rebelo, 1999). The resulting larger drop in output and consumption implies that the real interest rate increases by more in order to balance households' desire for consumption smoothing. In this way, lower persistence contributes to the larger initial decline in GDP in the benchmark economy. The alternative model without heterogeneity over-predicts the persistence of debt overhang and therefore understates the aggregate effects of monetary policy.

6   Conclusion

More than two decades after the first seminal contributions introduced frictional firm financing into quantitative dynamic models of the macroeconomy (e.g., Bernanke et al., 1999), the contemporaneous literature offers new insights by focusing on debt heterogeneity.[30] As part of this broader research agenda, our paper documents the vast amount of heterogeneity in U.S. public firms' maturity choices. The maturity dimension of debt heterogeneity is typically absent from standard one-period-debt macro models.

We showed that heterogeneous debt maturity matters for monetary policy. We used micro data to show that firms respond more strongly to monetary policy shocks when a higher fraction of their debt matures. We then developed a heterogeneous firm New Keynesian model with financial frictions and endogenous debt maturity. The model accounts for the maturity of debt and its distribution across firms. It replicates the empirical result that firms with higher shares of maturing debt react more strongly to monetary policy shocks. At the aggregate level, we showed that both long-term debt and heterogeneity amplify the effects of monetary policy shocks on GDP, investment, and inflation. We conclude that the maturity of firm debt and its distribution are important for the aggregate effects of monetary policy.

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[30]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; Gurkaynak et al., 2021), or between credit lines and term loans (Greenwald et al., 2021).

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

Another natural application of our framework is to study the consequences of unconventional monetary policy and quantitative easing. The persistent decline in the term structure of interest rates during the ten years following the Great Recession had different implications for firms borrowing at short and long maturities. Our results highlighted systematic differences between these firm groups. A rigorous analysis of the aggregate effects of quantitative easing therefore requires a model of heterogeneous debt maturity. We hope that the results presented in this paper provide a useful starting point for addressing these open questions.

One interesting empirical finding was that the precise timing of bond maturity can make a difference for firms' investment response to monetary policy shocks. An open question is whether non-convex adjustment costs induce firms to be more responsive to aggregate shocks at times of re-financing. While conceptually and computationally demanding, introducing non-convex adjustment costs to a framework of endogenous debt maturity and default could yield additional valuable insights.[31]

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[31]For recent contributions on aggregate implications of lumpy firm-level adjustment, see Koby and Wolf (2020), Baley and Blanco (2021), and Winberry (2021).

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Appendix A   Data Construction

A.1   Bond-level data

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

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

We then create a monthly panel of bonds which tracks the outstanding amount – the par value computed as number of bonds issued times principal amount – over the lifetime of a bond. Mergent FISD further records (only) 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 a a call, reorganization, or default. In this case, the data records the date, amount, and reason of reductions in the amount outstanding that occur before maturity, e.g., due to a a call, reorganization, or default. Among the total sample of bonds, about half record an action, while for only 5% of non-callable bonds an action is recorded. We use those records to adjust the outstanding amount in our bond panel. When the bond matures at its scheduled maturity date, we use the remaining amount of the bond at maturity as maturing amount.

A.2   Linking bonds and firms

To match bonds to the debtor firm in every period over the bond's lifetime, we proceed in three steps. First, we construct a mapping from `gvkey`, the Compustat firm identifier, to the historical firm `cusip`. A firm `cusip` identifier is contained in the bond `cusip` identifier, which allows us to match bonds to firms. However, the bond `cusip` contains an identifier of a firm valid at the time of issuance. Because these firm `cusips` frequently change over time (for a given firm), we need to identify the historic firm `cusip` identifier valid in a given time period. To link `gvkey` and historical firm `cusip`, we combine the Compustat–CRSP link table (linking `gvkey` and `permno`, a firm identifier in CRSP) with CRSP, which links `permno` and historical firm `cusip`. The Compustat–CRSP link contains the start and end dates for which `gvkey-permno` links are valid. We only use links which are classified as reliable, coded "C" or "P" in the link table. We join this link table with the CRSP data and keep records that fall within link validity. For few `cusips` we have a link to more than one `gvkey`, which may arise due to the presence of subsidiary firms in CRSP. Among these ambiguous links, we drop links from `cusip` to `gvkey` with missing sales in Compustat. For the remaining ambiguous links we keep the `gvkey` link to the firm with the largest sales.

Second, we cannot simply match the bond panel to the firm panel by using the historical `cusip` in both panels. In the bond panel, the historical firm `cusip`, encoded in the bond `cusip`, is the

firm `cusip` at the time of bond issuance. In contrast, the firm panel records the historical firm `cusip` as the one valid in a given period, which may change over time. Reasons for changes in the historical `cusip` are changes in the firm name or the firm trading symbol. To match firm and bond panel, we use the so-called *header* firm `cusip` associated to the bond's initial *historical* firm `cusip`. The header `cusip` is the latest observed `cusip` in a firm's history. The mapping between header `cusips` and historical `cusips` over time is provided in CRSP data. We match the header `cusip` to both the firm and the bond panel. The link between bond and firm panel along the header `cusip` is ambiguous in a small number of cases. We delete those bonds for which no link to `gvkey` is available in the Compustat—CRSP table and drop the bonds with remaining ambiguous links. Given the header `cusip` of the bond issuer, we can attach the historical `cusip` series throughout the lifetime of the bond using the same mapping. If the debtor firm of the bond does not change (e.g., because of M&A), this procedure correctly identifies the bond debtor over the lifetime of the bond.

Third, we account for M&A events. The Thomson–Reuters SDC database records events at which firms - as identified by historical `cusip` - are merged or acquired by another firm, also identified by historical `cusip`. This allows us to change a bond's firm identifier to the identifier of the acquiring firm. We prepare the SDC data as follows. We do not consider M&A events for which no date is reported, the M&A status is not reported as completed, the target firm is classified as a subsidiary, or if the acquiring firm does not buy the target firm fully. If an M&A event is associated to multiple buyers, we drop buyers that do not have associated gvkeys as per the Compustat—CRSP link table and drop remaining events of this sort entirely. With this data at hand, we merge M&A events to the bond panel. For bond-months in which the creditor was subject to an M&A event, we replace the historical firm `cusip` associated to the bond by the acquiring firm's `cusip` from the M&A date going forward. Because the acquiring firm may have changed its `cusip` after the M&A event, we need to repeat the steps outlined above to find the actual evolution of the historical `cusip` for the new creditor firm. Having done so, we search for additional M&A events that may have happened after the first M&A event, now with the first acquiring firm being the target firm. We repeat this procedure until we find no M&A events that would imply a change in the `cusip` identifier.

A.3 Variables

Capital growth We construct capital stock series either using a perpetual inventory method (PIM) or deflated book values. Both are based on net property, plants, and equipment (PPE, `ppentq` in Compustat), and we exclude firm-quarters with negative values of net PPE. For the PIM, we first identify investment spells for which net PPE is observed without gaps. If the gap is only a single quarter, we impute net PPE via linear interpolation. We exclude a small number of one-quarter capital spikes. These are quarters in which the real absolute growth rate of PPE exceeds 50% and is followed by a reversal in the opposite direction of more than 50% in the following quarter. For the first period of every investment spell we initialize capital by (deflated) gross PPE (`ppegtq`). For all subsequent quarters of the same spell we compute capital by adding the first difference in (deflated) net PPE to capital of the previous quarter. To construct deflated book values we simply deflate net PPE by the CPI. For both measures of capital, 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 current and long-term liabilities (`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. The alternative denominators for $\mathcal{M}_{it}$ we consider are 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 2.4.

Control variables   The list of control variables includes leverage, liquidity, average maturity, sales growth, and log assets. Leverage is total debt (`dlcq+dlttq`) divided by assets (`atq`). Liquidity is cash and short-term investments (`cheq`) divided by assets (`atq`). Average maturity is the average remaining maturity across outstanding bonds for firm i in quarter t, weighted by the par value of the outstanding bonds. Sales growth is the growth rate of deflated sales (`saleq`). Log assets is the natural logarithm of deflated assets (`atq`). All control variables are winsorized at the top and bottom 0.5% of the distribution. We measure firm age as the time since a firm's entry into the Compustat database. For this we complement quarterly Compustat data with annual Compustat data, as some firms initially only issue annual statements.

Other outcomes   In Figures 3 and B.2, we consider growth in debt, sales, employment, and cost of goods sold as outcomes. We use total debt (`dlcq+dlttq`), sales (`saleq`), and costs of goods (based on `cogsq`), all deflated. We smooth out firm-specific seasonal factors and other transitory fluctuations by using the backward-looking four-quarter moving average of debt, sales, and cost of goods sold. We then estimate local projections on the log differences of these smoothed variables. This yields similar results as Smooth Local Projections proposed by Barnichon and Brownlees (2019). Employment is only recorded annually in Compustat. We construct quarterly firm-level employment via the Chow and Lin (1971) method by combining annual employment and quarterly cost of goods sold. We use `cogsq` because it contains employment expenses, which means quarterly variation in `cogsq` should be informative about employment. We trim the cumulative growth rates of debt, sales, employment, and cost of goods sold at the top and bottom 1% of the distribution.

Appendix B   Additional empirical results

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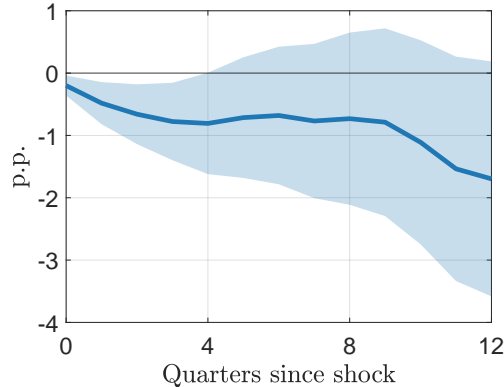
Note: The figure shows the estimated β_1^h coefficients in the local projection $\Delta^{h+1} \log k_{it+h} = \alpha_i^h + \alpha_{sq}^h + \beta_1^h \varepsilon_t^{\mathrm{mp}} + \Gamma_1^h Y_{t-1} + \nu_{it}^h$, where α_i^h and α_{sq}^h are firm and sector-fiscal quarter fixed effects, $\varepsilon_t^{\mathrm{mp}}$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

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

|	$\Delta^{h+1} \log k_{it+h}$			
	$h = 0$	$h = 4$	$h = 8$	$h = 12$
$\mathcal{M}_{it}$	0.0140	0.00278	0.0743	0.238**
	(0.0238)	(0.0858)	(0.0951)	(0.0967)
$\mathcal{M}_{it} \times$ MP shock	-0.0116	-0.0453	-0.214***	-0.102
	(0.0156)	(0.0511)	(0.0663)	(0.0679)
$\mathcal{M}_{it} \times$ GDP growth	-0.0331	-0.0244	-0.000532	-0.231
	(0.0348)	(0.0971)	(0.161)	(0.154)
Firm FE	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes
R^2	.15	.26	.33	.38
N	35,499	35,113	33,583	31,691

