Firm Balance Sheet Liquidity, Monetary Policy Shocks, and Investment Dynamics*

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Abstract

This paper evaluates the role of firms' balance sheet liquidity in the transmission of monetary policy to investment. I estimate that in response to contractionary monetary policy shocks, both firms with higher leverage or with fewer liquid assets reduce investment relative to others. However, controlling for liquid assets, leverage loses its significance in explaining such heterogeneity while liquid assets remain important conditional on leverage. To explain these results, I introduce fixed issuance costs on long-term debt financing in an otherwise conventional general equilibrium model of heterogeneous firms and borrowing constraints. In the calibrated model, balance sheet liquidity predicts investment sensitivity to corporate debt rates better than leverage. Fixed issuance costs give rise to relatively wealthy firms who are not borrowing constrained but exhibit large marginal propensities to invest out of liquid income. This can considerably amplify the aggregate effects of shocks and policies which affect firms' cash flows.

Keywords: monetary policy, investment, financial frictions, firm balance sheets

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1 Introduction

It is a commonly held view that net worth and debt are relevant for investment dynamics in the aggregate economy. The leverage of nonfinancial firms is often considered to be either a source of or a key factor in the transmission of economic fluctuations.[1] And the idea that indebtedness could measure the severity of financial frictions has motivated studies comparing the cyclicality of high- and low-leverage firms.[2] However, the conventional macro-finance view regularly abstracts from the notion that firms' decisions to accumulate liquid assets ("cash") are distinguishable from their management of debt. Cash is not "negative debt". Firms' holdings of liquid assets can be distinct from their borrowing, for example because of the different hedging and liquidity properties of cash and debt. In addition, cash management has implications for firms' financial policies and investment behavior.[3]

In this paper I argue that the balance sheet liquidity of nonfinancial firms, as measured by assets held in cash, can explain heterogeneous investment behavior in response to aggregate shocks. Based on empirical results which establish this, I develop a model of firms and financial frictions, and show that liquidity considerations can be important for the transmission of shocks that affect firms' cash flows.

To do so, I first provide empirical evidence on the heterogeneous sensitivity of firms' fixed capital accumulation to monetary policy announcements depending on their financial position. I employ local projections in the spirit of Jordà (2005) and estimate differences in Compustat firms' investment dynamics in response to monetary policy shocks identified using a high-frequency event-study analysis. I find that during roughly two years after an unexpected policy rate increase, firms with higher leverage at the time of the shock exhibit relatively weaker capital accumulation. Second, I find that firms with low liquid asset holdings contract their capital stock relative to others after an unexpected policy rate increase. A 10 percentage point higher leverage ratio or a 10 pp lower ratio of liquid assets to total assets predict approximately 0.2 and 0.4 pp slower cumulative growth of capital during the two to three years after a one standard deviation monetary policy contraction.[4]

Third, the ability of leverage to explain this heterogeneity disappears when simultaneously controlling for liquid asset holdings. In contrast, the estimates for the relevance of liquid asset holdings barely change when conditioning on leverage. These results suggest that the negative correlation between leverage and liquid asset holdings in the cross-section of firms leads to an omitted variable bias in the leverage regression. In particular, cash holdings more consistently predict heterogeneous investment responses to monetary policy shocks over the horizon under consideration. The findings are robust to a wide array of variations in the empirical approach.

The findings on the relevance of firms' balance sheet liquidity for the interest-sensitivity of investment are also corroborated by survey evidence. Sharpe and Suarez (2015) study the responses of Chief Financial Officers to open ended survey questions on why their company's

[1] Prominent examples include Bernanke and Gertler (1989); Kiyotaki and Moore (1997); Carlstrom and Fuerst (1997); Bernanke et al. (1999); and Jermann and Quadrini (2012).

[2] Early examples include Sharpe (1994) and Opler and Titman (1994).

[3] For example, see Almeida et al. (2004), Acharya et al. (2007), Acharya et al. (2012), Bolton et al. (2014). Examples in macro-finance distinguishing between cash and debt are Xiao (2018); Bachetta et al. (forthcoming).

[4] Such a contraction effectively corresponds to a 25 basis point unexpected increase in the federal funds rate.

investment would be insensitive to fluctuations in borrowing costs. The most cited reason for insensitivity was the firm having ample cash and not using debt as the marginal source of financing. Among other factors, firms were more insensitive if they were not planning to borrow to invest in the year ahead and not concerned about working capital management.

The empirical evidence suggests that in the transmission of interest rate shocks to investment, a key role is played by firms' ability to finance investment using liquid funds on hand, and that debt is not necessarily the marginal source of financing at all times. When this is the case, interest rates on corporate debt become irrelevant as an opportunity cost of investment. To introduce these ideas into a macroeconomic framework, explain the empirical findings on the heterogeneous interest-sensitivity of investment, and examine their relevance for aggregate dynamics, I develop a general equilibrium model in which such incentives come into play.

I extend a conventional model of heterogeneous firms subject to collateral constraints, as by Khan and Thomas (2013), and introduce long-term debt financing subject to fixed issuance costs. Firms invest using internal funds and raising debt. I assume that whenever a firm wishes to issue new debt or prepay debt faster than the repayment schedule governs, it must pay a fixed cost.[5] Because the issuance cost renders debt essentially illiquid, firms also manage liquidity by saving in cash with a lower return than the implied one-period rate on their long-term debt. The fixed cost creates an endogenous disconnect of firms from current borrowing conditions. The outstanding debt of non-issuers is a sunk decision which requires periodic coupon payments and reduces available cash flows. But the supply of credit and the returns required by lenders do not directly affect current investment decisions. Only when actively engaging in debt issuance or prepayment does the firm consider corporate debt rates as a relevant opportunity cost.

Under these circumstances, a firm's liquid asset holdings become a good predictor of a lower future likelihood of debt issuance and insensitivity to borrowing rates. Since cash pays a lower return than the effective rate on debt, accumulating liquid assets is a costly substitute for future debt issuances in providing liquid resources. Thus, if a firm expects to issue debt in the near future, it is less likely to hold liquid assets. At the same time, high leverage can indicate firms with little internal wealth and good growth prospects – likely to issue more debt. Or it can indicate a firm having reached a near-optimal scale of operations with past issuances, making new issuances less likely, reducing responsiveness to borrowing costs.

The economy also features a perfectly competitive representative financial intermediary who takes in deposits and holds the long-term debt of firms. It is subject to an exogenous intermediation cost which drives a spread between the return on cash and the implied one-period return on long-term debt. An important aspect in my study of monetary policy shocks is the empirically established fact that in response to an unexpected monetary tightening, the corporate sector's borrowing costs increase relatively more than policy rates. And the reasons for this are not explained by firm characteristics or their default risk. This is commonly interpreted as a reduction in the financial sector's effective risk-bearing capacity (Gilchrist and Zakrajšek, 2012). As emphasized by Gertler and Karadi (2015), even though high-frequency identified monetary policy shocks affect short-term nominal rates only modestly, they have large effects on the real

[5]The tendency of firms to exhibit considerable inactivity in issuing or repurchasing their own securities is an established feature of empirical firm financing behavior, suggesting the existence of financial adjustment costs with a fixed component (Leary and Roberts, 2005).

cost of long-term credit due to fluctuations in credit and term premia. In the baseline model, I take empirically estimated responses in credit premia as exogenous and introduce them as a disturbance to the intermediation cost in the model.[6] To induce the relevance of monetary policy for real interest rate fluctuations in general equilibrium, I use a New Keynesian structure with rigid nominal prices as the baseline. I also verify that one can generate the main results in a flexible price framework with real interest rate shocks.

I calibrate the model to aggregate and microeconomic data and match the frequency of firms' long-term debt issuances, among other targets. I then conduct a contractionary monetary policy shock experiment repeating the empirical exercise of estimating differences in firms' capital accumulation dynamics conditional on their leverage and liquid asset holdings. The model replicates the key stylized facts observed in the empirics. Firms with higher leverage reduce their capital stocks by relatively more over the medium run. Low cash holdings predict a stronger contraction of capital. And controlling for liquid assets, the predictive power of leverage over the medium run disappears, while cash remains relevant over and above leverage. In terms of quantitative magnitudes, the model can explain up to half of the heterogeneity in responses seen in the data. This can partially be explained by the fact that the model abstracts from fluctuations in term premia, an important feature of the data (Hanson and Stein, 2015).

The conventional Khan and Thomas (2013)-type specification of the model without fixed debt issuance costs cannot match all of the stylized empirical facts. Motivated by the consistency of the issuance cost model with my empirical findings and the survey evidence by Sharpe and Suarez (2015), I examine the implications of the existence of issuance costs for the macroeconomy. The costs keep firms from continuously raising external finance to fuel their growth when internal funds are low and marginal productivity of capital is high. This results in depressed investment and misallocation of capital. In the calibrated model, the elimination of debt issuance costs leads to a 1.3% increase in steady state output. Because of the fixed nature of the issuance cost, it is a friction that most significantly affects the behavior of firms whose benefits from raising debt are moderate. The firms with least internal wealth and most to gain from raising debt are more willing to pay the fixed cost so their investment behavior is not as affected by its existence. Since firms with moderate marginal productivities of capital tend to be medium-sized in the model, small issuance costs can lead to significant aggregate effects.

Parallel to the notion of "wealthy hand-to-mouth" households in the consumption literature (Kaplan and Violante, 2014), the existence of fixed debt issuance costs gives rise to firms who might not face a binding borrowing constraint yet exhibit very high marginal propensities to invest out of liquid income. In the baseline calibration, such firms hold a considerable fraction of aggregate capital. This implies that the existence of fixed debt issuance costs can significantly increase the corporate sector's aggregate marginal propensity to invest out shocks to cash flows. To demonstrate the mechanism in the most direct manner, I study the response of the aggregate economy to an unexpected one-time government transfer to all firms, assuming passive monetary policy and rigid prices. The model with fixed debt issuance costs exhibits a pass-through to the aggregate capital stock that is roughly three times larger than a model without these costs.

[6] Fluctuations in credit spreads could be endogenized with conventional macro-finance tools using an extra layer of financial frictions on the intermediary.

Related Literature. This paper contributes to several strands of the literature. First, there is a substantial growing literature of studies on firm heterogeneity, financial frictions, and their relevance in the aggregate economy. Some prominent examples which model frictions in external financing include Gomes (2001), Cooley and Quadrini (2001, 2006), Khan and Thomas (2013), Gilchrist et al. (2014), Khan et al. (2014), Crouzet (2018), Begenau and Salomao (2018), Xiao (2018), and Bachetta et al. (forthcoming). I contribute to these studies by introducing an extensive margin decision for financing activities and a persistent distinction between cash and debt, and by emphasizing the relevance of liquid asset positions for shock-responsiveness.

Second, there is an empirical literature which uses monetary policy as a source of aggregate variation and studies the heterogeneity in firms' responses as indication of the presence of financial frictions. Several earlier papers, such as Gertler and Gilchrist (1994), Oliner and Rudebusch (1996), and Bernanke et al. (1996) use firm size as a proxy for the financing constraints they might be facing, and find that small firms are relatively more responsive to contractionary monetary policy actions. More closely to the current paper, Kashyap et al. (1994) find that firms with low liquid asset holdings contracted their inventories significantly more during a tight monetary policy period. Other examples which study the heterogeneity in firm or industry behavior in response to monetary policy shocks include Gaiotti and Generale (2002), Ehrmann and Fratzscher (2004), Peersman and Smets (2005), Bougheas et al. (2006), Crouzet and Mehrotra (2018), Ippolito et al. (2018).[7] In reference to this literature, my empirical work contributes by using high-frequency identified monetary policy shocks in conjunction with quarterly firm panel data, and by tracing out the full dynamic heterogeneity in firms' responses conditional on leverage and liquid asset holdings.

Two recent papers closest to this one are by Ottonello and Winberry (2019) and Cloyne et al. (2018). Ottonello and Winberry (2019) study Compustat firms' capital accumulation responses to monetary policy shocks conditional on leverage, credit ratings, and a "distance to default" measure as proxies for default risk. They find that firms with higher default risk, including higher leverage, are less responsive to monetary policy shocks. Cloyne et al. (2018) also take a very similar approach, emphasizing the explanatory power of firms' age in capital investment responsiveness. They find that the investment of young firms who have not recently paid dividends is the most responsive to monetary policy shocks. And classifying firms based on the age-dividends dimensions predicts stronger heterogeneity than various measures of firms' finances. I further discuss the differences in my empirical approach and results from these two papers, and the robustness of my results, in Section 2.5 and the Appendix.