Note: The table shows all estimated coefficients from the baseline local projection (2.2). 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 B.2: Full list of coefficients in extended local projection for selected forecast horizons h

|	$\Delta^{h+1}\log k_{it+h}$			
	$h=0$	$h=4$	$h=8$	$h=12$
$\mathcal{M}_{it}$	-0.0148	-0.124	-0.137	-0.0272
	(0.0243)	(0.0834)	(0.0861)	(0.109)
$\mathcal{M}_{it}$ × MP shock	-0.0219	-0.127*	-0.317***	-0.220**
	(0.0182)	(0.0652)	(0.0788)	(0.0965)
$\mathcal{M}_{it}$ × GDP growth	0.00539	0.196**	0.367**	0.222
	(0.0385)	(0.0958)	(0.140)	(0.160)
Leverage	-0.284**	-2.333***	-3.392***	-4.246***
	(0.130)	(0.579)	(1.017)	(1.230)
Leverage × MP shock	-0.0360	-0.102	0.0479	0.309**
	(0.0445)	(0.268)	(0.280)	(0.150)
Leverage × GDP growth	-0.212*	-0.620	-0.956	-0.827
	(0.122)	(0.374)	(0.692)	(0.764)
Liquidity	0.516***	1.162**	2.370***	2.835***
	(0.104)	(0.472)	(0.752)	(0.919)
Liquidity × MP shock	0.120**	-0.0549	-0.0434	0.151
	(0.0584)	(0.154)	(0.248)	(0.314)
Liquidity × GDP growth	-0.160*	0.361	-0.373	-0.122
	(0.0830)	(0.386)	(0.631)	(0.639)
Sales growth	0.0999	0.929***	0.803***	1.007***
	(0.0686)	(0.196)	(0.236)	(0.271)
Sales growth × MP shock	0.0454	-0.114	-0.266	-0.370**
	(0.0625)	(0.136)	(0.197)	(0.168)
Sales growth × GDP growth	-0.0258	0.266	0.467	0.129
	(0.0777)	(0.238)	(0.317)	(0.312)
Size	-0.695***	-5.400***	-10.26***	-15.75***
	(0.182)	(0.906)	(1.754)	(2.385)
Size × MP shock	-0.0187	0.108	-0.265	-0.768
	(0.0857)	(0.305)	(0.419)	(0.533)
Size × GDP growth	0.0754	0.0404	0.167	0.621
	(0.168)	(0.531)	(1.039)	(1.118)
Avg. bond maturity	-0.00414	-0.234	-0.370	-0.423
	(0.0494)	(0.269)	(0.439)	(0.566)
Avg. bond maturity × MP shock	0.0271	0.000360	0.0244	0.0274
	(0.0332)	(0.196)	(0.205)	(0.121)
Avg. bond maturity × GDP growth	0.0594	0.414	0.599	0.500
	(0.0579)	(0.286)	(0.412)	(0.371)
Firm FE	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes
R^2	.2	.37	.48	.56
N	13,568	13,495	13,115	12,643

Note: The table shows all estimated coefficients from the extended local projection (2.3). 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 B.2: Differential response of other variables associated with higher $\mathcal{M}_{it}$ using baseline local projection

(a) Debt

(b) Sales

(c) Employment

(d) Costs of goods sold
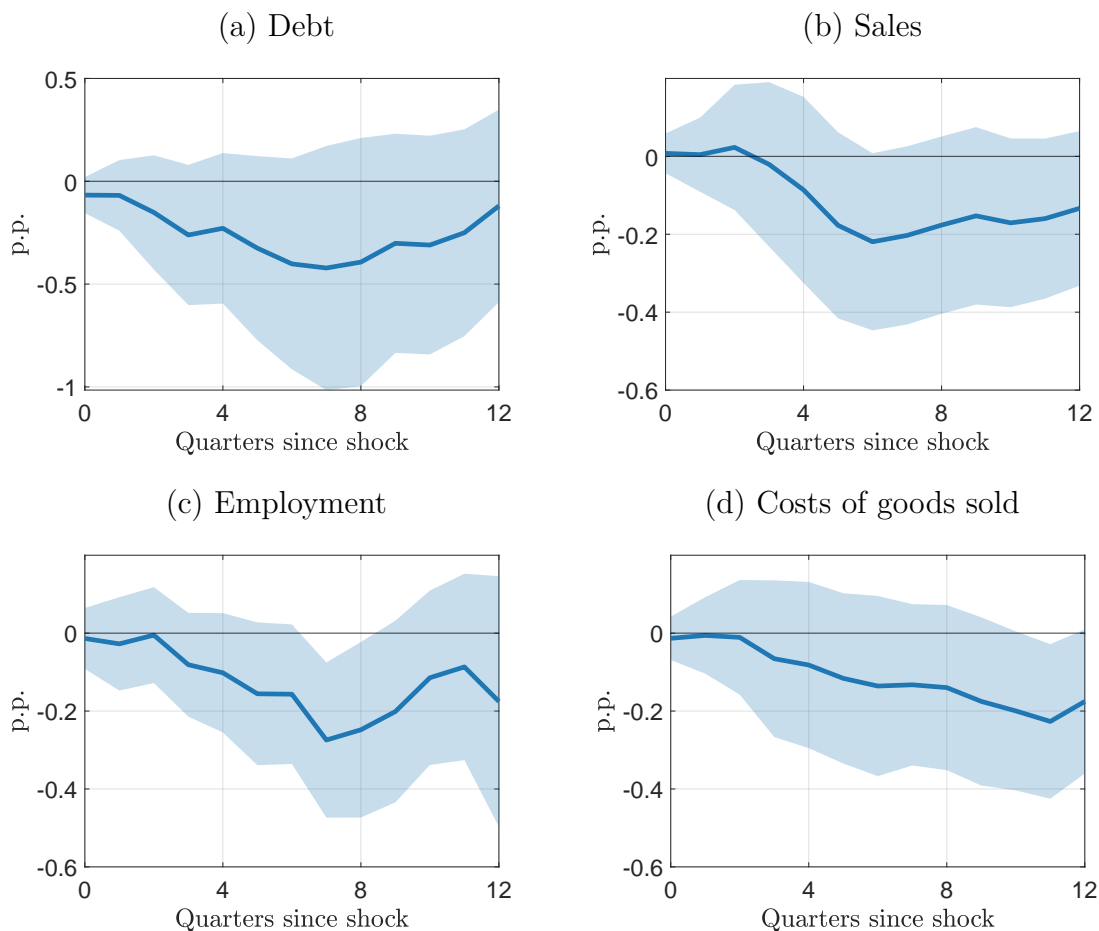
Note: The figure shows the estimated β_1^h coefficients based on equation (2.2), but where the left-hand side is $\Delta^{h+1} \log(\text{debt})_{it+h}$ in panel (a), $\Delta^{h+1} \log(\text{sales})_{it+h}$ in panel (b), $\Delta^{h+1} \log(\text{employment})_{it+h}$ in panel (c), and $\Delta^{h+1} \log(\text{cost of goods sold})_{it+h}$ in panel (d). The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\text{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.3: Differential investment response associated with lagged maturing bond share $\mathcal{M}_{t-1}$
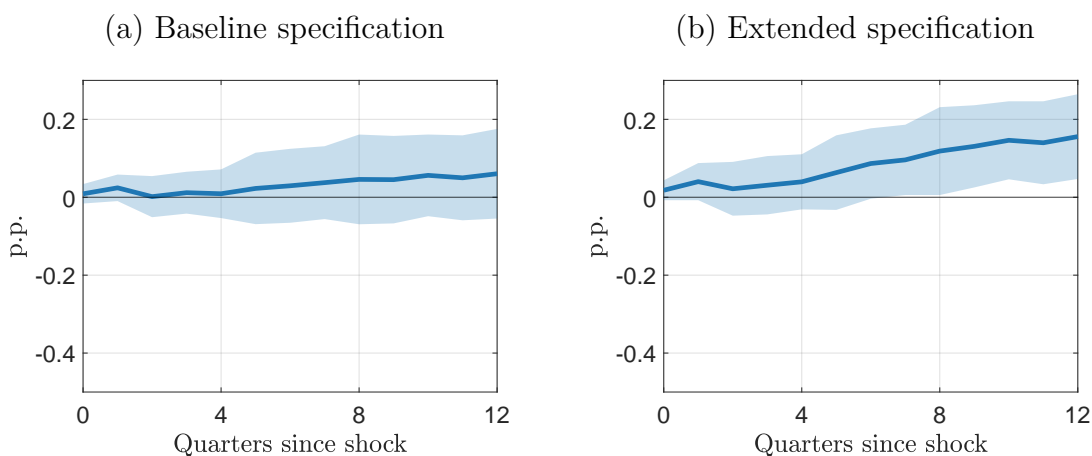
(a) Baseline specification

(b) Extended specification

Note: Panel (a) shows the estimated β_1^h coefficients based on the baseline local projection (2.2) using $\mathcal{M}_{it-1}$ instead of $\mathcal{M}_{it}$. Panel (b) shows the estimated β_1^h coefficients based on the extended local projection (2.3), using $(\mathcal{M}_{it-1} - \overline{\mathcal{M}}_i)$ instead of $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it-1}$ and $(\mathcal{M}_{it-1} - \overline{\mathcal{M}}_i)$, respectively. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.4: Differential investment response associated with higher Compustat maturing debt share
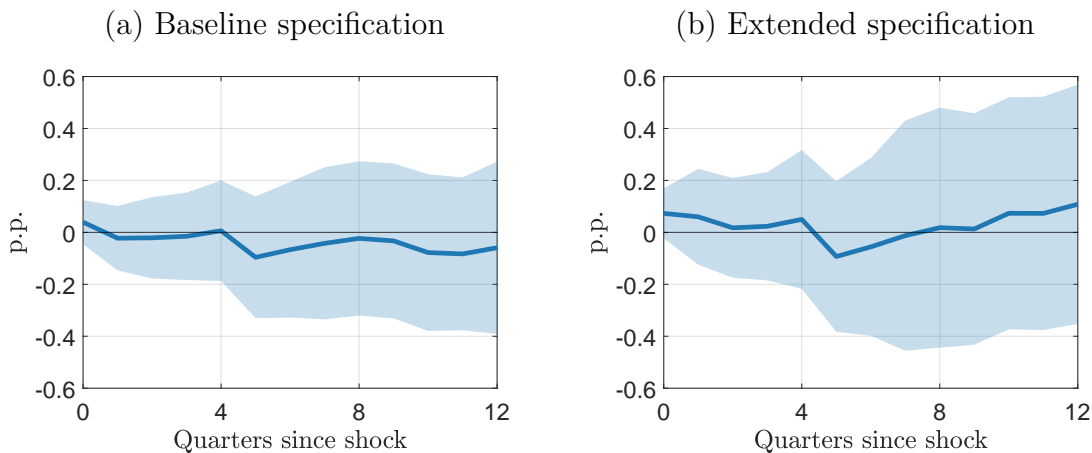
(a) Baseline specification

(b) Extended specification

Note: Panel (a) shows the estimated β_1^h coefficients based on the baseline local projection (2.2), using $\widetilde{\mathcal{M}}_{it}$ instead of $\mathcal{M}_{it}$. Panel (b) shows the estimated β_1^h coefficients based on the extended local projection (2.3), using $(\widetilde{\mathcal{M}}_{it} - \overline{\widetilde{\mathcal{M}}}_i)$ instead of replacing $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$. The variable $\widetilde{\mathcal{M}}_{it} = (\text{current liabilities})_{it}/(\text{total debt})_{it-1}$ measures maturing debt based on Compustat data only. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\widetilde{\mathcal{M}}_{it}$ and $(\widetilde{\mathcal{M}}_{it} - \overline{\widetilde{\mathcal{M}}}_i)$, respectively. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.5: Differential investment response associated with higher maturing bond share including callable bonds or bonds with variable coupon
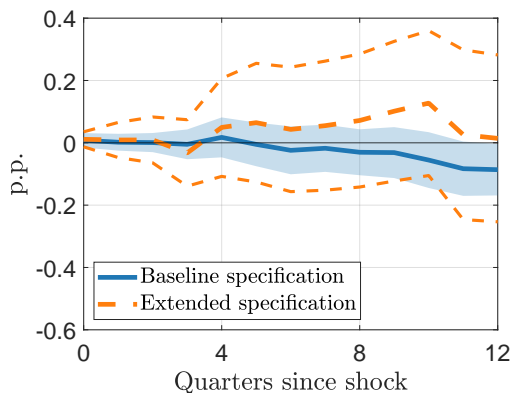
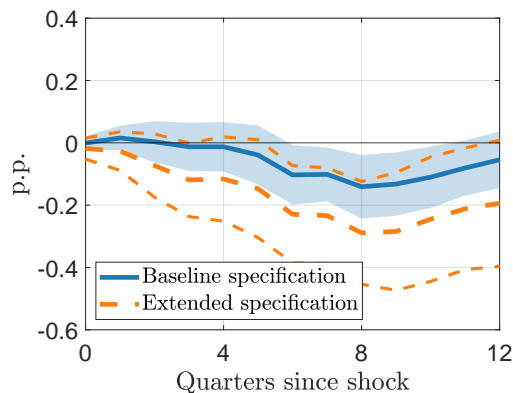(a) $\mathcal{M}_{it}$ including only callable bonds
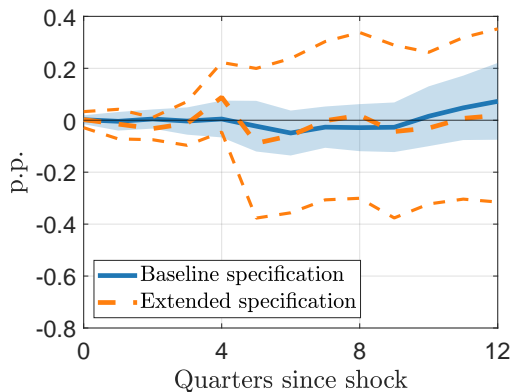
(b) $\mathcal{M}_{it}$ including callable and non-callable bonds
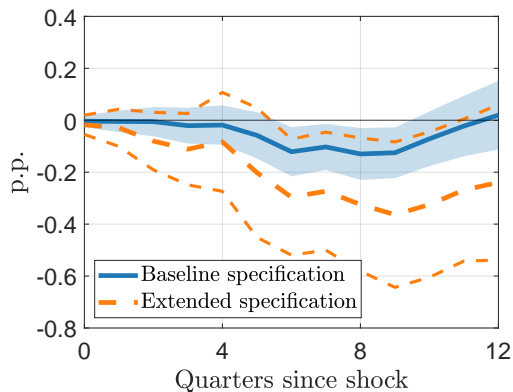
(c) $\mathcal{M}_{it}$ including only variable coupon bonds

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

Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2) (solid lines) and extended local projection (2.3) (dashed lines), 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 re-define $\mathcal{M}_{it}$ based on callable (fixed coupon) bonds. In panel (b), we include both callable and non-callable (fixed coupon) bonds. In panel (c), we re-define $\mathcal{M}_{it}$ based on variable coupon (non-callable) bonds. In panel (d), we include both variable coupon and fixed coupon (non-callable) bonds. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.6: Differential investment response associated with $\mathcal{M}_{it}$ using alternative denominators

(a) Capital

(b) Sales

(c) Assets

(d) Non-moving average
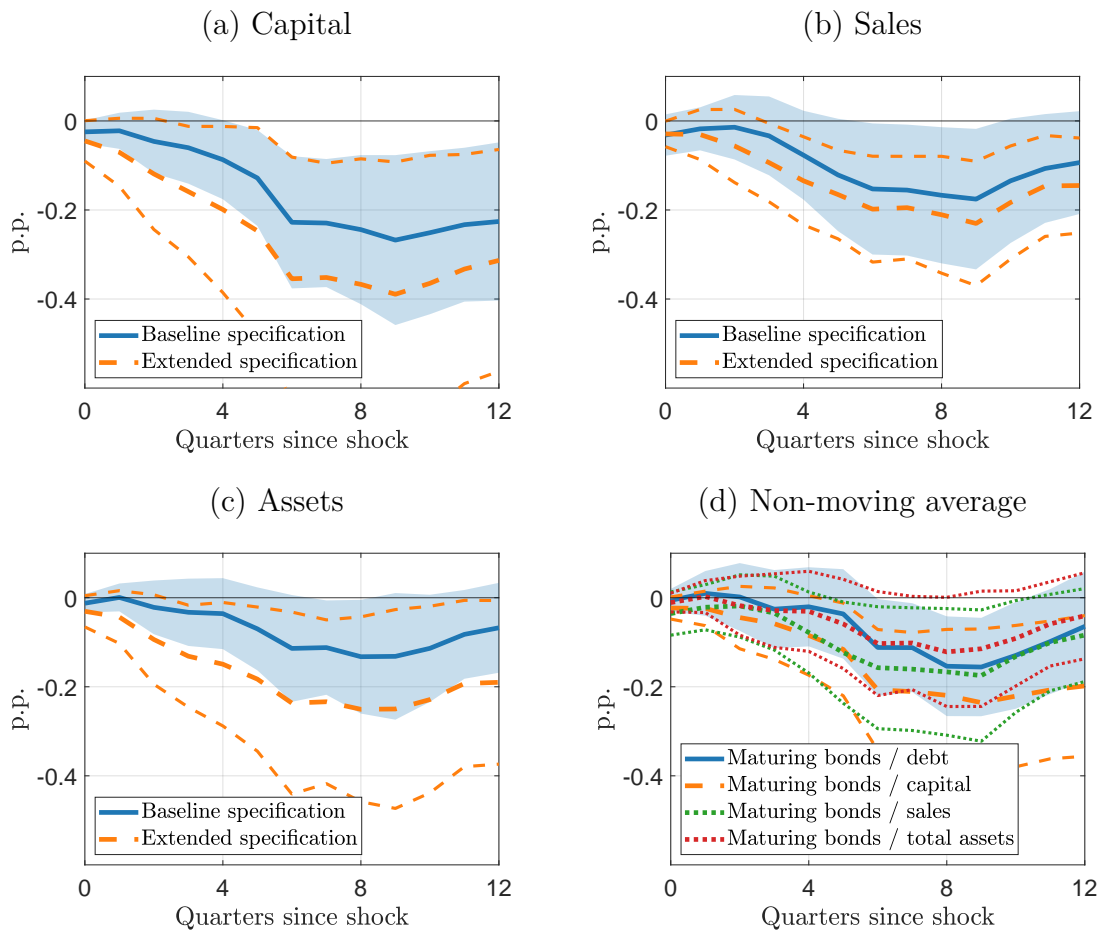
Note: In panels (a) to (c) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2) (solid lines) and extended local projection (2.3) (dashed lines), for various alternative definitions of $\mathcal{M}_{it}$. In panel (a), we re-define $\mathcal{M}_{it}$ as the ratio of maturing bonds over the average capital stock in the preceding four quarters, in (b) the denominator is average sales, in (c) average assets. In panel (d) the figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2) 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 (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$ for baseline specifications and and $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$ for extended specifications. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.7: Differential investment response associated with $\mathcal{M}_{it}$ when including firm age as control variable
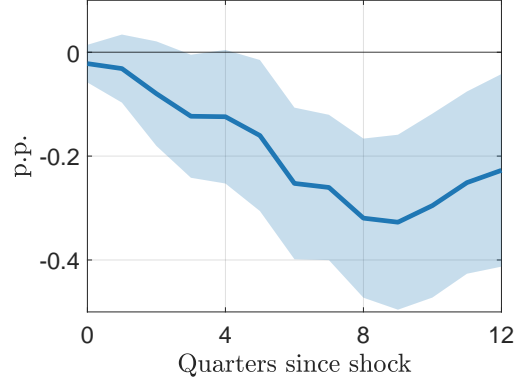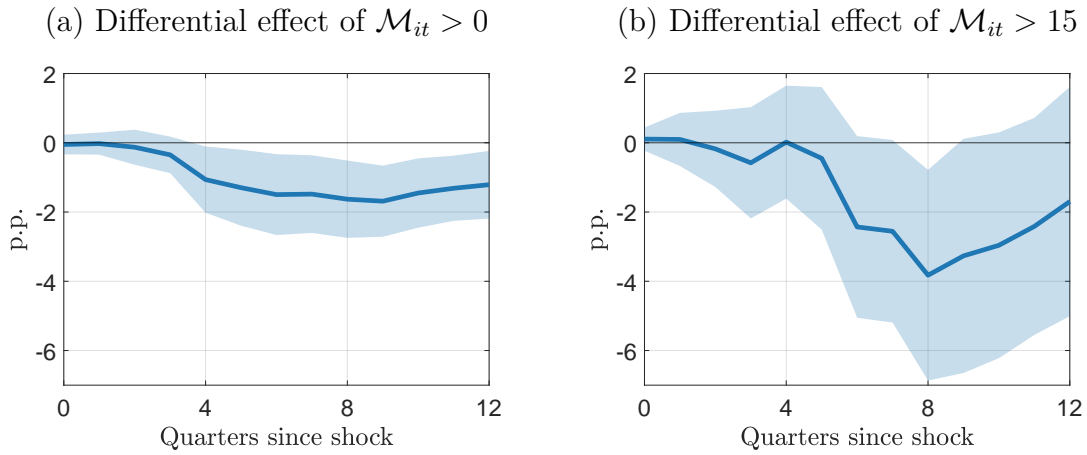
Note: The figure shows the estimated β_1^h coefficients based on the extended local projection (2.3) where here Z_{it} additionally includes firm age. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.8: Differential investment response associated with $\mathcal{M}_{it}$, based on book value of capital
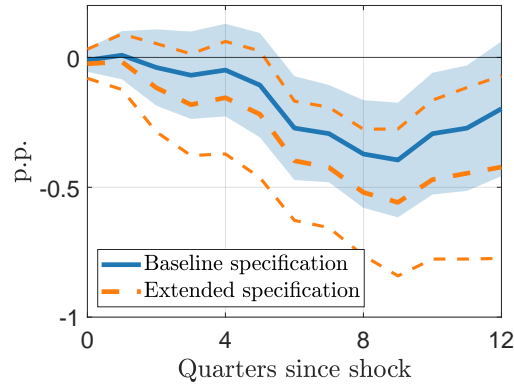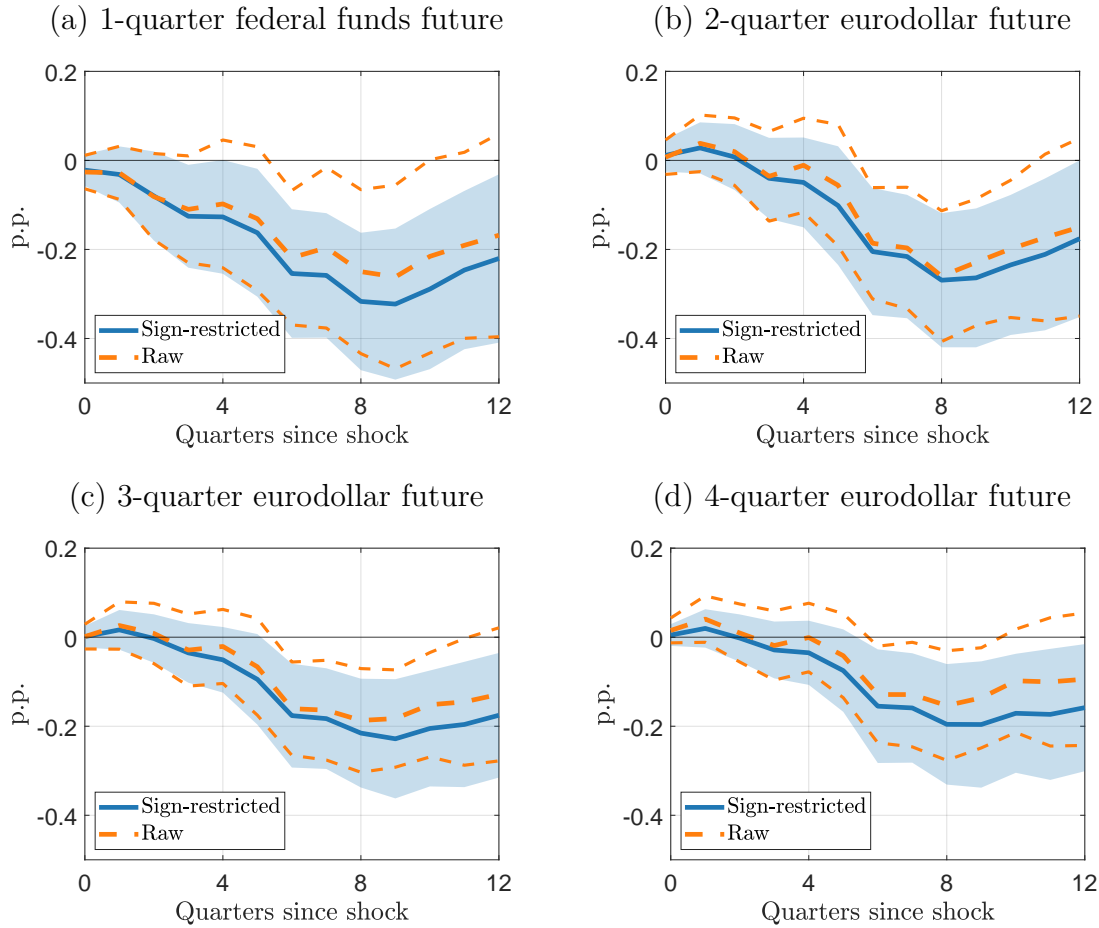
Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2) (solid lines) and extended local projection (2.3) (dashed lines), using book value of capital (deflated net fixed assets) instead of capital stocks constructed using a perpetual inventory method. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$ for the baseline specification and $(\mathcal{M}_{it} - \overline{\mathcal{M}}_i)$ for the extended specification, respectively. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.9: Differential investment response associated with $\mathcal{M}_{it}$ using dummy specification of bond maturity
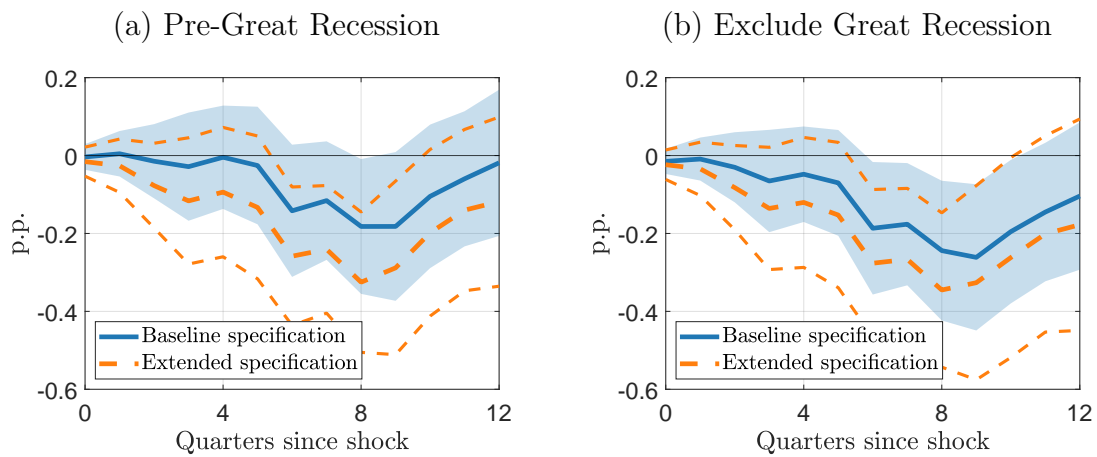
(a) Differential effect of $\mathcal{M}_{it} > 0$ (b) Differential effect of $\mathcal{M}_{it} > 15$

Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2), using $\mathbb{1}\{\mathcal{M}_{it} > 0\}$ instead of $\mathcal{M}_{it}$ in panel (a) and $\mathbb{1}\{\mathcal{M}_{it} > 15\}$ instead of $\mathcal{M}_{it}$ in panel (b). The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with, respectively, $\mathcal{M}_{it} > 0$ and $\mathcal{M}_{it} > 15$ (i.e., 15 % of debt). Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.10: Differential investment response associated with $\mathcal{M}_{it}$ for alternative monetary policy shocks

(a) 1-quarter federal funds future

(b) 2-quarter eurodollar future

(c) 3-quarter eurodollar future

(d) 4-quarter eurodollar future

Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2) using various alternative monetary policy shocks $\varepsilon_t^{\mathrm{mp}}$. In panel (a), $\varepsilon_t^{\mathrm{mp}}$ is the surprise change (in a 30 minute window around regular FOMC meetings) in the one-quarter ahead federal funds future, in (b) the two-quarter ahead eurodollar future, in (c) the three-quarter ahead eurodollar future, and in (d) the four-quarter ahead eurodollar future. Solid lines show the responses based on sign-restricted shocks and dashed lines additionally show the responses based on raw surprises. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Figure B.11: Differential investment response associated with $\mathcal{M}_{it}$ based on alternative samples

(a) Pre-Great Recession

(b) Exclude Great Recession

Note: The figure shows the estimated β_1^h coefficients based on the baseline local projection (2.2) (solid lines) and extended local projection (2.3) (dashed lines), using alternative samples. Panel (a) uses only monetary policy shocks until 2008Q2. Panel (b) excludes monetary policy shocks between 2008Q3 and 2009Q2. The β_1^h estimates are standardized to capture the differential response (approx. in p.p.) to a one standard deviation increase in $\varepsilon_t^{\mathrm{mp}}$ associated with a one standard deviation higher $\mathcal{M}_{it}$ for the baseline specification and $(\mathcal{M}_{it} - \overline{\mathcal{M}_i})$ for the extended specification, respectively. Shaded areas indicate 95% confidence bands two-way clustered by firms and quarters.

Appendix C   Model

In this section we provide additional details of the model set up in Section 3 (Appendix C.1) and derive the first-order conditions presented in Section 4 (Appendix C.2).

C.1   Model: Details

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

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

This implies that firm revenue net of labor costs is

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

where

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

This is used in equation (3.3).

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

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

Rotemberg-style costs of price adjustment are expressed as a fraction of aggregate real output Y_t. Retail goods are bought by a perfectly competitive final goods sector which produces final goods Y_t at constant returns to scale:

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

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

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

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

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

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

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

The final good is the numéraire: $P_t = 1$. Using $\pi_t = P_t/P_{t-1}$ yields the New Keynesian Phillips Curve in (3.13).

Market clearing. Labor market clearing implies

$$L = \int_x l(x;S)\mu(x)dx. \qquad \text{(C.9)}$$

The aggregate amount of final goods Y is

$$Y = \int_x y(x;S)\mu(x)dx. \qquad \text{(C.10)}$$

Output net of fixed costs of operation and default costs is

$$Y^{net} \equiv Y - \int_x \left[f + \xi\int_\varepsilon \mathcal{D}(x,\varepsilon;S)\underline{q}(x,\varepsilon;S)\varphi(\varepsilon)d\varepsilon\right]\mu(x)dx. \qquad \text{(C.11)}$$

Final goods market clearing implies that

$$Y^{net} = C + \mathcal{G} + \mathcal{H} + I, \qquad \text{(C.12)}$$

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

$$\mathcal{G} = \int_x\int_\varepsilon\int_{z'} G\left(e(x,\varepsilon,z';S)\right)\Pi(z'|z)dz'(1-\kappa)[1-\mathcal{D}(x,\varepsilon;S)]\varphi(\varepsilon)d\varepsilon\mu(x)dx + \int_{x'} \tilde{G}(x';S)\mathcal{E}(x';S)dx', \qquad \text{(C.13)}$$

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

$$\mathcal{H} = \int_x\int_\varepsilon\int_{z'} H\left(b^{S'}(x,\varepsilon,z';S), b^{L'}(x,\varepsilon,z';S), b^L(x)/\pi\right)\Pi(z'|z)dz'(1-\kappa)[1-\mathcal{D}(x,\varepsilon;S)]\varphi(\varepsilon)d\varepsilon\mu(x)dx$$
$$+ \int_{x'} \tilde{H}(x';S)\mathcal{E}(x';S)dx', \qquad \text{(C.14)}$$

where $\tilde{H}(x';S)$ is debt issuance costs of entrants starting in state x'. Aggregate investment I follows from (3.14):

$$I = K\left[\frac{\phi-1}{\phi}\delta^{-\frac{1}{\phi}}\left(\frac{K'}{K} - 1 + \delta\frac{\phi}{\phi-1}\right)\right]^{\frac{\phi}{\phi-1}} \qquad \text{(C.15)}$$

Capital goods market clearing implies:

$$K = \int_x k(x)\mu(x)dx, \quad \text{and} \quad K' = \int_{x'} k'(x')\mu(x')dx' \qquad \text{(C.16)}$$

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

C.2 Characterization: Details

To derive the first-order conditions in Section 4.1 we express the firm problem (3.20) in terms of three choice variables: the scale of production k', and the amounts of short-term debt $b^{S'}$ and long-term debt $b^{L'}$:

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

$$
+ \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} V(x', \varepsilon'; S')\varphi(\varepsilon')d\varepsilon', \tag{C.17}
$$

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

$$
p^S = \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'} \left[[1 - \mathcal{D}(x', \varepsilon'; S')]\frac{1+c}{\pi'} \right.
$$

$$
\left. + \mathcal{D}(x', \varepsilon'; S')\frac{1-\xi}{b^{S'} + b^{L'}} \left[Q'k' + (1-\tau)\left[A'k'^\alpha + (\varepsilon' - \delta)Q'k' - f\right]\right] \right]\varphi(\varepsilon')d\varepsilon', \tag{C.18}
$$

where $\mathcal{D}(x', \varepsilon'; S') = 1$ iff $W(x', \varepsilon'; S') < 0$ in (3.20), and $x' = (z', k', b^{S'}, b^{L'})$. The long-term bond price p^L is

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

$$
\left. + \mathcal{D}(x', \varepsilon'; S')\frac{1-\xi}{b^{S'} + b^{L'}} \left[Q'k' + (1-\tau)\left[A'k'^\alpha + (\varepsilon' - \delta)Q'k' - f\right]\right] \right]\varphi(\varepsilon')d\varepsilon'. \tag{C.19}
$$

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

$$
G(e) = \nu\left(\max\{e, 0\}\right)^2, \quad \text{where:} \quad e = Qk' - q(x, \varepsilon; S) - b^{S'}p^S - \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)p^L. \tag{C.20}
$$

Debt issuance costs are

$$
H\left(b^{S'}, b^{L'}, \frac{b^L}{\pi}\right) = \eta\left(b^{S'} + \max\left\{b^{L'} - \frac{(1-\gamma)b^L}{\pi}, 0\right\}\right)^2. \tag{C.21}
$$

It follows that the firm objective (C.17) is a function of the three choice variables k', $b^{S'}$, and $b^{L'}$.