Finally, the model of the firm that I employ is in its details inspired by analyses of firm financing, liquidity, and issuance costs in corporate finance, with prominent examples including Leland (1994, 1998), Hennessy and Whited (2007), Gamba and Triantis (2008), Riddick and Whited (2009), Bazdresch (2013), Nikolov and Whited (2014), Eisfeldt and Muir (2016), Bolton et al. (2014), and Nikolov et al. (2017). My work builds on this literature by using a model of the firm to study heterogeneous responses to interest rate shocks and draw the implications of fixed issuance costs for the macroeconomy.

[7] Papers examining firm heterogeneity along financial characteristics in episodes of credit disruption include Chodorow-Reich (2014); Giroud and Mueller (2017); Buera and Karmakar (2018). Work employing household-level data on consumption responses to monetary policy shocks is done by Cloyne et al. (forthcoming).

Layout. The rest of the paper is organized as follows. Section 2 discusses the identification of monetary policy shocks, describes the firm-level data used and empirical specification employed, and presents the estimation results for fixed capital accumulation responses to a monetary policy shock. Section 3 presents the model and its calibration. Section 4 discusses results on firm behavior in the model's steady state, provides intuition, and conducts a monetary policy shock experiment to shed light on the empirical results of Section 2. Section 5 examines the implications of fixed issuance costs for the aggregate economy. Section 6 concludes.

2 Empirical Estimates of Response Heterogeneity to Monetary Policy

2.1 Identifying Monetary Policy Shocks

I identify shocks to monetary policy following the literature which employs high-frequency movements in financial markets around Federal Open Market Committee (FOMC) press releases to make inference about the unexpected components of monetary policy announcements.[8] To isolate the unanticipated component of the content in FOMC press releases, federal funds futures on the current-month funds rate are a common financial instrument to study. As the benchmark measure of a monetary policy shock at the time of the announcement, I use the change in market expectations of the federal funds rate over the remainder of the month in which the FOMC meeting occurs. These changes are construmcted from federal funds futures data as in Gürkaynak et al. (2005). Let this change at the exact time of the announcement $\tilde{t}_k$ be denoted $\nu_{\tilde{t}_k}$.[9] I use the convention that a positive $\nu_{\tilde{t}_k}$ refers to an unexpected increase in the federal funds futures rate, and thus a contractionary monetary policy shock.[10] Instead of unexpected changes in *current* month fed funds futures rates, one can also employ changes in futures prices contracted over longer horizons. As I show in Jeenas (2018), using shock measures constructed based on three month ahead fed funds futures, also when instrumenting for changes in one-year Treasury rates, leads to similar results as the ones presented below.

To go from the high-frequency measures to quarterly measures of monetary policy shocks, I aggregate the high-frequency $\nu_{\tilde{t}_k}$ by simple summation within any quarter t to yield a measure of the monetary shock in that quarter, denoted ε_t^m.[11] The key identifying assumption is that by measuring $\nu_{\tilde{t}_k}$ in a narrow window around a press release, there are no other factors affecting the fed funds futures contracts within that interval, ensuring that $\nu_{\tilde{t}_k}$ captures the effects of the monetary policy announcement. If the $\nu_{\tilde{t}_k}$ are uncorrelated with structural monetary policy shocks at other instances of time and other types of structural shocks at any point in time, then

[8] Prominent early examples of such an event study based approach to examining monetary policy are the works by Cook and Hahn (1989), Kuttner (2001), Cochrane and Piazzesi (2002), Rigobon and Sack (2004), Bernanke and Kuttner (2005), Gürkaynak et al. (2005).

[9] As conventionally done in previous work, I consider futures price changes in a window of 10 minutes before until 20 minutes after the FOMC announcement.

[10] I obtain the data on times and dates of the FOMC press releases and the implied measures of shocks from Gorodnichenko and Weber (2016) for the sample period 1994–2008. The data on announcement times and measures of shocks for the sample period 1990–1994 comes from Gürkaynak et al. (2005).

[11] By letting $\underline{\tilde{t}}$ be the exact time of beginning of quarter t, $\bar{\tilde{t}}$ the ending, and $\{\tilde{t}_k\}_k$ the exact dates and times at which FOMC announcements occur, this means that $\varepsilon_t^m \equiv \sum_{\tilde{t}_k \in (\underline{\tilde{t}}, \bar{\tilde{t}})} \nu_{\tilde{t}_k}$.

the unweighted quarterly measure ε_t^m is also independent of other types of structural shocks at any point in time, and structural monetary policy shocks in other quarters.

In Jeenas (2018) I provide a more detailed discussion on how $\nu_{\tilde{t}_k}$ are constructed, and on the identification assumptions and pitfalls behind using such high-frequency identification methods. Most importantly, the ε_t^m should be thought of as imperfect measures of quarterly structural monetary policy shocks ε_t^p which are understood as primitive, unanticipated economic forces uncorrelated with other shocks. Given that the ε_t^p cannot be observed, one can follow Stock and Watson (2018), and instead use ε_t^m as instruments for changes in policy rates in analogous instrumental variables regressions, as I discuss in Jeenas (2018). However, as the results therein show, ordinary least squares regressions employing ε_t^m as direct measures of monetary policy shocks yield virtually identical results for the regressions of interest. Therefore, for brevity, I will only focus on the OLS regression results with ε_t^m below.

In interpreting the effects of the monetary policy shocks measured by ε_t^m, it is important to keep in mind that although the shocks are measured based on unexpected movements in short-term policy rates, they can cause nontrivial fluctuations in various other prices and interest rates, including credit spreads, term spreads, and expectations regarding future short rates. And these fluctuations may themselves have considerable effects on agents' behavior, over and above the changes in current rates. For example, Gertler and Karadi (2015) find that contractionary monetary policy shocks identified using changes in fed funds futures rates lead to persistent increases in the Gilchrist and Zakrajšek (2012) excess bond premium. Since the excess bond premium is a measure of credit spreads purged of default premia, this result is likely capturing a credit channel of firms' borrowing costs, exogenous to the corporate sector. Moreover, there are numerous analyses which document the fact that changes in short-term rates measured around FOMC announcements are associated with considerable movements in *long*-term rates, both real and nominal, at maturities up to 10 years – for example, see Cochrane and Piazzesi (2002), Gertler and Karadi (2015), Gilchrist et al. (2015), and Hanson and Stein (2015).[12]

2.2 Firm-level Data

I draw the firm-level dataset from the quarterly Compustat universe of publicly listed U.S. incorporated firms. The central measure of firm i's capital accumulation is the book value of its tangible capital stock $k_{i,t}$. In the empirical work, I follow Compustat's timing convention and denote as $k_{i,t}$ the capital stock in place at the *end* of quarter t.[13] More specifically, in the dynamic panel regressions, I estimate the responsiveness of firms' capital *stocks*, rather than investment rates because micro-level investment is notoriously lumpy and erratic (Doms and Dunne, 1998), making it potentially difficult to precisely detect systematic responses in investment rates in the cross-section, especially their dynamics over longer horizons.

The main explanatory variables I consider are book leverage and the holdings of liquid assets. As the measure of a firm's leverage I employ its total debt divided by its total assets, both

[12] Some of these papers identify surprises in monetary policy based on rates at slightly longer maturities, such as two-year Treasury rates to capture forward guidance aspects of the announcements.

[13] I construct the series of capital based on measures of property, plant and equipment using a perpetual inventory method, as commonly done in the investment literature. I provide further details on sample selection and data construction in Appendix B.

measured at book values. As the measure of the liquid asset holdings of a firm, I use the ratio of the Compustat variable *Cash and Short-Term Investments* to total assets. This definition of "cash" directly follows the view taken in corporate finance that firms can manage their liquidity and financial savings using various marketable securities that potentially pay nonzero returns.[14] For notational brevity, I refer to a single explanatory financial variable as x and their union as $\mathcal{X} \equiv \{lev, liq\}$, referring to leverage and the liquid asset ratio. To eliminate seasonality in the key financial ratios, coming from either the numerator or denominator, I measure them as the past four quarter rolling means instead. Any reference to firm i's empirical leverage or liquid asset ratio in quarter t below thus refers to the corresponding yearly average $\sum_{j=0}^{3} x_{i,t-j}$, unless noted otherwise. As a control, my main regressions also include firm size, measured as (log) total book assets. I discuss robustness in Section 2.5 below.

After constructing the measures of capital stocks, I focus the main analysis on the firm-quarter observations for the sample period 1990Q1–2007Q4. This is because measures of monetary policy shocks identified using changes in fed funds futures rates are not available earlier and to exclude the exceptional conditions around the onset of the Great Recession and the implications of the federal funds rate potentially hitting the zero lower bound. Since the regression specification includes firm-level fixed effects, I only include data from firms which are observed for at least 40 quarters during 1990Q1–2007Q4 in the regressions to improve precision and alleviate issues of endogeneity.[15]

Table 1 presents summary statistics of the key variables of interest in the underlying data. In this case, the data for leverage and liquid asset ratios are not rolling averages. Since the sample only contains public firms, the average size is large, about \$1,700 million over the sample period. The highly right-skewed size distribution of firms motivates the usage of log assets as the relevant measure of size in regressions and when computing correlations. The mean of firms' leverage ratios is approximately 30% and the liquid asset ratio approximately 14%. Both exhibit considerable variation in the cross-section, with standard deviations of 42.6% and 18.1%, respectively. Quarterly capital growth exhibits significant variation as well.

Table 1: Summary statistics for underlying Compustat sample

	Size	Leverage	Liquidity	$\Delta\log(k_{i,t})$
Mean	\$1725.70	0.297	0.141	1.06%
Median	\$151.65	0.223	0.062	-0.18%
St. dev	\$8866.55	0.426	0.181	13.49%
$\mathrm{cor}(\cdot, \log(\mathrm{size}_{i,t}))$	–	-0.070	-0.214	0.052
$\mathrm{cor}(\cdot, \mathrm{leverage}_{i,t})$	–	–	-0.250	-0.065
$\mathrm{cor}(\cdot, \mathrm{liquidity}_{i,t})$	–	–	–	0.037

Notes: Size measured as book assets in millions of real 2009 dollars; leverage as total debt to assets; liquidity as cash and short-term investments to assets ratio. Statistics involving size, leverage and liquidity computed as time-averages of corresponding statistics in quarterly cross-section. Statistics for growth rates computed over all firm-quarters. Leverage and liquidity winsorized at 99.9% cutoff, growth rates at 0.1% and 99.9% cutoffs.

Based on cross-sectional correlations, firms with higher leverage also tend to hold fewer liquid

[14]For example, see Kaplan and Zingales (1997), Opler et al. (1999), Bates et al. (2009).
[15]The number of observations in the main regressions can be gauged from regression tables in Jeenas (2018).

assets as a fraction of their balance sheet. However, larger firms tend to have both slightly lower leverage and liquid assets. One must be careful in interpreting the liquid asset holdings as an effective measure of liquidity *per se*. Firms with high holdings of liquid assets might choose to hold them as a precautionary measure because of a lack of access to other sources of liquidity, such as trade credit or credit lines. To alleviate such issues, all the specifications that I consider control for firm size in explaining the heterogeneity in shock-responsiveness between firms, and robustness tests consider various other controls.

2.3 Panel Local Projection Specification

The main goal of my analysis is to estimate how the firms' capital stocks $k_{i,t+h}$, at horizon $h \geq 0$, behave in response to a monetary policy shock at time t conditional on firm i's financial position just before the shock. I do so by estimating panel regressions in the spirit of Jordà (2005) local projections, regressing the cumulative difference $\varDelta_h \log(k_{i,t+h}) \equiv \log(k_{i,t+h}) - \log(k_{i,t-1})$ on interaction terms of the firms' financial indicators at time $t-1$ and the monetary policy shock at time t, alongside a set of control variables.

I first study the relevance of leverage and liquid asset holdings in characterizing firms' responses separately, including only leverage among the regressors while *not* controlling for liquid asset holdings and vice versa. Finally, I include the relevant terms in both indicators to evaluate whether either of the two plays a more significant role in explaining firms' capital accumulation after a monetary policy shock.

The general form of the baseline panel regression specification is as follows:

$$\varDelta_h \log(k_{i,t+h}) = f_{i,h} + d_{n,h,t+h} + \left(\Theta'_h + \varepsilon^m_t \Omega'_h\right) W_{i,t-1} + \sum_{x \in \mathcal{X}^s} \left(\beta^x_h + \gamma^x_h \varepsilon^m_t\right) x_{i,t-1} + u_{i,h,t+h} \quad (1)$$

$h = 0, 1, \ldots, H$ denotes the horizon at which the relative impact effect is being estimated. $f_{i,h}$ denotes firm i's fixed effect in its cumulative k growth over horizon $h+1$. $d_{n,h,t+h}$ is shorthand for industry-quarter dummies at the SIC 1-digit level for $h+1$-quarter growth measured in period $t+h$. $W_{i,t-1}$ is a vector of lagged firm-level controls not included among the financial indicators in $\mathcal{X}$. ε^m_t is the measure of the quarterly monetary shock as constructed in Section 2.1. Θ_h, Ω_h, β^x_h and γ^x_h are regression coefficients.

$\mathcal{X}^s \subseteq \mathcal{X}$ is the set of financial explanatory variables under consideration in a given specification. For ease of interpretation, when $x_{i,t-1}$ refers to liquid asset holdings, I instead use the *negative* of the liquid asset ratio in (1). The controls $W_{i,t-1}$ and the variables in $\mathcal{X}$ are measured as of the end of the quarter before the shock ε^m_t to ensure exogeneity with respect to the shock. In the baseline case, $W_{i,t} = [\log(\text{size}_{i,t})]$. In robustness analysis, I also test for the relevance of various other firm-level controls. Since the main goal of the analysis is to evaluate differences among firms' responses to monetary policy shocks conditional on the variables in $\mathcal{X}$, including a detailed industry-time dummy to control for aggregate fluctuations allows for a flexible way to do so. This precludes including a measure of the shock ε^m_t itself in (1) and evaluating the level responses of $k_{i,t}$. I address this issue and conduct the estimation in Jeenas (2018).

I drop capital growth rate observations below the 1st and above the 99th percentile to control for outliers which might significantly affect the estimates. I do this separately based on each

$(h+1)$-quarter log-growth rate $\Delta_h \log(k_{i,t})$ by quarter t, prior to estimation for any given h. Similarly, for the controls in $\mathcal{X}$ I drop all firm-quarters for which $x_{i,t}$ is above the 99th percentile in the quarter t cross-section. I conduct estimation of the firms responses up to the horizon of $H = 20$ quarters. I consider standard errors clustered at the quarter and firm levels.[16]

For interpretability, prior to estimation I multiply the $\Delta_h \log(k_{i,t+h})$ by 100. I also rescale the monetary policy shock measures' series ε_t^m by its standard deviation of approximately 12 basis points as measured by changes in fed funds futures rates. To relate this shock size to the corresponding observed changes in the actual federal funds rates, note that an unexpected 1 bp change in the futures' rates is usually accompanied by a larger than 1 bp change in the actual federal funds rate, due to the discrete nature of how the FOMC sets the federal funds rate target. More specifically, this 1 sd shock in federal funds futures rates corresponds to a roughly 25 bp change in the federal funds rate.[17]

The key coefficients of interest in regression (1) are the γ_h^x, measuring the relevance of variable x in predicting heterogeneity in firms' responsiveness at horizon h. A positive ε_t^m stands for a fed funds rate increase. This means that a negative estimate for γ_h^x implies that firms with higher x prior to the shock experience relatively lower capital growth (or a larger contraction) over horizon h after a contractionary shock.

Finally, note that the specification (1) imposes linearity in the marginal effect of the financial variables x on explaining firms' responsiveness, with $\frac{\partial^2 \Delta_h \log(k_{i,t+h})}{\partial \varepsilon_t^m \partial x_{i,t-1}}$ assumed to be constant. As the results in Appendix B.2 and in Jeenas (2018) show, for the explanatory power of leverage such an assumption is not exactly supported by the estimates which imply that conditional on being above the 40th percentile in the cross-sectional leverage distribution, there do not seem to be significantly different responses between firms with higher or lower leverage. This explains why the estimates for γ_h^{lev} below exhibit relatively low statistical significance in the separate regression, when $\mathcal{X}^s = \{lev\}$.

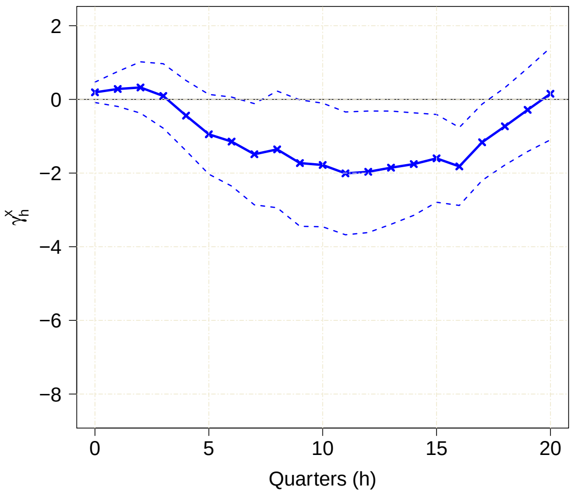
2.4 Panel Regression Estimates

Figure 1 presents the estimates for γ_h^{lev} and γ_h^{liq} from the separate estimation of (1) with either $\mathcal{X}^s = \{lev\}$ or $\mathcal{X}^s = \{liq\}$, respectively. From Panel 1a, one can see that firms with more leverage at the time of a contractionary monetary policy shock tend to experience relatively slower fixed capital growth in the years to follow. The differences based on the point estimates become negative starting about 4 quarters after the shock and statistically significant 7 quarters after, and start to revert about 3 years after the shock. The differences in fixed capital accumulation

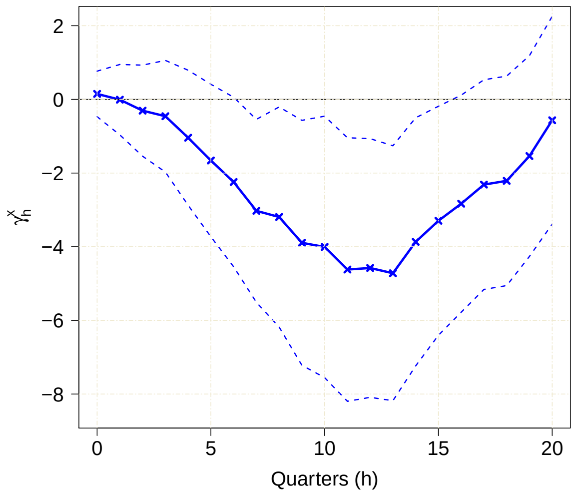
[16] Clustering at the firm level allows for fully flexible dependence in the error terms across time within each firm, arising in local projections (Jordà, 2005). Clustering by time would only be necessary if firm-level shocks were correlated within a quarter over and above the comovement caused by industry-level shocks captured by the industry-quarter dummies. To provide the most conservative confidence intervals, I also cluster at the quarter level. Without doing this, any confidence intervals on estimates presented below tend to be considerably narrower.

[17] As shown by the results in Jeenas (2018), this is exactly the conclusion one arrives at when conducting an instrumental variables estimation, using ε_t^m as a source of exogenous variation for the fed funds rate: the effects of a 1 sd shock in ε_t^m are virtually indistinguishable from that of an exogenous 25 bp change in the fed funds rate. This shock magnitude is also exactly in line with the VAR estimates by Gertler and Karadi (2015) who estimate that a 1 sd surprise monetary tightening leads to a roughly 25 bp increase in the one-year government bond rate which is their preferred monetary policy indicator. A univariate linear OLS regression of the quarterly change in the fed funds rate on ε_t^m yields a slope coefficient point estimate of approximately 2.2.

arise over a relatively long horizon, in line with the response of aggregate economic activity estimated by Gertler and Karadi (2015). Quantitatively, the estimates imply that in response to a 1 sd monetary policy shock as measured by fed funds futures rates, 10 pp higher leverage predicts about 0.2 pp lower fixed capital growth over the 3 years following the shock.



(a) $x =$ leverage



(b) $x = -$liquid asset ratio

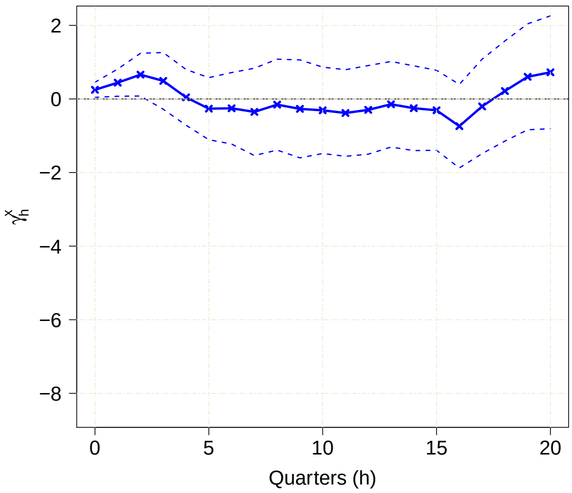
Figure 1: Heterogeneity in responses of capital accumulation conditional on leverage or liquid asset holdings

Notes: Point estimates and 95% confidence intervals for γ_h^x from estimating specification (1), with $\mathcal{X}^s = \{x\}$. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

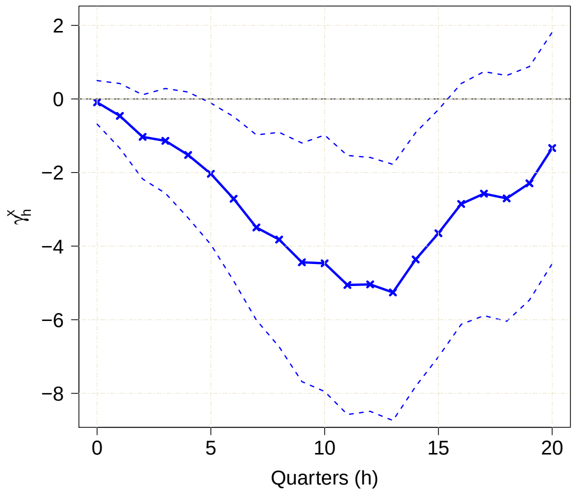
Analogously, Panel 1b shows that firms with lower liquid asset holdings reduce their capital stock relative others after an unexpected contractionary monetary policy shock. The general dynamics of the differences in capital accumulation are similar to those conditional on leverage. The largest differences approximately 3 years after the shock imply that a 10 pp lower liquid asset ratio predicts about 0.4 pp lower cumulative capital growth after a 1 sd monetary policy shock. Thereafter the differences disappear. Given the cross-sectional standard deviations of leverage and liquid asset ratios shown in Table 1, scaling the coefficients γ_h^x accordingly implies that a 1 sd increase in leverage or decrease in liquid asset holdings both predict an approximately 0.8 pp stronger cumulative contraction in a firm's capital stock over three years after a 1 sd monetary policy shock as measured by fed funds futures rates.

These results thus show that high leverage and low liquid asset holdings predict weaker growth of fixed capital for firms in the Compustat sample after a contractionary monetary policy shock. Yet as shown in Table 1, firms with higher leverage also tend to hold less liquid assets in the cross-section. To explore the possiblity that the estimates above could be suffering from omitted variable bias and obscuring the fact that only one of these financial variables might explain the differences in responses, I include both controls for leverage and liquid assets in estimating (1), with $\mathcal{X}^s = \mathcal{X} = \{lev, liq\}$.

Figure 2 presents the estimates for γ_h^{lev} and γ_h^{liq} from the joint regression. When simultaneously controlling for liquid asset holdings, the relevance of leverage in explaining differences in firms' capital accumulation responses over the medium run disappears. On the other hand, the positive relation between leverage and fixed capital accumulation in the quarters right after a contractionary monetary policy shock apparent already in Figure 1 strengthens slightly and becomes statistically significant. At the same time, the estimates in Panel 2b indicate



(a) x = leverage



(b) $x = -$liquid asset ratio

Figure 2: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings in joint regression

Notes: Point estimates and 95% confidence intervals for γ_h^x from estimating specification (1), with $\mathcal{X}^s = \{lev, liq\}$. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

that there are no significant changes in the explanatory power of liquid assets in characterizing heterogeneity among the firms' capital stock responses.

2.5 Discussion and Robustness of Empirical Results

There are three main takeaways from the empirical analysis. High leverage predicts considerably weaker capital growth in the years following a contractionary monetary policy shock. So does a low liquid asset ratio. And controlling for both leverage and liquid asset holdings, the former loses its explanatory power whereas the implications of the latter barely change.

These findings are robust to a wide array of variations in the empirical approach. In the interest of brevity, I delegate the establishing of their robustness to the work in Jeenas (2018). Therein, I show that the main findings hold when instead grouping firms based on their positions in the cross-sectional leverage and liquid asset ratio distribution at any given point in time, either based on quintiles or more coarse groupings. The results are also robust to allowing the heterogeneity of responses to be explained by the Standard & Poor's Long-Term Issue credit ratings or whether the firm has paid dividends in the past year, also by sales growth, cash flow or the market-to-book ratio. To ensure that the shape of the dynamic responses in Figures 1 and 2 is not affected by the sample selection of monetary shock observations imposed by (1), I also consider only using observations of ε_t^m up to 2002Q4, while the firm-level outcomes are included until 2007Q4. In addition, one can focus only on a balanced panel of firms which that have no missing data between 1990Q1–2007Q4. I also extend the sample of monetary shocks until

2012Q2 and firm-level data until 2015Q4 without any considerable changes in the estimates.