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

$$
\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[-Q + b^{S'}\frac{\partial p^S}{\partial k'} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial k'}\right]
$$

$$
+ \mathbb{E}_{S'|S}\Lambda \int_{\varepsilon'}[1 - \mathcal{D}(x', \varepsilon'; S')]\frac{\partial W(x', \varepsilon'; S')}{\partial k'}\varphi(\varepsilon')d\varepsilon' = 0, \tag{C.22}
$$

where

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

and

$$
\frac{\partial q'}{\partial k'} = \left[Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon' - \delta)Q'\right]\right]. \tag{C.24}
$$

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Equation (C.23) uses the fact that the future price of long-term debt $g(x', \bar{\varepsilon}', z''; S')$ can be expressed as a function of the reduced state vector $(q', b', z''; S')$ (as explained in Section 5.1). Written in this way, the future price of long-term debt $\tilde{g}(q', b', z''; S')$ depends on the endogenous firm states

$$q' = q(x', \varepsilon'; S') = Q'k' - \frac{b^{S'}}{\pi'} - \frac{\gamma b^{L'}}{\pi'} + (1-\tau)\left[A'k'^\alpha + (\varepsilon'-\delta)Q'k' - f - \frac{c(b^{S'} + b^{L'})}{\pi'}\right] \quad (C.25)$$

and $b' = (1-\gamma)b^{L'}$. To compute $\partial p^S / \partial k'$ and $\partial p^L / \partial k'$ in (C.22), 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 (3.20). At this threshold realization $\bar{\varepsilon}'$, the firm is just indifferent between defaulting and servicing its current debt obligations, i.e.,

$$(1-\kappa)\mathbb{E}_{z''|z'}W^C(x', \bar{\varepsilon}', z''; S') + \kappa\left(q' - \frac{(1-\gamma)b^{L'}}{\pi'}\mathbb{E}_{z''|z'}\tilde{g}(q', b', z''; S')\right) = 0. \quad (C.26)$$

Applying the implicit function theorem to (C.26), we derive

$$\frac{\partial \bar{\varepsilon}'}{\partial k'} = -\frac{\frac{\partial q'}{\partial k'}}{\frac{\partial q'}{\partial \bar{\varepsilon}'}} = -\frac{Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\bar{\varepsilon}'-\delta)Q'\right]}{(1-\tau)Q'k'}. \quad (C.27)$$

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

$$\begin{aligned}
\frac{\partial p^S}{\partial k'} = \mathbb{E}_{S'|S}\Lambda\Bigg[&\int_{-\infty}^{\bar{\varepsilon}'} \frac{1-\xi}{b^{S'}+b^{L'}}\left[Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon'-\delta)Q'\right]\right]\varphi(\varepsilon')d\varepsilon' \\
&+ \varphi(\bar{\varepsilon}')\frac{\partial \bar{\varepsilon}'}{\partial k'}\left[-\frac{1+c}{\pi'} + \frac{(1-\xi)}{b^{S'}+b^{L'}}\left[Q'k' + (1-\tau)\left[A'k'^\alpha + (\bar{\varepsilon}'-\delta)Q'k' - f\right]\right]\right]\Bigg]. \quad (C.28)
\end{aligned}$$

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

$$\begin{aligned}
\frac{\partial p^L}{\partial k'} = \mathbb{E}_{S'|S}\Lambda\Bigg[&\int_{\bar{\varepsilon}'}^{\infty} \frac{1-\gamma}{\pi'}\mathbb{E}_{z''|z'}\frac{\partial \tilde{g}(q', b', z''; S')}{\partial q'}\frac{\partial q'}{\partial k'}\varphi(\varepsilon')d\varepsilon' \\
&+ \int_{-\infty}^{\bar{\varepsilon}'} \frac{1-\xi}{b^{S'}+b^{L'}}\left[Q' + (1-\tau)\left[A'\alpha k'^{\alpha-1} + (\varepsilon'-\delta)Q'\right]\right]\varphi(\varepsilon')d\varepsilon' \\
&+ \varphi(\bar{\varepsilon}')\frac{\partial \bar{\varepsilon}'}{\partial k'}\Bigg[-\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q', b', z''; S')}{\pi'} \\
&+ \frac{1-\xi}{b^{S'}+b^{L'}}\left[Q'k' + (1-\tau)\left[A'k'^\alpha + (\bar{\varepsilon}'-\delta)Q'k' - f\right]\right]\Bigg]\Bigg] \quad (C.29)
\end{aligned}$$

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

$$\begin{aligned}
&\left[1 + \frac{\partial G(e)}{\partial e}\right]\left[p^S + b^{S'}\frac{\partial p^S}{\partial b^{S'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi}\right)\frac{\partial p^L}{\partial b^{S'}}\right] - \frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^{S'}} \\
&+ \mathbb{E}_{S'|S}\Lambda\int_{\bar{\varepsilon}'}^{\infty}\frac{\partial W(x', \varepsilon'; S')}{\partial b^{S'}}\varphi(\varepsilon')d\varepsilon' = 0, \quad (C.30)
\end{aligned}$$

where

$$\frac{\partial W(x', \varepsilon'; S')}{\partial b^{S'}} = \frac{\partial q'}{\partial b^{S'}} \left[(1-\kappa)\mathbb{E}_{z''|z'} \left(1 + \frac{\partial G(e')}{\partial e'} \right) + \kappa \left(1 - \frac{(1-\gamma)b^{L'}}{\pi'} \mathbb{E}_{z''|z'} \frac{\partial \tilde{g}(q', b', z''; S')}{\partial q'} \right) \right],$$
(C.31)

$$\text{and} \quad \frac{\partial q'}{\partial b^{S'}} = -\frac{1 + (1-\tau)c}{\pi'}.$$
(C.32)

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

$$\frac{\partial p^S}{\partial b^{S'}} = \mathbb{E}\Lambda \Bigg[- \int_{-\infty}^{\bar{\varepsilon}'} \frac{1-\xi}{(b^{S'} + b^{L'})^2} \left[Q'k' + (1-\tau) \left[A'k'^\alpha + (\varepsilon' - \delta)Q'k' - f \right] \right] \varphi(\varepsilon')d\varepsilon'$$
$$+ \varphi(\bar{\varepsilon}')\frac{\partial \bar{\varepsilon}'}{\partial b^{S'}} \left[-\frac{1+c}{\pi'} + \frac{1-\xi}{b^{S'} + b^{L'}} \left[Q'k' + (1-\tau) \left[A'k'^\alpha + (\bar{\varepsilon}' - \delta)Q'k' - f \right] \right] \right] \Bigg], \quad \text{(C.33)}$$

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

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

$$\frac{\partial p^L}{\partial b^{S'}} = \mathbb{E}_{S'|S}\Lambda \Bigg[\int_{\bar{\varepsilon}'}^{\infty} \frac{1-\gamma}{\pi'} \mathbb{E}_{z''|z'} \frac{\partial \tilde{g}(q', b', z''; S')}{\partial q'} \frac{\partial q'}{\partial b^{S'}} \varphi(\varepsilon')d\varepsilon'$$
$$- \int_{-\infty}^{\bar{\varepsilon}'} \frac{1-\xi}{(b^{S'} + b^{L'})^2} \left[Q'k' + (1-\tau) \left[A'k'^\alpha + (\varepsilon' - \delta)Q'k' - f \right] \right] \varphi(\varepsilon')d\varepsilon'$$
$$+ \varphi(\bar{\varepsilon}')\frac{\partial \bar{\varepsilon}'}{\partial b^{S'}} \left[-\frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q', b', z''; S')}{\pi'} \right.$$
$$\left. + \frac{1-\xi}{b^{S'} + b^{L'}} \left[Q'k' + (1-\tau) \left[A'k'^\alpha + (\bar{\varepsilon}' - \delta)Q'k' - f \right] \right] \right] \Bigg]$$
(C.35)

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

$$\left[1 + \frac{\partial G(e)}{\partial e} \right] \left[p^L + b^{S'} \frac{\partial p^S}{\partial b^{L'}} + \left(b^{L'} - \frac{(1-\gamma)b^L}{\pi} \right) \frac{\partial p^L}{\partial b^{L'}} \right] - \frac{\partial H(b^{S'}, b^{L'}, b^L/\pi)}{\partial b^{L'}}$$
$$+ \mathbb{E}_{S'|S}\Lambda \int_{\bar{\varepsilon}'}^{\infty} \frac{\partial W(x', \varepsilon'; S')}{\partial b^{L'}} \varphi(\varepsilon')d\varepsilon' = 0,$$
(C.36)

where

$$\frac{\partial W(x', \varepsilon'; S')}{\partial b^{L'}} = \frac{\partial q'}{\partial b^{L'}} \left[(1-\kappa)\mathbb{E}_{z''|z'} \left(1 + \frac{\partial G(e')}{\partial e'} \right) + \kappa \left(1 - \frac{(1-\gamma)b^{L'}}{\pi'} \mathbb{E}_{z''|z'} \frac{\partial \tilde{g}(q', b', z''; S')}{\partial q'} \right) \right]$$
$$+ \frac{\partial b'}{\partial b^{L'}} \mathbb{E}_{z''|z'} \left[(1-\kappa)\frac{\partial \tilde{W}^C(q', b', z''; S')}{\partial b'} - \frac{\kappa}{\pi'} \left(\tilde{g}(q', b', z''; S') + b'\frac{\partial \tilde{g}(q', b', z''; S')}{\partial b'} \right) \right], \quad \text{(C.37)}$$

$$\text{with} \quad \frac{\partial q'}{\partial b^{L'}} = -\frac{\gamma + (1-\tau)c}{\pi'} \quad \text{and} \quad \frac{\partial b'}{\partial b^{L'}} = 1 - \gamma.$$
(C.38)

Equation (C.37) uses the fact that the future value $W^C(x', \bar{\varepsilon}', z''; S')$ can be expressed as a function of the reduced state vector $\tilde{W}^C(q', b', z''; S')$ (as explained in Section 5.1). The derivative of p^S with respect to $b^{L'}$ is

$$\frac{\partial p^S}{\partial b^{L'}} = \mathbb{E}_{S'|S} \Lambda \Big[- \int_{-\infty}^{\bar{\varepsilon}'} \frac{1-\xi}{(b^{S'}+b^{L'})^2} \left[Q'k' + (1-\tau) \left[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f \right] \right] \varphi(\varepsilon')d\varepsilon'$$
$$+ \varphi(\bar{\varepsilon}') \frac{\partial \bar{\varepsilon}'}{\partial b^{L'}} \left[-\frac{1+c}{\pi'} + \frac{1-\xi}{b^{S'}+b^{L'}} \left[Q'k' + (1-\tau) \left[A'k'^{\alpha} + (\bar{\varepsilon}'-\delta)Q'k' - f \right] \right] \right] \Big], \quad \text{(C.39)}$$

where

$$\frac{\partial \bar{\varepsilon}'}{\partial b^{L'}} = - \frac{\frac{\partial q'}{\partial b^{L'}}}{\frac{\partial q'}{\partial \bar{\varepsilon}'}} - \frac{\frac{\partial b'}{\partial b^{L'}}}{\frac{\partial q'}{\partial \bar{\varepsilon}'}} \frac{\mathbb{E}_{z''|z'} \left[(1-\kappa) \frac{\partial \tilde{W}^C(q',b',z'';S')}{\partial b'} - \frac{\kappa}{\pi'} \left(\tilde{g}(q',b',z'';S') + b' \frac{\partial \tilde{g}(q',b',z'';S')}{\partial b'} \right) \right]}{\left[(1-\kappa) \mathbb{E}_{z''|z'} \left(1 + \frac{\partial G(e')}{\partial e'} \right) + \kappa \left(1 - \frac{b'}{\pi'} \mathbb{E}_{z''|z'} \frac{\partial \tilde{g}(q',b',z'';S')}{\partial q'} \right) \right]}.$$
$$\text{(C.40)}$$