To verify that the monetary policy shock measures are not correlated with the business cycle in any specific way that could explain the results, one can allow the lags in output growth and the Gilchrist and Zakrajšek (2012) excess bond premium to explain the heterogeneity in the firms' behavior alongside the monetary policy shocks. To check whether the responses might instead be explained by the revelation of the FOMC's private information on the economic outlook instead of news purely about monetary policy[18], one can do the same with forecasts of GDP growth and inflation from the Greenbook of the Federal Reserve Board of Governors. Finally, one can repeat the estimations by replacing ε_t^m in (1) with the quarterly change in a policy rate, such as the federal funds rate or the one-year Treasury rate, and instrumenting it with ε_t^m or an instrument constructed based on changes in the three month ahead fed funds futures rates. The work in Jeenas (2018) also estimates the heterogeneous responses of the capital stock levels for groups of firms with different balance sheet positions.

Appendix B.2 discusses the main results in relation to the findings of Ottonello and Winberry (2019). They point out that when financial variables, such as leverage, are demeaned at the firm level, with the goal of controlling for permanent differences between firms, the predictions regarding shock-responsiveness can change. Higher within-firm leverage predicts significantly weaker responses in capital stocks for up to a year after a monetary shock and the differences become insignificant afterwards.[19] I focus on the variation explained by the levels of firm financials and capital stock impact horizons of four quarters and more – the time frame during which the response of aggregate activity is commonly estimated to peak (Gertler and Karadi, 2015). Appendix B.2 shows that my main results are robust to not taking past-year rolling averages, which otherwise may put more emphasis on permanent differences between firms explaining the response heterogeneity. And using the model of Section 3, it emphasizes why demeaning financial variables at the firm level can eliminate important persistent differences when no permanent differences between firms exist. I also show that my main results hold when dropping firms who have permanently high or low leverage or liquid asset holdings, as an alternative way of controlling for permanent differences.

Appendix B.3 shows that the main results above are robust to controlling for firm age, measured as time since incorporation following Cloyne et al. (2018). Moreover, it illustrates that the response heterogeneity predicted by leverage and liquid asset holdings is considerably larger among younger firms. This aligns with the common idea that financial considerations and frictions are very likely more important for the investment behavior of younger firms.

Figure B.6 in Appendix B.4 presents the estimates of γ_h^x from the separate and joint specifications of (1) by employing measures of monetary policy shocks ε_t^m constructed using the approach of Romer and Romer (2004). The three main takeaways from Section 2.4 are unchanged, including the peak differences predicted by leverage and liquid asset holdings in response to a 1 sd shock. The Romer and Romer (2004) shocks induce differences between firms' capital accumulation which appear slightly earlier, peaking around two years after. This difference in the impact horizon is in line with the fact that in local projections, the high-frequency identified shocks

[18] See Nakamura and Steinsson (2018) or Jarocinski and Karadi (2018), for example.

[19] Ottonello and Winberry (2019) do find significant differences in capital stocks at longer horizons predicted by within-firm variation in the distance to default measure.

induce long-lived hump-shaped responses of short rates while the effects of the Romer-Romer shocks are more short-lived – see Figures 2B and 3B in Ramey (2016).

Evidence from a survey of CFOs. Additional evidence for the relevance of firms' liquid asset positions in explaining (in)sensitivity to interest rate fluctuations, and balance sheet strength being of less importance, comes from the work by Sharpe and Suarez (2015). To explore the reasons for firms' insensitivity to borrowing costs, they use data from the Duke University/CFO Magazine Global Business Outlook survey of financial executives which in September 2012 asked participants how much their borrowing costs would have to decrease (increase) to cause them to accelerate (decelerate) investment projects in the upcoming year. If no rate change would affect their investment plans, they were asked "Why not?". The most commonly cited answer to this open ended question was in the spirit of the firms having ample cash reserves or cash flow so that debt was not a marginal source of finance, while barely anyone stated high levels of debt or lack of access to credit being a reason.[20]

Among other firm-specific factors that predicted reported borrowing cost sensitivity, Sharpe and Suarez (2015) find that one of the most influential was whether the firm had plans to borrow to finance investment in the year ahead. Firms with no plans to borrow were on average 28 pp less likely to indicate that they would cut back investment in response to any borrowing rate increase. Sensitivity of investment was also stronger if the firm indicated working capital management among its top three company-specific concerns. At the same time, firms reporting weak balance sheets as a concern did not report higher nor lower sensitivity. This provides another piece of evidence in support of the idea that financial matters and frictions are more likely to alter the pass-through of borrowing costs to investment through a "liquidity channel" (working capital), rather than a "leverage channel" (weak balance sheets).

According to the empirical findings, a framework which aims to explain the (heterogeneous) transmission of monetary policy to investment based on financial considerations should include the following ideas and features not present in conventional macro-finance models. First, the marginal source of financing matters and it might not always be external funds but rather internal cash buffers and cash flows. Second, the timing of debt issuances matters and has direct consequences for firms' interest-sensitivity, implying that the opportunity cost of investing at a given point in time is not necessarily the interest rate on corporate borrowing. Finally, since the marginal source of investment financing matters, accounting for fluctuations in the corresponding opportunity costs, such as corporate borrowing rates versus returns on internal savings, is not inconsequential. Results in Jeenas (2018) also show that lower liquid asset holdings predict stronger responses in a proxy of the average interest rates firms pay on their debt, while this is not the case for higher leverage. This further supports a mechanism by which firms with less liquid balance sheets expose themselves to fluctuations in rates by being more likely to raise new debt, while at least some previously outstanding debt has been issued at fixed rates. In what is to follow, I develop and study a model that introduces these insights into a macroeconomic framework.

[20] Among those insensitive to borrowing rate increases, 49% cited ample cash reserves or cash flows as a reason, and 32% did for decreases. 1% and 4%, respectively, stated a high level of debt or a weak balance sheet as the reason. 2% among those insensitive to either borrowing cost increases or decreases cited lack of access to credit.

3 Model

In this section I construct a heterogeneous firm model which allows to explain the empirical results on heterogeneous sensitivity to monetary policy shocks presented in Section 2. The baseline specification features a New Keynesian structure with rigid nominal prices of a final good. Given that the central mechanism of interest behind differences in firms' responses to monetary policy shocks is their heterogeneous exposure to real interest rate fluctuations, one can generate similar results and conduct the analysis with a flexible price version with household discount factor shocks. I cover this in Appendix A.10.

Because I study stationary equilibria[21] and perfect foresight transition paths in response to unexpected aggregate shocks, I do not include aggregate uncertainty in the notation below. I represent fluctuations in prices, aggregate quantities and value functions using time-subscripts. Agents' choices in individual optimization problems employ primes to refer to future values. Although I consider transitions after unexpected aggregate shocks under rigid prices, the notation allows for fluctuations in the nominal price level. The "cash" held by agents is a label for their deposits in the financial intermediary in general equilibrium and embodies claims to the final good. References to "nominal units" should simply be understood in terms of units of account.

3.1 Environment

Time in the model is discrete and infinite. There is a final good that is used for consumption and capital formation. The key agents in the economy are heterogeneous firms producing wholesale goods, while facing financial and capital adjustment frictions.[22] There is also a representative household, a financial intermediary, and a government. In order to model price setting outside the firms which face financial frictions, the economy includes a representative final good producer and a unit mass of monopolistically competitive retail goods producers, following Bernanke et al. (1999). The wage and the price of wholesale goods are flexible. In essence, the model employs the structure used by Khan and Thomas (2013), introducing long-term debt and fixed costs to issuing this debt. For brevity, I present the model in real terms, using the final good as the numeraire and being explicit about movements in nominal variables over and above real fluctuations whenever relevant. I discuss key assumptions in detail in Appendix A.2.

3.1.1 Firms, Production, and Financial Frictions

In every period, a unit mass of incumbent firms produces a homogeneous wholesale good using labor n and predetermined capital k operating a decreasing returns to scale production function:

$$y = z^{1-\nu} k^{\alpha} n^{\nu} \tag{2}$$

Labor is flexible and hired in a perfectly competitive labor market for real wage w_t. z is a firm's idiosyncratic total factor productivity and follows a Markov chain $z \in \mathbf{Z} \equiv \{z_1, \ldots, z_{N_z}\}$, with

[21] By "stationary" equilibria or the "steady state" I refer to equilibria in which all aggregates, including the distribution of firms do not change and are expected to be fixed, while individual agents face idiosyncratic risk.

[22] To distinguish these heterogeneous wholesale goods producers from other productive entities, they are the only agents which I refer to as "firms".

$\mathbb{P}(z' = z_j | z = z_i) \equiv \pi_{ij} \geq 0$, and $\sum_{j=1}^{N_z} \pi_{ij} = 1, \forall i = 1, \ldots, N_z$. Let $\bar{\pi}_i$ denote the probability of z_i in the ergodic distribution of z. In addition, each firm faces an i.i.d. mean-zero cash flow shock ζ which potentially scales with capital: ζk^{χ}, with $\chi \geq 0$ a parameter, and $\zeta \sim U\left[-\bar{\zeta}, \bar{\zeta}\right]$. In period t, the firm sells the wholesale good at nominal price P_t^w which it takes as given. Each firm entering period t faces a constant probability $\eta \in (0,1)$ of receiving an exit shock that forces it to exit the economy after production in t. Exiting firms are are replaced by an equal mass of entrants whose initial states I describe below.

A firm's capital stock depreciates at rate $\delta \in (0,1)$ and adjustments to the individual capital stock are subject to irreversibility and convex investment costs. Whenever the firm wishes to sell a unit of capital, that is, engage in negative gross investment by setting $k' < (1-\delta)k$, the effective real price of investment is p_k^-. The real price of purchasing a unit of capital is 1, but a firm engaging in positive net investment ($k' > k$) incurs convex costs of $g_q \left(\frac{k'-k}{k}\right)^2 k$, with $g_q \geq 0$ a parameter. Thus, when a firm with capital stock k chooses next period's capital k', it must effectively pay for the gross investment $i \equiv k' - (1-\delta)k$, and the adjustment costs:

$$AC(k', k) \equiv \left(1 - p_k^-\right) \left[(1-\delta)k - k'\right] \mathbb{1}\left\{k' < (1-\delta)k\right\} + g_q \left[\left(\frac{k'-k}{k}\right)_+\right]^2 k \tag{3}$$

$\mathbb{1}\{\mathcal{P}\}$ is an indicator function of event $\mathcal{P}$, and the subscript "+" refers to $(\vartheta)_+ \equiv \max\{0, \vartheta\}$.

In addition to holding illiquid capital k, firms can save in liquid assets m, which I interchangeably refer to as "cash". Liquid assets acquired in period t provide a real net return r_{t+1}^m in period $t+1$ – the "lending rate". Firms cannot borrow using cash, facing the constraint $m' \geq 0$.

Firms can borrow using long-term debt contracts. I model long-term debt as a geometrically decaying coupon, with one unit of debt issued in period t stipulating that the debtor pay the creditor $(1-\gamma)$ units of the final good in $t+1$, $\gamma(1-\gamma)$ in $t+2$, $\gamma^2(1-\gamma)$ in $t+3$ etc. q_t is the price of a unit of such debt raised in t.[23] Whenever the firm wants to issue new debt, or repurchase existing debt to repay it faster than the repayment schedule dictates, it must pay a real fixed cost c_B. In each period, the firm draws a new adjustment cost c_B, i.i.d. across firms and time, distributed uniformly: $c_B \sim U[0, \bar{c}_B]$. I assume that the fixed cost c_B can be paid by the firm's equityholders, and an exiting firm does not have to pay any cost when repaying its debt outstanding. Let the function G denote the cumulative distribution function of c_B.

For notational ease and to aid in working with spreads between borrowing and lending rates, I reformulate the firm's problem in period t as that of choosing a real market value of debt outstanding b' at the end of the period whenever adjusting. And a net real interest rate r_t^b must be paid per unit of incoming b. If a firm does not adjust its debt in t, it must repay a fraction $(1-\gamma_t)$ of the principal b and carry $b' = \gamma_t b$ forward. Appendix A.1 shows how a long-term debt contract with a geometrically decaying coupon can be rewritten in such a form. Essentially, r_{t+1}^b is the real net return received by a lender holding the debt contract between periods t and $t+1$, and the time-varying γ_t is a readjustment of the underlying γ due to changes in the price of long-term debt outside steady state. q_t must be conformable with r_t^b and γ_t as

[23] Given that I am abstracting from fluctuations in the nominal price level, the assumption of debt denominated in real versus nominal units of account is innocuous. With fluctuations in inflation, nominally denominated debt would be more in line with reality (Gomes et al., 2016).

shown in Appendix A.1. In a steady state without inflation, $\gamma_t = \gamma$. In all perfect foresight equilibria considered below, $r^b_{t+1} > r^m_{t+1}, \forall t$.

The firm also faces a borrowing constraint which states that whenever adjusting its debt, the market value of its whole debt outstanding entering the upcoming period must be less than a fraction θ of its capital stock brought into that period. In the calibrations considered, the loan-to-value (LTV) parameter θ is low enough such that a firm can always afford to repay all of its debt outstanding by liquidating its undepreciated capital, and it is not allowed to default. Firms cannot save in long-term debt. Incumbent firms are not allowed to issue equity. Entering firms are fully equity-financed.

Because the cash flow shock ζ is i.i.d., I treat it as directly shocking the firm's available liquid assets $a \equiv (1 + r^m_t)m + \zeta k^{\chi}$. Given this definition, at the beginning of a period after having realized shocks (z, ζ), a firm is defined by capital $k \in \mathbf{K} \subset \mathbb{R}_+$, the value of available liquid assets $a \in \mathbf{A} \subset \mathbb{R}$, the incoming real market value of debt outstanding $b \in \mathbf{B} \subset \mathbb{R}_+$, and the realization of its current idiosyncratic productivity $z \in \mathbf{Z}$. Given this idiosyncratic state, the firm then takes a sequence of decisions in order to maximize its value to its shareholders. First, it labor hires, produces and pays its wage bill. If the firm must exit, it repurchases all outstanding debt, liquidates its undepreciated capital, and pays any remaining funds as dividends to shareholders. Conditional on survival, it draws a fixed cost c_B. If the firm pays the cost, it chooses the market value of debt b' going forward, liquid assets m', the capital stock k', and current dividends, subject to the borrowing constraint and the non-negativity constraints on the assets and dividends. Otherwise, it sets $b' = \gamma_t b$ and chooses m', k', and dividends paid.

I summarize the distribution of firms over (k, a, b, z), engaging in production at the beginning of period t using the probability measure μ_t defined on the Borel σ-algebra $\mathcal{S}$. $\mathcal{S}$ is generated by the open subsets of the product space $\mathbf{S} \equiv \mathbf{K} \times \mathbf{A} \times \mathbf{B} \times \mathbf{Z}$.

Entrants. The entrants replacing the exiting mass η of incumbents in t enter at the end of t with initial capital stock k_0, a calibrated parameter, and no debt nor cash. They then draw an initial level of persistent productivity from the ergodic distribution of z and a cash flow shock ζ, and continue as incumbents, hiring labor and producing at the beginning of period $t + 1$.

3.1.2 Household

There is a representative infinitely-lived household which derives utility from consumption of the final good c and supplies labor n^h for the real wage w_t. The household saves its wealth in liquid assets m^h and in one-period shares in firms. I denote the distribution of the household's ownership of the firms' shares using the measure Λ^h. The household also owns the financial intermediary and the retail and final good producers. I assume that the household cannot save in long-term debt. For brevity, I also assume that it cannot borrow in long-term debt. The latter without loss of generality because the household owns the financial intermediary and intermediation is costly, so it would never borrow in equilibrium. As a benchmark, I assume that the aggregate debt issuance costs, denoted $\Psi_{B,t}$, and the intermediation costs $\Psi_{I,t}$ are rebated lump sum to the household, so they do not show up as exhaustion of resources in the economy's aggregate resource constraint.

The Bellman equation for the representative household's lifetime utility is:[24]

$$\mathcal{V}_t^h\left(m^h, \Lambda^h\right) = \max_{c,n^h,m^{h\prime},\Lambda^{h\prime}} \left\{\log c - \psi n^h + \beta \mathcal{V}_{t+1}^h\left(m^{h\prime}, \Lambda^{h\prime}\right)\right\}$$
$$\text{s.t. } c + m^{h\prime} + \int_{\mathbf{S}} \rho_{1,t}(k', a', b', z')\Lambda^{h\prime}(dk', da', db', dz') \leq$$
$$\leq w_t n^h + (1 + r_t^m) m^h + \int_{\mathbf{S}} \rho_{0,t}(k, a, b, z)\Lambda^h(dk, da, db, dz) + div_t^I + \Xi_t^r + \Psi_{I,t} + \Psi_{B,t} - T_t$$
$$m^{h\prime} \geq 0$$

$\rho_{0,t}(k, a, l, z)$ is the (*cum dividend*) real price of shares of firms entering period t with state (k, a, b, z), and $\rho_{1,t}(k', a', l', z')$ is the price of new shares of firms which begin the next period with the state (k', a', b', z').[25] div_t^I are the dividends from the financial intermediary. Ξ_t^r are the profits of the retail goods producers and T_t denotes lump sum taxes raised by the government to cover cost subsidies to retailers. Given that the household must hold the shares of all firms in equilibrium, I am not explicitly imposing a no-shorting constraint on firm equity.

3.1.3 Financial Intermediary

There is a representative, perfectly competitive "pass-through" financial intermediary who takes deposits from the firms and the household and lends these out in the form of long-term debt. The intermediary faces intermediation costs $\phi_{t+1}^I > 0$ per unit of real long-term debt held at the end of period t, which it incurs in $t+1$.[26] The intermediary is owned by the household, pays dividends div^I and faces no other financial frictions apart from the intermediation cost.

Using the reformulation of the real market value of long-term debt and the real return of r_t^b on this debt as for the heterogeneous firms, the recursive problem of the intermediary is:

$$\mathcal{V}_t^I(B, D) = \max_{div^I, B', D'} \left\{div^I + M_{t+1}\mathcal{V}_{t+1}^I(B', D')\right\}$$
$$\text{s.t. } div^I \leq \left(1 + r_t^b\right) B - (1 + r_t^m) D - B' + D' - \phi_t^I B$$
$$B', D' \geq 0$$

B and D are the real debt held and real deposits taken in, respectively, by the intermediary at the end of $t-1$. M_{t+1} is the real stochastic discount factor of the owner of the intermediary.

3.1.4 Retail Goods, Final Good Production, and the Government

Retail Goods Production. There is a unit mass of retailers $j \in [0, 1]$, each with a linear production function that transforms wholesale goods into intermediate goods: $y_{j,t} = y_{j,t}^w$. $y_{j,t}^w$ is the amount of wholesale goods employed as input by retailer j in period t. The retailers

[24]For brevity, I leave out purchases of shares in the intermediary or the retail and final good producers.

[25]I follow Khan and Thomas (2013) and use the notation which allows the household to choose its ownership of type (k', a', b', z') firms because the law of large numbers applies and the transition probabilities of z are known.

[26]I assume that the value of ϕ_{t+1}^I is always known at t, and any unexpected shocks to intermediation costs are revealed at least one period ahead. After paying the intermediation cost, the intermediary can trade the remaining debt outstanding in a frictionless secondary market in which the only participants are the representative intermediary and any adjusting firms trading in their *own* debt contracts.

purchase from the heterogeneous firms producing wholesale goods in a competitive market for the nominal price P_t^w, and sell their production for price $p_{j,t}$. They take the demand curve for their retail good as a function of $p_{j,t}$ as given.

Given that I study stationary equilibria with no inflation, I set the stationary equilibrium prices $p_{j,SS}$ to equal their long run, flexible price counterparts given a nominal price level. As a benchmark, I also assume that a constant cost subsidy is in place, so that a retailer must only pay a fraction $1-\tau_w$ of its production costs. Choosing τ_w accordingly, one can ensure that steady state gross markups of retail goods prices over wholesale prices are 1. The stationary equilibrium with monopolistic competition is thus identical to that of a real business cycle version of the model without inefficiencies arising from monopolistic competition in steady state.

Final Good Production. The final good is produced by a perfectly competitive final good producer who takes the prices of the final good and the retail goods as given. It has a constant elasticity of substitution production function, combining the retail goods into the final good with elasticity of substitution $\varepsilon > 1$: $Y_t = \left(\int y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$.

Government. I combine the conduct of fiscal and monetary policy under the hood of the government. Given that I am focusing on equilibria with rigid prices, I assume that the government can set the interest rate r_{t+1}^m on liquid assets in the short run. And in steady state, $r_{SS}^m = \beta^{-1} - 1$. The government runs a balanced budget, setting lump sum taxes on the household equal to the cost subsidies paid to the retailers.

3.2 Equilibrium and Analysis

3.2.1 Heterogeneous Firms' Optimization

I characterize the problem of a firm recursively. Let $\tilde{V}_{0,t}(k,a,b,z)$ represent the real beginning-of-period expected discounted value of a firm that enters t with capital k, available liquid assets a, incoming real market value of debt outstanding b, and idiosyncratic TFP realization z:

$$\begin{aligned} \tilde{V}_{0,t}(k,a,b,z) =& \eta \left\{ \max_n \left[\frac{P_t^w}{P_t} z^{1-\nu} k^\alpha n^\nu - w_t n \right] + p_k^-(1-\delta)k + a - (1+r_t^b)b \right\} \\ &+ (1-\eta)\mathbb{E}_{c_B} \left[\tilde{V}_{1,t}(k,a,b,z,c_B) \right] \end{aligned} \tag{4}$$

$\tilde{V}_{1,t}(k,a,b,z,c_B)$ is the value of a firm which is not hit by the exit shock in t and has drawn an issuance cost c_B. $\mathbb{E}_{c_B}$ is the expectations operator with respect to c_B. Once the firm's exit shock is realized, it knows which part of (4) is operative. If the firm is assigned to exit, it simply chooses labor n to maximize current profits and pays these out to shareholders alongside the returns from capital liquidation and available liquid assets, net of debt repayments.

If the firm survives and continues, it draws a debt adjustment cost for the current period, and must then choose whether to pay this cost and be free to choose its continuation debt, or not pay and follow the debt repayment schedule. The firm's value conditional on continuing is:

$$\tilde{V}_{1,t}(k,a,b,z,c_B) = \max \left\{ \tilde{V}_t^A(k,a,b,z,c_B), \tilde{V}_t^N(k,a,b,z) \right\}$$

where $\tilde{V}_t^A$ and $\tilde{V}_t^N$ are the values associated with adjusting and not adjusting the debt in period

t, respectively. If the firm pays the adjustment cost, it solves the problem:

$$\begin{aligned}
\tilde{V}_t^A(k,a,b,z,c_B) = &\max_{div,n,k',m',b'} \left\{ div - c_B + M_{t+1}\mathbb{E}_{z',\zeta'}\left[\tilde{V}_{0,t+1}\left(k',a',b',z'\right)|z\right]\right\} \\
\text{s.t.}\quad & 0 \le div \le \frac{P_t^w}{P_t} z^{1-\nu}k^{\alpha}n^{\nu} - w_t n - (1+r_t^b)b + b' + a - m' - k' + (1-\delta)k - AC(k',k) \\
& 0 \le \left(1+r_{t+1}^b\right)b' \le \theta k'; \quad m' \ge 0; \quad a' = \left(1+r_{t+1}^m\right)m' - \zeta' k'^{\chi}
\end{aligned}$$

Note that in this case, the firm's debt b becomes an irrelevant state variable over and above a measure of its financial wealth, such as $a - \left(1+r_t^b\right)b$, helpful when solving the problem computationally. If the firm does not adjust its debt, it solves:

$$\begin{aligned}
\tilde{V}_t^N(k,a,b,z) = &\max_{div,n,k',m'} \left\{ div + M_{t+1}\mathbb{E}_{z',\zeta'}\left[\tilde{V}_{0,t+1}\left(k',a',\gamma_t b,z'\right)|z\right]\right\} \\
\text{s.t.}\quad & 0 \le div \le \frac{P_t^w}{P_t} z^{1-\nu}k^{\alpha}n^{\nu} - w_t n - \left(1-\gamma_t+r_t^b\right)b + a - m' - k' + (1-\delta)k - AC(k',k) \\
& m' \ge 0; \quad a' = \left(1+r_{t+1}^m\right)m' - \zeta' k'^{\chi}
\end{aligned}$$

Given that labor is flexible and hired in a perfectly competitive market, a firm's labor demand at any given point in time is a function of the real wage and aggregate markup $\mathcal{M}_t \equiv \frac{P_t}{P_t^w}$, independent of its financial position or the realization of the exit shock: $n_t(k,z) = z\left[\nu/(\mathcal{M}_t w_t)\right]^{\frac{1}{1-\nu}} k^{\frac{\alpha}{1-\nu}}$. This implies current production y and earnings net of labor costs y^p:

$$y_t(k,z) = z\left[\frac{\nu}{\mathcal{M}_t w_t}\right]^{\frac{\nu}{1-\nu}} k^{\frac{\alpha}{1-\nu}}; \qquad y_t^p(k,z) = (1-\nu)z\mathcal{M}_t^{-\frac{1}{1-\nu}}\left[\frac{\nu}{w_t}\right]^{\frac{\nu}{1-\nu}} k^{\frac{\alpha}{1-\nu}}$$