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

$$\frac{\partial p^L}{\partial b^{L'}} = \mathbb{E}\Lambda \Bigg[\int_{\bar{\varepsilon}'}^{\infty} \frac{1-\gamma}{\pi'} \mathbb{E}_{z''|z'} \left(\frac{\partial \tilde{g}(q',b',z'';S')}{\partial q'} \frac{\partial q'}{\partial b^{L'}} + \frac{\partial \tilde{g}(q',b',z'';S')}{\partial b'} \frac{\partial b'}{\partial b^{L'}} \right) \varphi(\varepsilon')d\varepsilon'$$
$$- \int_{-\infty}^{\bar{\varepsilon}'} \frac{1-\xi}{(b^{S'}+b^{L'})^2} \left[Q'k' + (1-\tau) \left[A'k'^{\alpha} + (\varepsilon'-\delta)Q'k' - f \right] \right] \varphi(\varepsilon')d\varepsilon'$$
$$+ \varphi(\bar{\varepsilon}') \frac{\partial \bar{\varepsilon}'}{\partial b^{L'}} \left[- \frac{\gamma + c + (1-\gamma)\mathbb{E}_{z''|z'}\tilde{g}(q',b',z'';S')}{\pi'} \right.$$
$$\left. + \frac{1-\xi}{b^{S'}+b^{L'}} \left[Q'k' + (1-\tau) \left[A'k'^{\alpha} + (\bar{\varepsilon}'-\delta)Q'k' - f \right] \right] \right] \Bigg] \quad \text{(C.41)}$$

The effect of a marginal increase in b' on $\tilde{W}^C(q', b', z''; S')$ in (C.37) can be derived using (C.17):

$$\frac{\partial \tilde{W}^C(q,b,z';S)}{\partial b} = \frac{\partial W(x',\varepsilon';S')}{\partial (1-\gamma)b^L} = -\frac{1}{\pi} \frac{\partial H(b^{S'},b^{L'},b^L/\pi)}{\partial \frac{(1-\gamma)b^L}{\pi}} - \frac{p^L}{\pi} \left[1 + \frac{\partial G(e)}{\partial e} \right] \quad \text{(C.42)}$$

Iterating forward one time period, this implies

$$\frac{\partial \tilde{W}^C(q',b',z'';S')}{\partial b'} = -\frac{1}{\pi'} \left(\frac{\partial H(\tilde{b}^{S''},\tilde{b}^{L''},b^{L'}/\pi')}{\partial \frac{(1-\gamma)b^{L'}}{\pi'}} + \tilde{g}(q',b',z'';S') \left[1 + \frac{\partial G(e')}{\partial e'} \right] \right). \quad \text{(C.43)}$$

Appendix D   Quantitative results

This section of the appendix complements the quantitative analysis in Section 5. We define a number of moments used in the model (Appendix D.1), give more details on the empirical moments used (Appendix D.2), present additional steady state results (Appendix D.3), provide details on the analysis of the heterogenous effects of monetary policy shocks (Appendix D.4), and decribe the models used to highlight the importance of heterogeneous debt maturity (Appendix D.5).

D.1 Model moments

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

$$b^S + \gamma b^L + (1-\gamma)\gamma b^L + (1-\gamma)^2 \gamma b^L + ... = b^S + \gamma b^L \sum_{j=0}^{\infty} (1-\gamma)^j = b^S + b^L. \tag{D.1}$$

Firm leverage (total debt over total assets) is given by $(b^S + b^L)/k$.

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

$$\frac{b_{it}^S + \gamma b_{it}^L + (1-\gamma)\gamma b_{it}^L + (1-\gamma)^2 \gamma b_{it}^L + (1-\gamma)^3 \gamma b_{it}^L}{\frac{1}{4}\sum_{j=0}^{3}\left(b_{it-j}^S + b_{it-j}^L\right)}. \tag{D.2}$$

As in the empirical part of the paper, we use a four-quarter moving average of debt in the denominator.[32] For firms which are younger than four quarters, the denominator is average debt over the maximum number of past quarters available.

The maturing bond share $\mathcal{M}$ from (4.4) measures the share of total debt which matures within one quarter:

$$\mathcal{M}_{it} = \frac{b_{it}^S + \gamma b_{it}^L}{b_{it}^S + b_{it}^L}. \tag{D.3}$$

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

The Macaulay duration 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:

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

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

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

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

$$\mu = \frac{1+r^*}{\gamma+r^*}. \tag{D.6}$$

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:

$$spr^S \equiv \left(\frac{1+c}{p^S}\right)^4 - \left(\frac{1+c}{P_r^S}\right)^4, \tag{D.7}$$

where P_r^S is the price of a riskless short-term bond: $P_r^S = (1+c)/(1+i)$.

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[32]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.

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:

$$spr^L \equiv \left(\frac{\gamma + c + (1-\gamma)p^L}{p^L}\right)^4 - \left(\frac{\gamma + c + (1-\gamma)P_r^L}{P_r^L}\right)^4 = \left(\frac{\gamma + c}{p^L} + 1 - \gamma\right)^4 - \left(\frac{\gamma + c}{P_r^L} + 1 - \gamma\right)^4 \tag{D.8}$$

The average credit spread used in Figure 5 is defined as

$$\frac{b^{S'}}{b^{S'} + b^{L'}} spr^S + \frac{b^{L'}}{b^{S'} + b^{L'}} spr^L. \tag{D.9}$$

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

$$\frac{1}{4} \cdot (\max\{0, e_{it}\} + \max\{0, e_{it-1}\} + \max\{0, e_{it-2}\} + \max\{0, e_{it-3}\}) \cdot \frac{1}{k_{it}} \tag{D.10}$$

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 $\log(k_{it}) - \log(k_{it-1})$. The capital growth moments in Table 3 are medians across firm-level averages and standard deviations of quarterly firm-level capital growth.

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

$$\int_x \int_\varepsilon \mathcal{D}(x, \varepsilon; S)\varphi(\varepsilon)d\varepsilon\mu(x)dx + \kappa \left(1 - \int_x \int_\varepsilon \mathcal{D}(x, \varepsilon; S)\varphi(\varepsilon)d\varepsilon\mu(x)dx\right) \tag{D.11}$$

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 moments

In this section, we provide details on the empirical moments used in Table 3. As described in Section 2, we use quarterly firm-level balance sheet data from Compustat and FISD bond-level information. The time sample is 1995–2017. We exclude firms that are not incorporated in the U.S. and we delete firms in the public administration, finance, insurance, real estate, and utilities sectors. 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 is constructed using firm-level credit ratings combined with rating-specific corporate bond spreads, following Arellano et al. (2019). We use quarterly Standard & Poor's credit ratings from Compustat Monthly Updates. Based on this rating, each firm-quarter is assigned the time-varying median spread of the corresponding rating class from the FISD data. Because FISD data only includes bonds with maturity above one quarter, this data is informative with respect to long-term credit spreads in our model. See Jungherr and Schott (2021) for details on the construction

of time-varying rating-specific credit spreads using FISD data. For leverage, the credit spread on long-term debt, and the share of debt due within a year we exclude observations below the 1st and above the 99th percentile. The share of debt due within a year is winsorized at 100%.

Equity issuance is defined as the average of quarterly sale of common and preferred stock over the preceding four quarters divided by assets (`atq`). Quarterly sale of common and preferred stock is constructed from the yearly cumulative variable `sstky`, where missing entries are set to zero. We use an average of quarterly equity issuance over four quarters to reduce the skewness of equity issuance caused by rare but large positive spikes.

Firm-level capital stocks are constructed using the perpetual inventory method described in Appendix A.3. The capital growth moments in Table 3 are medians across firm-specific averages and standard deviations of quarterly firm-level capital growth. The firm exit rate is the quarterly value of the yearly exit rate of 8.7% reported in Ottonello and Winberry (2020).

D.3 Steady state results: Details

In our solution method described in Section 5.1, we exploit the fact that the idiosyncratic state $(z, k, b^S, b^L, \varepsilon, z'; S)$ in the firm problem (3.20) can be summarized by 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 $b = (1-\gamma)b^L$. We create grids for the endogenous firm states q and b which are specific to the exogenous firm state z'. The results presented in the paper are computed using a grid of five distinct firm productivity levels z'. Figures D.12 and D.13 show firm policy functions and the firm distribution over the lowest three levels of firm productivity z'.

As shown in Section 5.3, the model generates the fact that smaller firms borrow at shorter maturities and therefore have higher shares of maturing debt. The model generates this fact because low-productivity firms have higher default risk. This means that for them the price of long-term debt is more sensitive to the issuance of additional long-term debt. The derivative $\partial p^L / \partial b^{L'}$ in the first order condition for long-term debt (4.3) is steeper for low-productivity firms. This is illustrated in Figure D.14.

Figure D.15 shows additional steady state results on the co-movement of firm age with leverage, credit spreads, and debt maturity. In the data, firm size and leverage are increasing in age whereas credit spreads and the maturing debt share are falling. The model replicates these untargeted patterns.

D.4 Heterogenous effects of monetary policy shocks: Details

Figure 8 shows the estimated β_1^h coefficients from (5.2) using simulated model data. We construct these estimates as follows. Starting from the steady state of the model, we simulate two panels of a large number of firms for 50 time periods. In the first simulation firms are subject to idiosyncratic shocks in capital quality ε and productivity z', as well as exogenous exit, but there are no monetary policy shocks, i.e., the economy remains in steady state. In the second simulation, all idiosyncratic firm shocks are exactly identical to the first simulation. The only difference is a one-time innovation to $\varepsilon_t^{\mathrm{mp}}$ which on impact induces a 30bp increase in the nominal interest rate i. By regressing the difference in firm-level capital growth between the two simulations at various time horizons h on the pre-shock maturing bond share, we obtain β_1^h in (5.2) displayed in Figure 8. The estimates are standardized to measure the differential response associated with a one standard deviation higher $\mathcal{M}_{it}$. The estimates shown in Figure 10, as well as in Figures D.16 and D.17 using debt, sales, employment, and credit spreads as additional firm outcomes are constructed correspondingly.

D.5 Aggregate implications of heterogeneous debt maturity: Details

In Section 5.6, we compare the benchmark model to two alternative economies: an economy without long-term debt, and an economy without heterogeneity.

Economy without long-term debt. In the short-term debt model, the setup is identical to the benchmark model with endogenous debt maturity described above. The key difference is that we set $\gamma = 1$, i.e., there is no long-term debt. The remaining parameters are recalibrated to match the same empirical targets as in the benchmark model. As there is no trade-off between short-term debt and long-term debt, we set the debt issuance cost parameter η to zero and do not target the average share of debt due within one year. Because there is no long-term credit spread in the model, we use the short-term credit spread as model moment in the calibration instead. We increase τ to 60% because otherwise either leverage or credit spreads are too low in the short-term debt model. All remaining externally set parameters are left unchanged. The calibration is summarized in Table D.3.

Table D.3: Model without long-term debt: Internally calibrated parameters

Parameter	Value	Target	Data	Model
σ_ε	0.935	Average firm leverage *(in %)*	34.4	34.2
ξ	0.20	Average credit spread *(in %)*	3.1	3.1
ν	0.0007	Average equity issuance *(in %)*	11.4	13.5
ρ_z	0.6	Average firm capital growth *(in %)*	1.0	1.1
$\bar{z}$	0.184	Std. of firm capital growth *(in %)*	8.3	9.7
κ	0.014	Firm exit rate *(in %)*	2.2	2.3
f	0.2615	Steady state value of firm entry	-	0

Economy without heterogeneity. We solve an alternative model in which all firms are ex-ante identical every period. To do so, we make three assumptions: (1.) All firms have the same constant productivity level $z = 1$. (2.) We set the equity issuance cost parameter ν to zero. This implies that current cash flow and existing assets q do not appear in firms' first order conditions. The variable q no longer affects firm choices. (3.) We assume that all new entrants pay an entry cost which is financed with long-term debt. The entry cost is set such that entrants always operate with the same amount of outstanding long-term debt b as incumbent firms. This makes sure that entrants do not differ from incumbents because of different histories of long-term debt issuance. The setup is otherwise identical to the benchmark model with firm heterogeneity described above. In this model, firms differ ex-post in terms of realized earnings but all firms are ex-ante identical in the sense that they choose identical policies in every period.