As is common in this type of models, following Khan and Thomas (2008), it is convenient to impose the fact that in equilibrium the household owns the firms, so one can write the owner's stochastic discount factor $M_{t+1} = \beta\frac{\upsilon_{t+1}}{\upsilon_t}$, with υ_t being the household's marginal utility value of a unit of the final good, and redefine the firm's value in terms of marginal utility, rather than units of output, $V_{0,t} \equiv \upsilon_t \tilde{V}_{0,t}$, analogously for $V_{1,t}$, V_t^A, and V_t^N. Omitting the law of motion $a' = \left(1+r_{t+1}^m\right)m' - \zeta' k'^{\chi}$ for brevity, the above system of equations then becomes:

$$V_{0,t}(k,a,b,z) = \eta\upsilon_t\left\{y_t^p(k,z) + p_k^-(1-\delta)k + a - (1+r_t^b)b\right\} + (1-\eta)\mathbb{E}_{c_B}\left[V_{1,t}(k,a,b,z,c_B)\right] \tag{5}$$

$$V_{1,t}(k,a,b,z,c_B) = \max\left\{V_t^A(k,a,b,z,c_B), V_t^N(k,a,b,z)\right\} \tag{6}$$

$$\begin{aligned}
V_t^A(k,a,b,z,c_B) = &\max_{div,n,k',m'\ge 0,b'} \left\{ \upsilon_t(div - c_B) + \beta\mathbb{E}_{z',\zeta'}\left[V_{0,t+1}\left(k',a',b',z'\right)|z\right]\right\} \qquad (7) \\
\text{s.t.}\quad & 0 \le div \le y_t^p(k,z) - (1+r_t^b)b + b' + a - m' - k' + (1-\delta)k - AC(k',k) \\
& 0 \le \left(1+r_{t+1}^b\right)b' \le \theta k' \\
V_t^N(k,a,b,z) = &\max_{div,n,k',m'\ge 0} \left\{ \upsilon_t div + \beta\mathbb{E}_{z',\zeta'}\left[V_{0,t+1}\left(k',a',\gamma_t b,z'\right)|z\right]\right\} \qquad (8) \\
\text{s.t.}\quad & 0 \le div \le y_t^p(k,z) - \left(1-\gamma_t+r_t^b\right)b + a - m' - k' + (1-\delta)k - AC(k',k)
\end{aligned}$$

Since V_t^A is linear in c_B, the firm's optimal decision to pay the fixed cost follows a simple cutoff policy, with the firm adjusting debt whenever $c_B \leq \hat{c}_{B,t}(k, a, b, z)$. The cutoff is determined as:

$$\hat{c}_{B,t}(k, a, b, z) = \frac{V_t^A(k, a, b, z, 0) - V_t^N(k, a, b, z)}{\upsilon_t}$$

The problem of a non-adjusting firm in (8) illustrates the relevance of debt issuance costs in decoupling the firms' investment from corporate debt rate dynamics. Because the firm is not making any active decisions regarding borrowing, the interest rates on corporate debt are not a relevant opportunity cost of investing in k'. This mirrors the indifference of firms' CFOs to borrowing cost fluctuations whenever they are not planning to raise new debt to fund investment (Sharpe and Suarez, 2015). Moreover, because of the structure of long-term debt contracts in the model, one can follow Appendix A.1 and rewrite $(1 - \gamma_t + r_t^b)b$ as $(1 - \gamma)b^n$. b^n denotes the units of long-term debt outstanding, in contrast to its market value b. And the path of b^n is fully determined whenever a firm issues debt, completely invariant to any shocks that arrive after. Thus, also the firm's available cash flows are unaffected by fluctuations in r_t^b.[27]

Solving the firm's problem and determining equilibrium allocations is based on the system of equations (5)–(8). Most of the insights and steps in the solution approach closely follow those in the literature, most closely Khan and Thomas (2013). The key added detail is the non-trivial choice between cash holdings and long-term debt, and the fact that adjustments in the latter are subject to adjustment costs. Nontheless, of significant assistance in solving the firm's problem is the possibility of distinguishing between financially *constrained* and *unconstrained* firms, and the implications of being in either status for the firms' optimal policies.

In equilibrium, $M_{t+1}\left(1 + r_{t+1}^m\right) = 1$, meaning that the return to liquid assets inside the firm is equal to the equityholders' discount rate. This implies that all firms have the incentive to save themselves out of financial constraints, until the shadow value of retained earnings is equal to the value of dividends paid to the shareholders. And this happens only when a firm knows that it will never again face a binding equity issuance constraint.[28] Before reaching that point, the valuation of retained earnings inside the firm is strictly higher than that of paying dividends, so the firm sets $div = 0$. Because of the spread between borrowing and lending rates, a firm might not be willing to issue debt, even in the absence of issuance costs, but its investment may still be constrained by the fact that it cannot freely raise equity. Thus, a binding equity issuance constraint is the relevant determinant of being "financially constrained".

A firm is financially unconstrained, if from any point onwards, it can follow the capital and debt policies of a firm which does not face a non-negativity constraint on its dividends. Even though an unconstrained firm would never issue long-term debt because of the spread between the borrowing costs captured by r^b and the required return to equity r^m, a firm which has been constrained in the past might have long-term debt on its books from previous issuances. And the existence of debt adjustment costs creates a non-trivial repayment problem also for

[27] Even if the long-term debt required payments at floating rates, the quantitative effect of fluctuations in $r_t^b b$ on investment through available cash flows would be small in comparison to the investment-sensitivity of a firm who is treating the rates as a direct opportunity cost of investing.

[28] This can be proved by using explicit Lagrange multipliers on the firm's constraints and relating the multiplier on the current equity issuance constraint to the infinite sum of expected multipliers on future equity issuance constraints, e.g. see Caggese (2007).

unconstrained firms: some of them might not find it worthwhile to prematurely pay down their debt because of high adjustment costs. Yet since the borrowing constraint is only applicable at debt adjustment and a firm which does not face a non-negativity constraint on dividends would never choose any other debt level than zero when adjusting, the problems of choosing capital and debt repayment can be separated from each other. This further simplifies solving for an unconstrained firm's capital and debt policies.

Having determined the capital and debt policies of unconstrained firms, one can deduce the minimal savings (cash) required to finance such policies without violating the $div \geq 0$ constraint at any point in the future. This is the analogue of the *minimum savings policy* employed by Khan and Thomas (2013). If a firm at any idiosyncratic state (k, a, b, z), and time t, cannot follow the unconstrained firm's policies and acquire the required minimal savings without setting $div < 0$, it must by definition be financially constrained and sets $div = 0$. I detail the steps required to implement this solution approach in Appendix A.3.1, and the computational methods applied in Appendix A.13. Let the equilibrium policies of firms' choices in t be denoted $n_t(k, a, b, z)$, $\hat{c}_{B,t}(k, a, b, z)$, and $\left\{k^E_{t+1}(k, a, b, z), m^E_{t+1}(k, a, b, z), b^E_{t+1}(k, a, b, z)\right\}_E$, with $E \in \{A, N\}$, denoting the choices of (k', m', b') conditional on adjusting debt or not, respectively.

In reference to the discussion below, I refer to a firm as *borrowing constrained* at a given point in time if it is engaging in debt issuance and the LTV constraint is binding. The set of borrowing constrained firms is thus a subset of the financially constrained ones.

3.2.2 Household and Financial Intermediary Optimality, Prices and Equilibrium

Using c^h_t, n^h_t, m^h_{t+1}, and $\Lambda^h_{t+1}(k', a', b', z')$ to denote the household's decisions in equilibrium, optimality implies that the following first order necessary conditions hold:

$$\beta \left(\frac{c^h_{t+1}}{c^h_t}\right)^{-1} (1 + r^m_{t+1}) \geq 1$$

$$w_t = \psi c^h_t \tag{9}$$

And, the stochastic discount factor used by all entities owned by the household in equilibrium equals $M_{t+1} = \beta \left(c^h_{t+1}/c^h_t\right)^{-1}$. Given the financial intermediary's problem in Section 3.1.3, by intermediary optimality and the fact that household optimality requires $M_{t+1}\left(1 + r^m_{t+1}\right) \geq 1$, whenever there is lending in equilibrium:

$$M_{t+1}\left(1 + r^m_{t+1}\right) = 1 \tag{10}$$

$$r^b_{t+1} = r^m_{t+1} + \phi^I_{t+1} \tag{11}$$

Because there are no frictions between the household's deposit and equity financing of the intermediary, the intermediary's dividends and deposits are not uniquely determined. Without loss of generality, I suppose that the intermediary follows a simple financial policy of not acquiring any internal net worth, paying out all its profits if any are realized due to unexpected shocks, and financing debt purchases with deposits in full.

Since I study equilibria with fixed retail good and final good nominal prices, there is no active price setting by the retail good producers outside of steady state and they accommodate the demand forthcoming by the final good producer. I describe the details of the retail good and final good producers' optimization in Appendix A.3.2. The equilibrium law of motion for the distribution of firms is shown in Appendix A.3.3. I state the full definition of a perfect foresight fixed price equilibrium given a path for the real liquid assets rate r^m_{t+1} and the intermediation cost ϕ^I_{t+1} in Appendix A.4. Therein, I also clarify how interest rates and debt prices are determined along a perfect foresight equilibrium path and in response to unexpected shocks.

3.3 Calibration

The length of a period is one quarter. In the calibration of most model parameters, I follow prior work and use parameter values which allow to either match common aggregate moments directly, or values deduced based on methods independent of model specifics. For the remaining parameters, central to the mechanisms of interest, I employ internal calibration, matching moments of the model's stationary equilibrium to time-averages observed in the data. To be consistent in comparing firm-level moments of interest, I explicitly treat the population of firms in the model as the theoretical counterpart of the Compustat panel. I do so for reasons of data availability, both because the frequency of firm-level long-term debt issuances computed from Compustat is a key calibration target, and because doing so allows to compare the model's performance to the empirical findings of Section 2 more directly.[29] Because of this, I will also employ empirical targets from the period 1990Q1–2007Q4 wherever possible.[30]

Externally calibrated parameters. I set $\beta = 1.02^{-1/4}$ to target a steady state annual real return on the liquid assets r^m_{SS} of 2%. I use a depreciation rate δ of 0.025 to match the aggregate investment-to-capital ratio, a common target in the business cycle literature. I calibrate the steady state spread ϕ^I_{SS} to yield an annual spread of 206 bp of the firms' borrowing rate over the lending rate. I derive this number by decomposing the $r^b_{SS} - r^m_{SS}$ spread in the model into the sum of a risk-free corporate borrowing spread over an implicit policy rate r^f and the policy rate spread over the effective real return on firms' liquid assets. The latter spread arises because firms hold assets in their liquid assets portfolio which do not earn the full risk-free policy rate in the economy.[31] I discuss further details on the computation of this spread in Appendix A.5.

I assume that the idiosyncratic productivity z follows a discretized AR(1) lognormal process $\log z' = \bar{z} + \rho_z \log z + \varepsilon'_z$, with $\varepsilon'_z \sim N\left(0, \sigma^2_\varepsilon\right)$.[32] I target the persistence and volatility of $\rho_z = 0.80$ and $\sigma_\varepsilon = 0.15$, as employed by Gilchrist et al. (2014) based on an estimation employing the sales data of Compustat firms. Following the same estimation, I set $\alpha = 0.255$ and $\nu = 0.595$, implying a value-added share of capital of 0.3 and decreasing returns to scale of 0.85.[33] I set the quarterly exit rate η to 0.088, as employed by Xiao (2018), following the survey of Business

[29] I only take the exit rate target from non-Compustat data. Another possibility of overcoming issues with data availability and model-data comparison would be to explicitly approximate firm selection into Compustat based on firms' age in the model, as done by Ottonello and Winberry (2019).

[30] The majority of the calibration targets I use are similar to those one would use for the whole U.S. firm population, so these assumptions are unlikely to be substantial. See Khan et al. (2014), for example.

[31] See Appendix B.5 for a decomposition of the U.S. nonfinancial corporate sector's liquid asset portfolio.

[32] I normalize the unconditional mean of z to 1, so $\bar{z} = -0.5\sigma^2_\varepsilon/(1+\rho_z)$. For discretization, I employ the Rouwenhorst (1995) method using four states ($N_z = 4$).

[33] The decreasing returns to scale of 0.85 is a commonly used target in the literature (Winberry, 2018). And the implied labor share is in line with recent estimates by Karabarbounis and Neiman (2013) for the U.S.

Employment Dynamics. As a baseline, I set $\chi = \alpha/(1-\nu)$ so that the i.i.d. risk introduced by ζ scales with a firm's capital stock the same way operating revenues do.

I calibrate the duration of firms' debt captured by γ to yield an average expected maturity of 4 years, adjusted for an implicit annual inflation rate of 2% following the discussion in Appendix A.1. This duration is relatively short compared to the maturity of firms' new debt issuances observed in the data. It is approximately in line with the maturity of bank debt but shorter than the average corporate bond. Rauh and Sufi (2010) study new loan and bond issuances of a random sample of Compustat firms with a long-term issuer credit rating and find a median maturity of 5 years for most credit ratings. Choi et al. (2017) find the median *residual* maturity of debt outstanding for Compustat firms to be 3.93 years. I choose to calibrate the model to a relatively low maturity to be conservative and rather deviate less from the existing models of heterogeneous firms and financial frictions with one-period debt.[34]

The degree of irreversibility in capital p_k^- employed in previous studies with macroeconomic versus corporate finance emphases can vary to an large extent. For example, Khan and Thomas (2013) match empirical targets of firm-level investment behavior and use $p_k^- = 0.954$. Treatments in which the irreversibilities affect firms' default risk or capture returns from firesales employ $p_k^- \approx 0.5$ or even lower.[35] An additional open question is whether the illiquidity of capital captured by a low resale value is coming from an actual loss of resources and production potential of the dismantled capital, or do the irreversibilities embody a low firesale price for a firm in distress and an effective transfer to the buyer of the capital. Because of this, I choose a middle ground and employ a liquidation value of capital of 0.85.

Internally calibrated parameters. I derive the targets for internal calibration from the Compustat sample of firm-quarters used as the basis of the empirical work of Section 2, before dropping all firms with fewer than 40 quarters of observations. For the purpose of the calibration, I use the capital stock k in the model and net assets (total assets minus cash) in the data as a measure of a firm's operational size. Although the moments of interest in the model are potentially affected by all of the parameters, it is helpful to discuss the parameters and the moments most relevant for determining their values in pairs. I discuss further details and notes on the computation of the empirical calibration targets in Appendix B.1.2.

Given that the degree of the transitory cash flow risk firms face directly affects their precautionary savings, I infer $\bar{\zeta}$ by matching the time-average of the aggregate cash-to-capital ratio in Compustat between 1990Q1–2007Q4, of 7.2%.[36] I choose the maximum loan-to-value ratio θ to generate an aggregate debt-to-capital ratio equal to the Compustat time-average of about 32.4% over the same period. To determine the degree of convex investment costs g_q, I match the frequency of annualized lumpy investment, the share of annual investment rates of greater than 0.2, observed in a representative balanced panel drawn from the stationary distribution of the

[34]Based on robustness analysis of recalibrating the model for various debt maturities up to 6 years, longer maturities tend to strengthen the novel mechanisms featured in this model regarding cash being a better predictor of the interest-sensitivity of investment than leverage. Yet the model's ability to explain the empirical findings of Section 2 does not change considerably.

[35]For example, see Gamba and Triantis (2008), Gilchrist et al. (2014), or Xiao (2018).

[36]This target cash-to-capital ratio is lower than commonly used in recent studies, such as by Xiao (2018). This is because over the last few decades, firms' cash holdings have followed an increasing trend, and thus measuring firms' cash holdings in more recent years leads to higher cash-to-capital ratios.

model and a balanced panel of firms available in the annual Compustat database. I set k_0 by targeting an entrant's size of 0.24 relative to the average firm's size in the economy. I compute the target by using information in Compustat on firms' IPO dates which I use as a proxy for the time of firms' "entry". As a reference, the relative size of entrants I employ is slightly larger than the 0.23 used by Begenau and Salomao (2018), and significantly higher than the 0.10 in Khan and Thomas (2013). The target is thus relatively conservative in terms of the aggregate relevance of financial frictions and the firms constrained by them.

Finally, to calibrate $\bar{c}_B$, I match the fraction of firms issuing long-term debt in the stationary distribution of the model to the unconditional frequency of Compustat firm-quarters with long-term debt issuance of at least 1% of the firm's lagged net assets between 1990Q1-2007Q4.[37] Both in the model and the data, I only sample firm-quarters for which the firm was smaller than the 75th percentile in the cross-sectional size distribution.[38] I match the issuance frequency of all firms except the largest ones because in reality, firms have motives for debt issuance that are absent from the model, such as tax benefits. A noteworthy result is that by matching the issuance frequency, the model generates an average observed ratio of the issuance cost to funds raised of approximately 1.1%. Altinkiliç and Hansen (2000) find that the average underwriter spreads in industrial bond offerings are about 1.09%. The joint calibration leads to the values of $\left[k_0, \bar{\zeta}, \theta, \bar{c}_B, g_q\right] = [0.211, 0.0238, 0.622, 0.0094, 0.005]$. Table A.1 in Appendix A.5 provides an overview of the full set of calibration targets and parameter values used.

4 Results

4.1 Firm Behavior in Steady State

In this section I discuss firms' behavior in the stationary equilibrium of the model. The main focus is on how a firm's extensive margin decisions to issue debt are affected by its financial position, and how optimal debt issuance behavior itself affects the firm's asset allocation and liquidity management. This provides intuition for why a firms' liquidity position is a good predictor of its sensitivity to borrowing cost fluctuations while leverage is not. Given that monetary policy shocks move corporate debt rates relatively more than returns to cash, this provides a backdrop for the heterogeneous shock-responsiveness of firms.

4.1.1 The Effect of Financial Positions on Debt Issuance

Figure 3 shows how a typical growing firm's probability of debt issuance in the stationary equilibrium depends on its current leverage and liquid asset holdings position, with the only remaining source of uncertainty being the draw of c_B. Fixing (k, z), the figure plots level

[37] I condition on issuances of at least a 1% of net assets' size to alleviate the effects of potential measurement and misreporting errors of values near zero. The unconditional frequency of *any* nonzero reported long-term debt issuance would be 0.306. Because my model is that of borrowing to finance investment and growth, I focus on *gross* issuances. This also yields more conservative estimates of the quantitative size and relevance of debt issuance costs since targeting *net* long-term debt issuances would necessarily imply a lower empirical target for the issuance frequency, leading to the inference of more severe costs of issuance, all else equal.

[38] In the data, I compute the 75th percentiles of the size distribution and compare each firm against them by SIC 1-digit industry, in each quarter.

curves in the $\left(\frac{b}{m+k}, \frac{m}{m+k}\right)$-space for which $G\left(\left[V_{SS}^{A}(k,m,b,z,0) - V_{SS}^{N}(k,m,b,z)\right]/\upsilon_{SS}\right) = \bar{g}$, for various constant values of $\bar{g}$, seen on the scale on the right hand side of Figure 3.

Conditional on leverage, an increase in the firm's cash holdings unambiguously decreases its probability of issuing debt. For example, at a leverage ratio of 0.1, going from a liquid asset ratio of 0 to 0.1 induces a drop in the likelihood of issuance from about 0.88 to 0.64. A firm with more cash, all else equal, can take advantage of its growth opportunities by using liquid assets to invest, lowering the marginal benefit of raising debt.

At the same time, fixing the firm's liquid asset holdings and increasing its indebtedness tends to increase its likelihood of issuing debt for the combination of (k, z) under consideration. And a one unit move along the leverage dimension has a considerably smaller absolute effect on the likelihood of issuance than an identical change in the liquid asset ratio. The positive relation between leverage and issuance probability can be explained by the fact that conditional on not issuing new debt, a more indebted firm must service higher coupon payments, exhausting a fraction of its cash flows which would otherwise be used for capital accumulation. The restricted ability to invest implies a higher marginal benefit of engaging in debt issuance. This effect is naturally counteracted by the fact that for a more levered firm, the amount of new debt that can be raised is smaller, all else equal, discouraging the payment of the issuance cost. The former effect tends to dominate for most portfolio combinations given the (k, z) at hand. Yet at higher levels of indebtedness, the latter effect prevails and the leverage-issuance relation flips in sign as the firm approaches its maximal debt capacity.

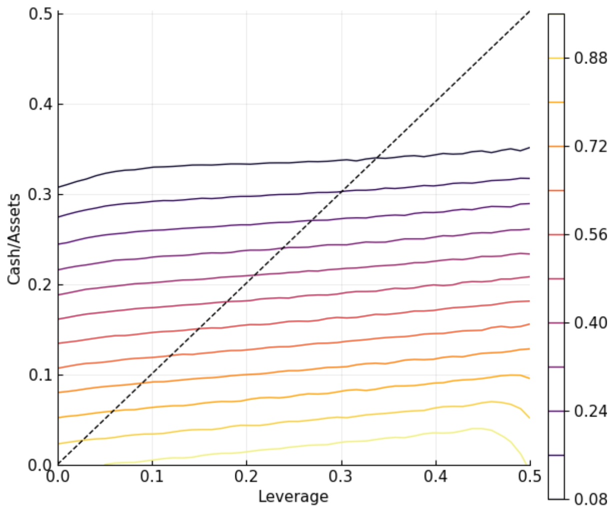


Figure 3: Isolines of debt issuance probability

Notes: Isolines of debt issuance probability, given $k = 0.85$, $z = z_4$, as a function of leverage and cash-to-assets ratio, based on policy functions in the stationary equilibrium. Black dashed line: portfolio combinations implying zero net financial wealth. Right hand scale: color-probability correspondences.

The black dashed line in Figure 3 depicts combinations of portfolios which imply a zero net financial position, so that cash holdings exactly cover the debt outstanding. In a model with liquid debt, firms along this line would behave in an identical manner because the sources of net financial wealth would be irrelevant.[39] Yet in a model with debt issuance costs, the liquidity

[39]The claim clearly applies to any line parallel to this one as well.

position matters for determining debt issuance, and thus affects investment and production. Going from a firm with zero cash and debt along the dashed line to one which has both ratios at 0.2, the probability of debt issuance drops from about 0.88 to below 0.40. Instead of having to pay the issuance cost, the more liquid firm can directly use funds on hand to invest and grow.

In order to focus on financial variation, Figure 3 is drawn conditional on a fixed capital stock. This naturally means that variations in the liquid asset ratio $\frac{m}{m+k}$ also imply changes in the total assets and the net worth of the firm. To demonstrate the stronger result that also when only the decomposition of a fixed amount of total assets between cash and capital is varied, these changes still affect the issuance probability more than leverage, per unit, Figure A.6 in Appendix A.12 repeats the exercise while keeping $m + k$ fixed.

The above illustrates how exogenous, *ceteris paribus* changes in a firm's financial position change its likelihood of issuing debt. However, when estimating regressions in the spirit of (1), the cross-sectional variation in liquid asset holdings and leverage is not exogenous. The regressions do not establish the causality of the financial positions affecting firms' sensitivity to monetary policy shocks. Rather, the financial conditions themselves are endogenously determined and depend on firms' past financial decisions and expected investment opportunities. Therefore, to explain the empirical results of Section 2, one must study the determination of firms' leverage and liquid asset ratios jointly with the likelihood of debt issuances, and consider how these are distributed in the observed population of firms. I do this in the following.

4.1.2 Leverage, Liquid Assets, and Debt Issuance in the Population

To increase its liquid resources available in any period t, a firm has three possibilities: it can sell part of its capital k brought into the period, acquire additional cash m in the previous period and bring it forward into t, or issue new debt in t. These three options are thus substitutes in providing additional liquidity. Because disinvestment is costly due to irreversibilities, it is suboptimal to use capital as a vehicle to provide liquidity. So the accumulation of cash and new issuances of debt are the two main alternatives in providing liquid resources whenever needed.

If debt was perfectly liquid, meaning $\bar{c}_B = 0$, no firm would simultaneously borrow and hold cash because $r^b_{t+1} > r^m_{t+1}$ and in the perfect foresight equilibrium there is no risk in the borrowing and lending rates. In this case, firms would necessarily set $m'b' = 0$, meaning that the usage of debt perfectly predicts the non-existence of liquid asset holdings and vice versa, the existence of liquid asset holdings implies non-usage of debt.

However, if $\bar{c}_B > 0$, firms have an incentive to economize on the fixed debt issuance costs, lump issuances together, and avoid tapping into the debt market frequently. Anticipating situations in which the benefits of new issuances are low, it has an incentive to acquire liquid assets at the time of raising new debt. Carrying forward liquidity using cash while borrowing is beneficial because the coupon payments shrink a firm's disposable cash flows while it is exposed to temporary cash flow drops through ζ. And because accessing the debt market is costly, firms may use earnings not invested into capital to build up cash buffers, instead of using them to repurchase previously issued debt.