We recalibrate the parameters to match the same empirical targets as in the benchmark model. Because firm productivity is constant, there is no role for the parameters ρ_z and $\bar{z}$ and the associated empirical targets. We also remove equity issuance from the list of our empirical targets, because the equity issuance cost parameter is set to $\nu = 0$. The calibration is summarized in Table D.4.
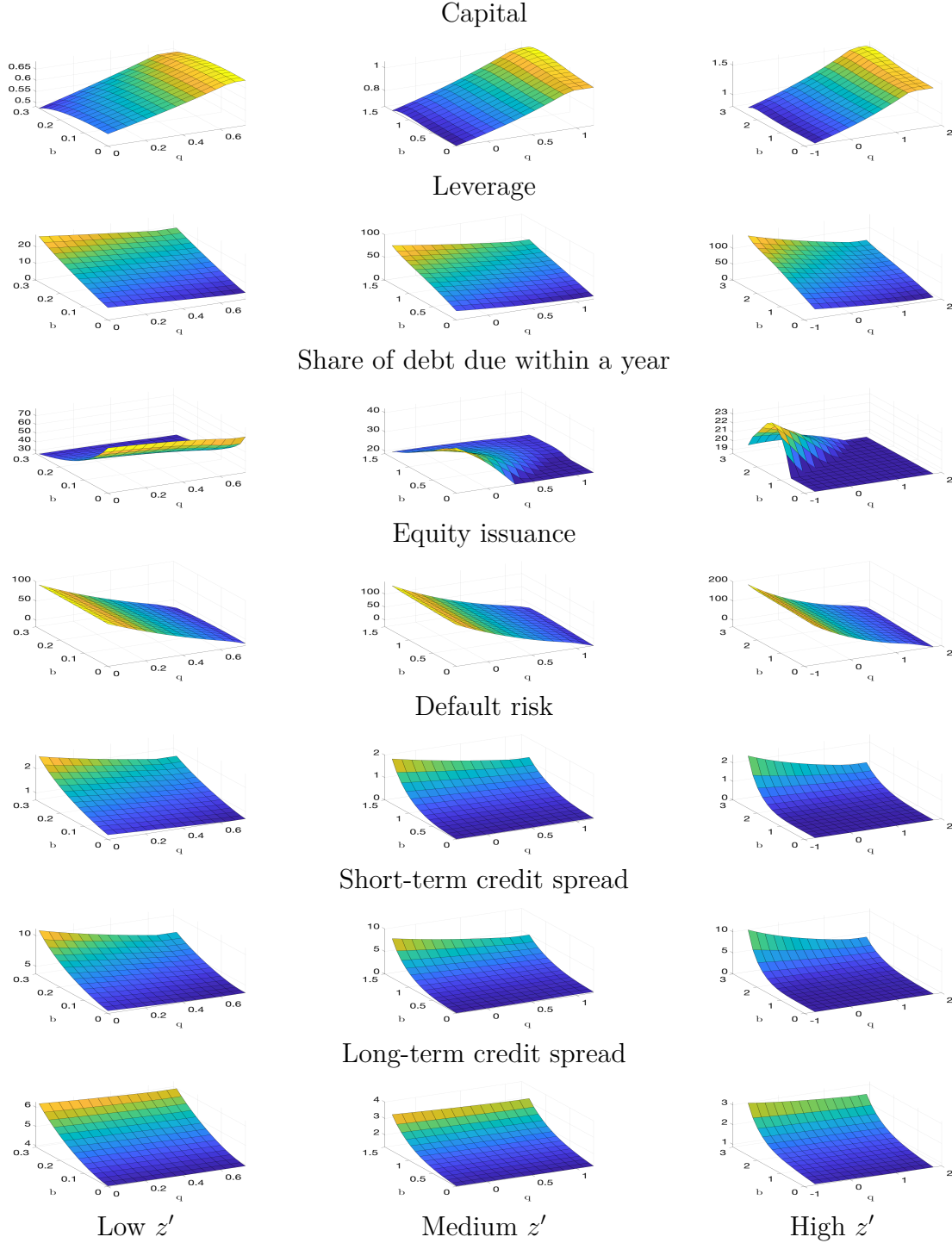
Model comparison relative to frictionless model. An alternative way to compare the different models in Figure 11 is to show their response as differences relative to a model with a

Table D.4: Model without heterogeneity: Internally calibrated parameters

| Parameter	Value	Target	Data	Model
σ_ε	0.75	Average firm leverage *(in %)*	34.4	31.1
ξ	0.90	Average credit spread on long-term debt *(in %)*	3.1	3.3
η	0.0045	Average share of debt due within a year *(in %)*	30.5	31.1
κ	0.0151	Firm exit rate *(in %)*	2.2	2.3
f	0.327	Steady state value of firm entry	-	0

frictionless production sector (without taxes, default costs, and equity or debt issuance costs). This is done in Figure D.18.

Figure D.12: Steady state policy functions

Capital

Leverage

Share of debt due within a year

Equity issuance

Default risk

Short-term credit spread

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 for *Capital* (k') are normalized by average firm capital. All remaining firm policies are in %. *Leverage* is total firm debt over assets $((b^{S'} + b^{L'})/k')$; the *Share of debt due within a year* is $(b^{S'} + \gamma b^{L'}(1+1-\gamma+(1-\gamma)^2+(1-\gamma)^3))/(b^{S'} + b^{L'})$; *Equity issuance* is relative to firm assets (e/k'); *Default risk* is quarterly; *Short-term* and *Long-term credit spread* are annualized.
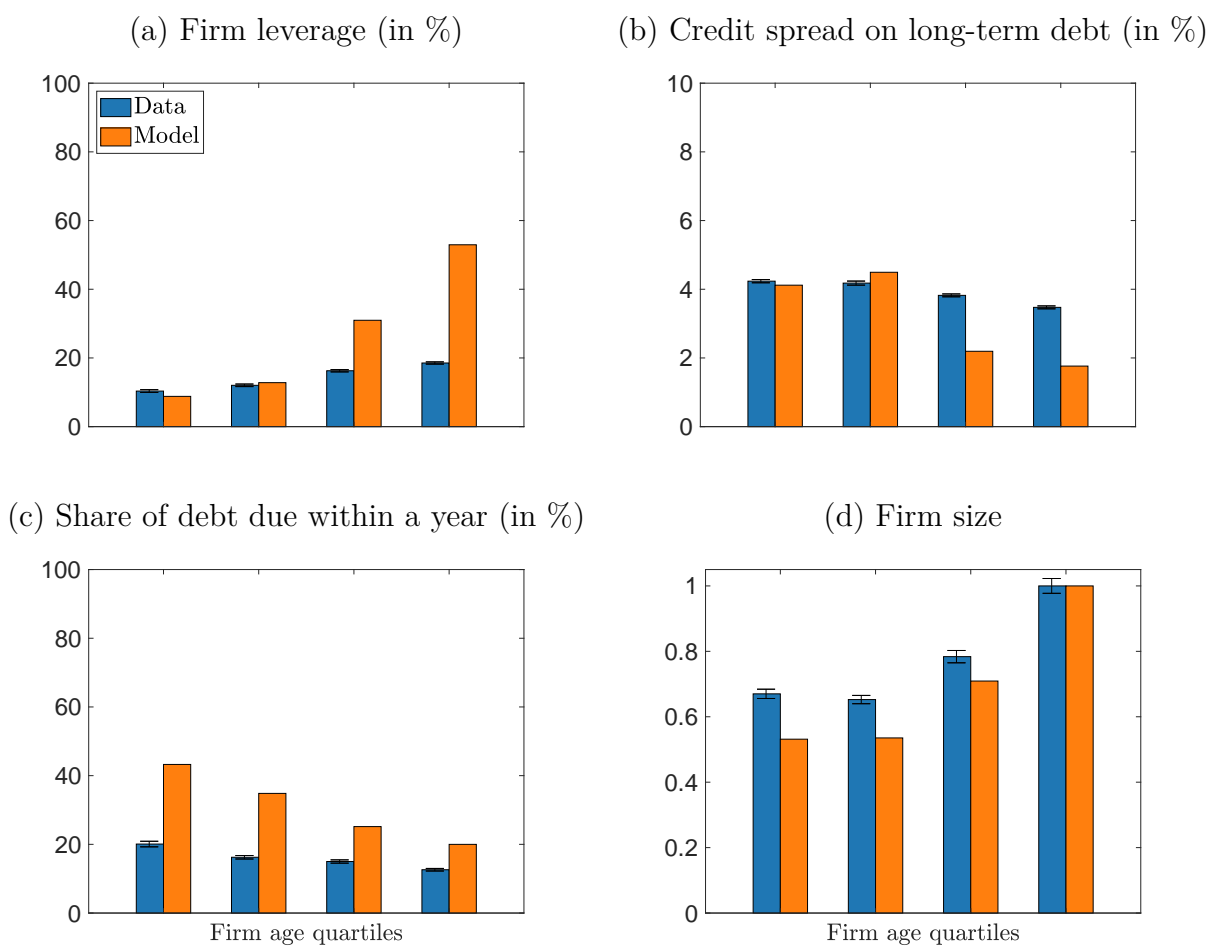
Figure D.13: Steady state firm distribution

(a) Low z' (b) Medium z' (c) High z'
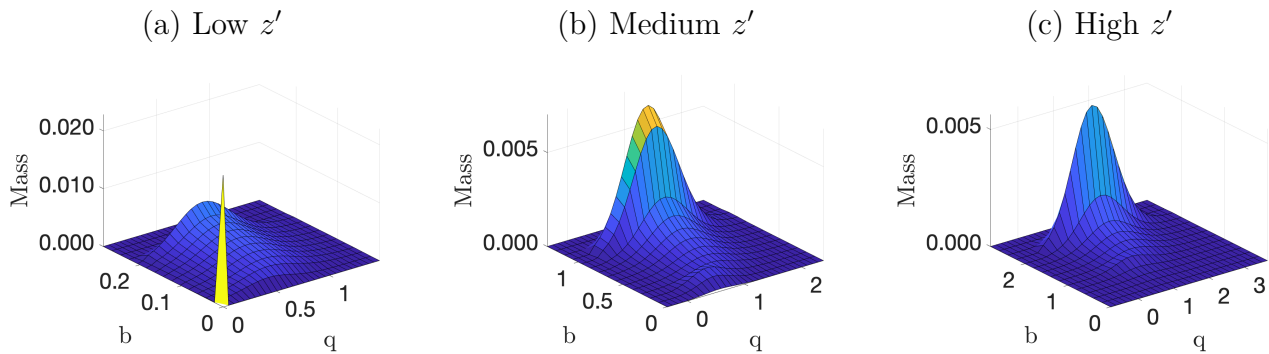
Note: The steady state firm distribution is plotted for different levels of firm productivity z' against firm assets $q = q(z, k, b^S, b^L, \varepsilon; S)$ and outstanding long-term debt $b = (1 - \gamma)b^L$. Assets q are normalized by average firm capital; outstanding long-term debt b is normalized by average firm debt. In panel (a), a large mass point is noticeable at $q = 0$ and $b = 0$ which is the state of new entrants.

Figure D.14: Price of long-term debt p^L
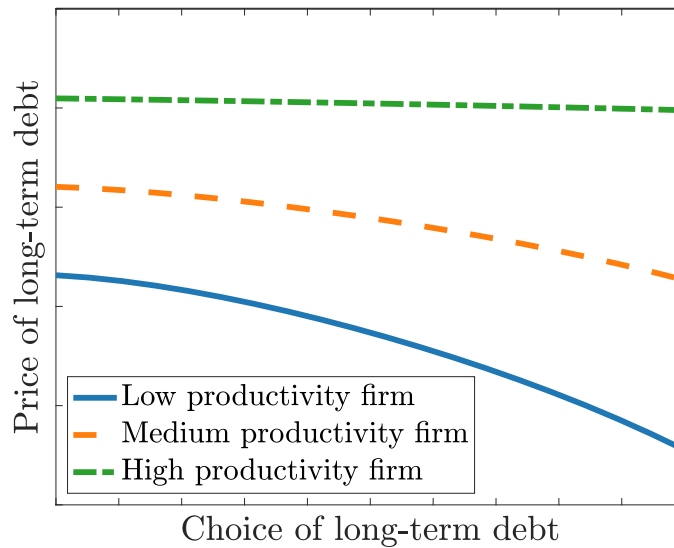
Note: The price of long-term debt p^L in (3.12) is shown as a function of the firm's choice of long-term debt $b^{L'}$ for a given state of firm assets q and outstanding long-term debt b, and three different productivity levels z'. All firm-level choices besides $b^{L'}$ (i.e., capital k' and short-term debt $b^{S'}$) are held at their steady-state values.

Figure D.15: Firm variables conditional on age

(a) Firm leverage (in %)

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

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

(d) Firm size

Note: For each variable, median values are shown by age quartile. The data sample is 1995-2017. Firm-level data on age (quarters since initial public offering), leverage, the share of debt due within a year, and size (log total firm assets relative to top age quartile) 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. In the data and the model, observations with age higher than 60 quarters are excluded. See Appendix D.1 and D.2 for details.

Figure D.16: Model: Differential firm-level responses associated with $\mathcal{M}_{it}$

(a) Capital

(b) Debt

(c) Sales
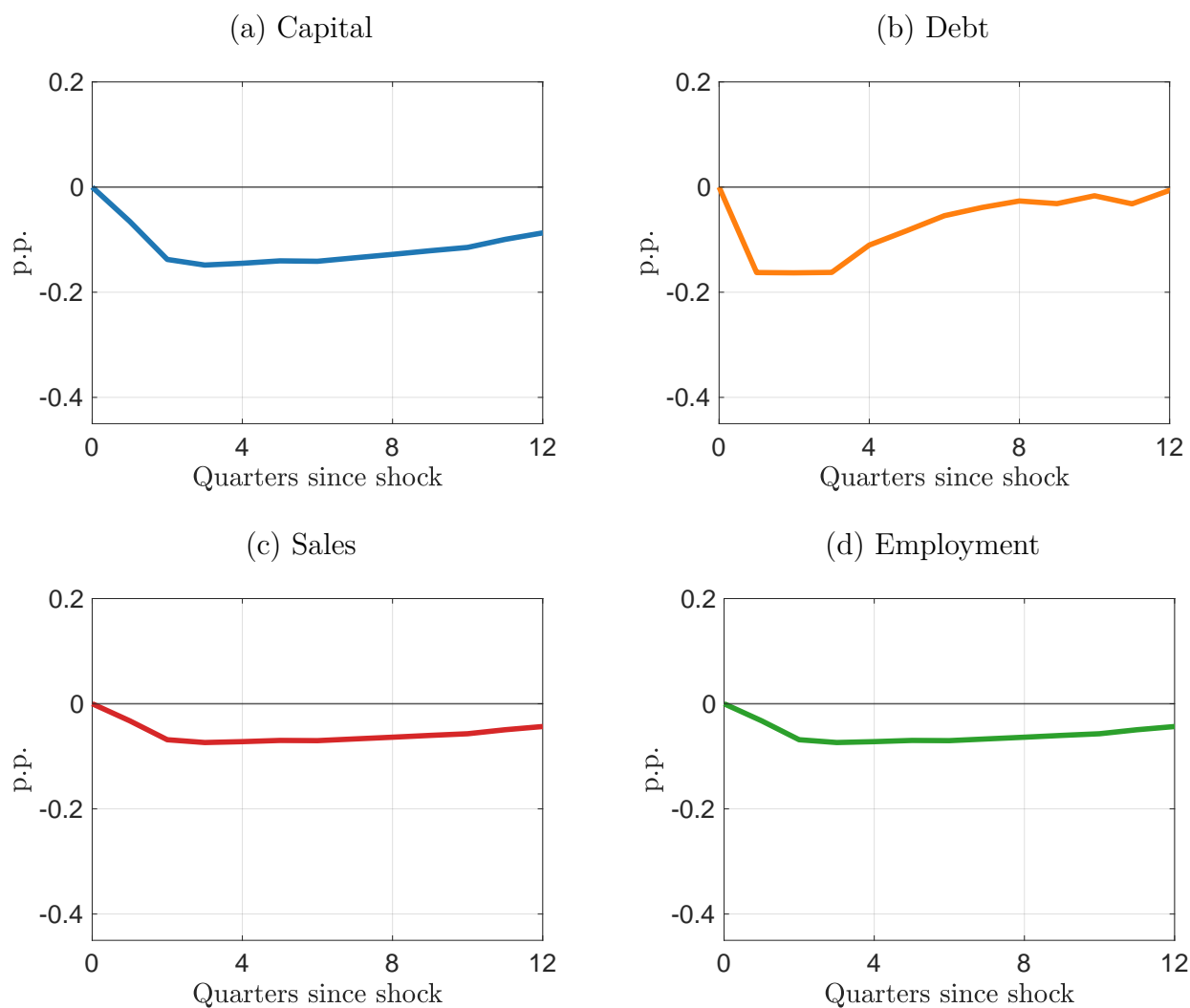
(d) Employment

Note: The lines show the differential response of capital growth, 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 (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 differential capital response in panel (a) is identical to Figure 8. Debt growth in panel (b) is change in total firm debt relative to pre-shock firm capital (as a control for firm size). Sales growth in panel (c) is log changes in sales y. Employment growth in panel (d) is log changes in labor demand l.

Figure D.17: Counterfactuals: Differential credit spread response associated with $\mathcal{M}_{it}$
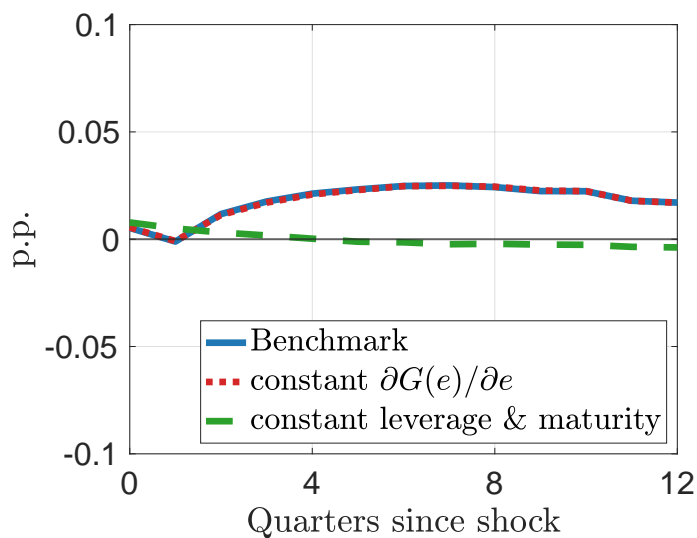
Note: The lines show the differential response of average credit spreads associated with $\mathcal{M}_{it}$ in simulated model data. All values are standardized to capture the differential response (in p.p.) to a one standard deviation (30bp) increase in the nominal interest rate i associated with a one standard deviation higher $\mathcal{M}_{it}$. The blue solid line shows the value from the benchmark model. The red dotted line shows the corresponding value in a counterfactual economy with fixed marginal equity issuance costs. It is barely indistinguishable from the blue solid line. The green dashed line shows the corresponding value in a counterfactual economy with fixed leverage and debt maturity.

Figure D.18: Aggregate response to monetary policy shock: Model comparison relative to frictionless model

(a) GDP

(b) Investment

(c) Real interest rate

(d) Inflation
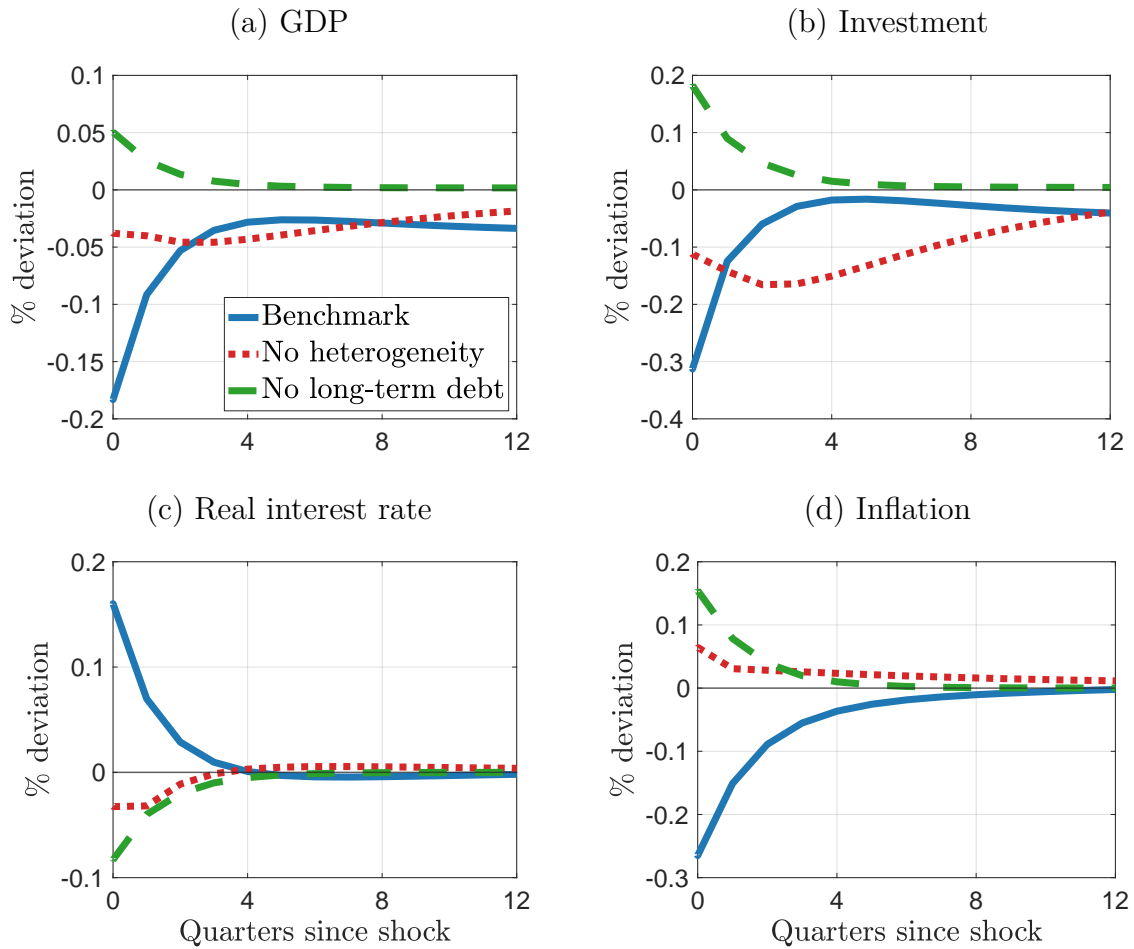
Note: Model responses of Figure 11 are shown as difference relative to the response in a model with a frictionless production sector (without taxes, default costs, and equity or debt issuance costs). A value less than zero thus implies a stronger negative response than the frictionless model and vice versa. Blue solid lines correspond to the benchmark economy, green dashed ones to the economy without long-term debt and red dotted ones to the economy without heterogeneity.