Although the existence of fixed debt issuance costs incentivizes firms to acquire cash at the time of borrowing, the spread $r^b_{t+1} > r^m_{t+1}$ makes it costly to do so. Liquid assets accumulated today are thus a costly substitute for future debt issuances in providing liquidity. Therefore, if a firm expects to issue debt in the near future, it is less likely to acquire liquid assets today. And vice versa, firms with high cash holdings must expect to be less likely to issue debt in the near future. It is in this sense that a firm's acquired cash holdings become a good predictor of a low likelihood of accessing the debt market and investment being insensitive to borrowing rates. The capital accumulation of firms with high cash holdings is more directly governed by the lending rate and their available cash flows, rather than the rate on corporate debt.

At the same time, a high level of indebtedness can be associated with both a high or a low likelihood of near future debt issuances. On the one hand, an above average amount of debt on a firm's balance sheet can indicate that it has good growth prospects and relatively low internal net worth, and thus it may be likely to issue debt again in the upcoming periods to finance growth further. Such firms' desire to raise funds by issuing debt is captured by their high marginal productivity of capital (MPK). On the other hand, debt issuances could have driven up a firm's indebtedness, yet further issuances might not be necessary if the size of its capital stock is near-optimal, given TFP, indicated by a relatively lower MPK. Moreover, high leverage means that the firm is closer to its debt capacity, reducing the benefits from new issuances. Such a high-leverage firm will likely refrain from paying issuance costs in the near future, remaining indifferent to fluctuations in borrowing costs and the availability of new credit.

In order to illustrate how these forces materialize in the observed distribution of firms and how they translate into regression results in the spirit of Section 2, Figure 4 below depicts how the stationary distribution of incumbent firms is spread across the leverage, cash-to-assets, and MPK dimensions. More specifically, I split firms into high and low leverage, liquidity, and MPK groups based on the medians of the respective cross-sectional distributions. As above, I present the data in the $\left(\frac{b}{m+k}, \frac{m}{m+k}\right)$-space, and I measure the fraction of firms with high MPK in each leverage-liquidity group, with the sizes of the circles representing the mass of firms in each group. The fraction of high MPK firms serves as a proxy for the likelihood of debt issuance.

The firms in the bottom-right corner of Figure 4, with high leverage and low cash holdings, have good growth opportunities, captured by a large fraction of high MPK firms (81%). They have low internal wealth relative to their optimal level of capital, and will continue to borrow in the near future. Second, the firms with high leverage and high liquid asset holdings have satiated their growth opportunities by borrowing in the past, as shown by a considerably lower fraction of high MPK firms. They are accumulating cash in preparation to finance future growth opportunities and protect against cash flow shortfalls, and will not access the debt market any time soon. Third, the group of firms with low leverage and low cash holdings, which similar to the previous group is relatively small, features a significant fraction of high MPK firms. This is because for some firms, the issuance cost can potentially be too high, given their past TFP, to have justified paying it and accessing the debt market. Finally, the firms with low leverage and high cash have in large part reached their optimal scale, captured by low levels of MPK, and have paid down most of any debt that financed this growth. They also accumulate cash to finance future growth opportunities and insure against cash flow drops.

Figure 4 illustrates how variation along the cash-to-assets ratio dimension is associated with considerably larger changes in the prevalence of high MPK firms than variation along

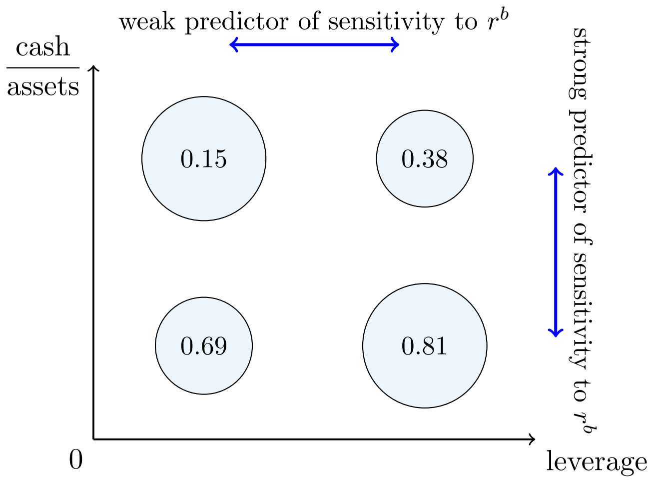


Figure 4: Leverage, liquid assets, and MPK among the stationary distribution of firms
Notes: Fraction of firms with high MPK in leverage-liquidity groups. High/low classification determined based the on median of each corresponding cross-sectional distribution. Circle size represents the mass in each group.

the leverage dimension. Conditional on having either low or high leverage, going from high to low liquid asset holdings implies increases of 0.54 and 0.43 in the respective conditional expectations of having high MPK. At the same time, going from low to high leverage increases the expectations conditional on having low or high cash-to-assets by 0.12 and 0.23, respectively. It is in this sense that the liquid asset holdings are a stronger predictor of firms' desire to raise funds and access the debt market in the observed population of firms. The same idea is also conveyed by the fact that both groups with high liquid asset holdings have a lower prevalence of high MPK firms than either of the two low-cash groups, independently of leverage.

To show that the stronger predictive power of liquid asset holdings also applies directly to debt issuance probabilities, both in the model and the Compustat data, Figure 5 plots the cross-sectional densities of debt issuance probabilities across the same four groups as depicted above in Figure 4. And it compares them to the corresponding observed issuance frequencies from Compustat across firms and time. As in the model, I split the Compustat firms into high and low groups based on the medians of the cross-sectional leverage and cash-to-assets ratio distributions. High leverage and low cash holdings both imply higher probabilities of debt issuance, with the high-cash low-leverage group having the lowest and the low-cash high-leverage group the highest likelihoods. Most importantly, the high-cash high-leverage group exhibits lower debt issuance probabilities than the low-cash low-leverage firms, both in the model and the data. Thus, both groups with high liquid asset holdings are less likely to issue debt than either of the two low cash groups, independently of leverage.

Finally, Appendix A.6 discusses how the life cycle of a typical firm in the steady state of the calibrated model economy looks like, and how the idea that cash holdings predict debt issuance better than leverage can be seen within one firm across time.

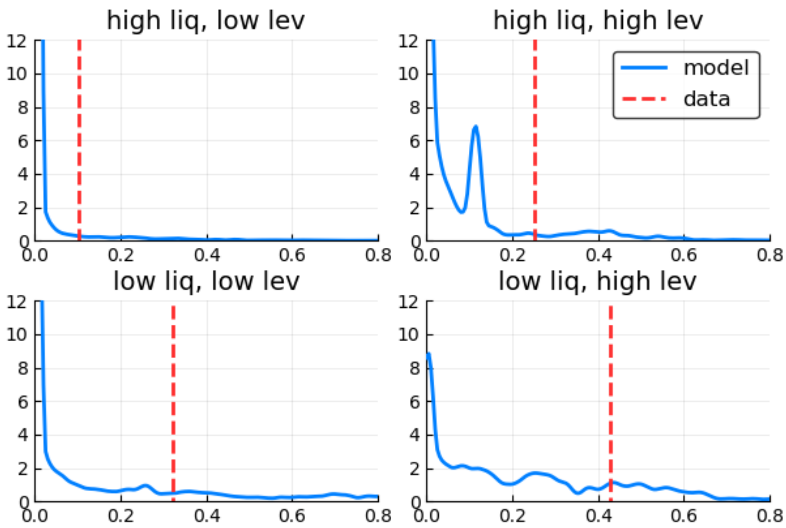


Figure 5: Probabilities of debt issuance in model and Compustat populations

Notes: Blue solid: density implied by model's stationary distribution, red dashed: observed issuance frequency in Compustat. Horizontal axis: probability of debt issuance over draw of c_B. Compustat groups defined based on one quarter lagged cross-sections of leverage and liquid asset ratios separately by quarter (1990Q1–2007Q4); frequencies computed based on long-term debt issuances above 1% of incoming net assets across firm-quarters, conditional on group definitions. Model densities based on sample of 50,000 incumbents in stationary distribution of model, computed using the Average Shifted Histograms method.

4.2 Monetary Policy Shock Experiment

In order to explain the empirical results covered in Section 2 and study the potential mechanisms behind them, I conduct a monetary policy shock experiment in the model economy, ensuring that the paths of interest rates on firms' saving and borrowing are empirically plausible.

4.2.1 Inference of Empirical Interest Rate Shock Paths

The exercise that I aim to replicate is the monetary authority unexpectedly announcing in $t = 0$, that between $t = 0$ and $t = 1$, the risk-free nominal policy rate is 25 bp higher, in annualized terms, and follows some given path thereafter.[40] However, as already emphasized, firms in reality do not exactly earn the risk-free policy rate on their liquid savings, nor can they borrow at exactly the policy rate. In accordance with the view taken when calibrating the model in Section 3.3, I consider the response of the firm's borrowing rate r^b as consisting of the response of the implicit policy rate r^f plus the response of the borrowing spread over the policy rate, $r^b - r^f$. And analogously, if some of the assets in the firms' liquid asset porfolio do not earn the full risk-free policy rate or exhibit partial pass-through to their returns, then the response of r^m is dampened in comparison to the response of the implicit r^f.

I estimate the empirical response paths for r^f and $r^b - r^f$ to an unexpected 25 bp policy rate increase from U.S. aggregate data by employing a vector autoregression (VAR) model identified using the high-frequency instruments ε_t^m from Section 2, following Gertler and Karadi (2015). I discuss the VAR specification, estimation and results in Appendix B.6. For simplicity, I

[40] In reality, agents form expectations regarding the future policy rate path, but given that I am studying perfect foresight equilibria, the expectations and the realized future path of policy rates coincide in the model.

suppose that $\hat{r}_t^m = \phi_m \hat{r}_t^f$ along the transition path, with hats denoting deviations from steady state values. I infer ϕ_m based on the U.S. nonfinancial corporate sector's liquid asset portfolio shares seen in Table B.1 of Appendix B.5. I assume that the shares are constant in response to the shock. Following the facts documented by Drechsler et al. (2017) on the responsiveness of bank deposit rates to changes in monetary policy, I suppose that the exposure of the return on *Time and savings deposits* to changes in the policy rate is 0.5. As in the calibration of the rates in steady state, discussed in Appendix A.5, I consider checkable deposits and currency as earning a zero nominal return and all remaining components of the liquid assets portfolio earning the implicit policy rate. All in all, combining the portfolio shares of checkable deposits and currency of 25.5%, and the time and savings deposits share of 25.4%, I infer: $\phi_m = 0.254 \times 0.5 + (1 - 0.255 - 0.254) \times 1 = 0.618$. So an increase of 1 bp in the implicit policy rate r^f corresponds to a 0.618 bp increase in r^m in the model. Figure B.8 in Appendix B.6 depicts the resulting paths for $\hat{r}_{t+1}^m$ and $\hat{r}_{t+1}^b$, alongside the reference path of $\hat{r}_{t+1}^f$.[41]

Finally, note that although I am incorporating empirically plausible fluctuations in credit spreads in the experiment, I do not introduce any additional changes in the cost of long-term borrowing that would be generated by fluctuations in term premia in the data. Over and above the intermediation cost, there are no term premia in the model and the expectations hypothesis holds. As discussed in Section 2.1, the observed empirical fluctuations in term premia caused by monetary policy shocks are non-negligible, providing one potential factor for why the model cannot generate the full response heterogeneity observed in the data.

4.2.2 Heterogeneity of Responses in General Equilibrium

To replicate the empirical exercises of Section 2 in the model, the goal is to estimate the collection of γ_h^x in an identical specification as (1) using a representative sample from the stationary distribution of incumbent firms. I detail how I identify and estimate γ_h^x in the model in Appendix A.7. To ensure that the results of the model experiment are not affected by sampling variation while there is a realistic degree of orthogonal, idiosyncratic noise obstructing the inference exercise, I conduct the estimation of $\hat{\gamma}_h^x$ based on repeatedly sampled panels of 2,000 firms[42] simulated subject to idiosyncratic shocks, recording the resulting set of point estimates of $\hat{\gamma}_h^x$. To emphasize that the results are not simply driven by age which is a good predictor of financial constraints and correlated with size in this relatively stylized model of the firm, I also allow firms' size measured by log capital to explain the response heterogeneity in all the regressions below, exactly as in the empirical regressions of Section 2.[43]

In what is to follow, I present the estimation results on firms' heterogeneous responses to the monetary policy shock experiment in the model. Given the repeated estimation of γ_h^x, I plot the median, and the 2.5th and 97.5th percentiles of the resulting collections of point estimates at each h. In the time-indexing of a firm's capital stock, I follow the timing convention used

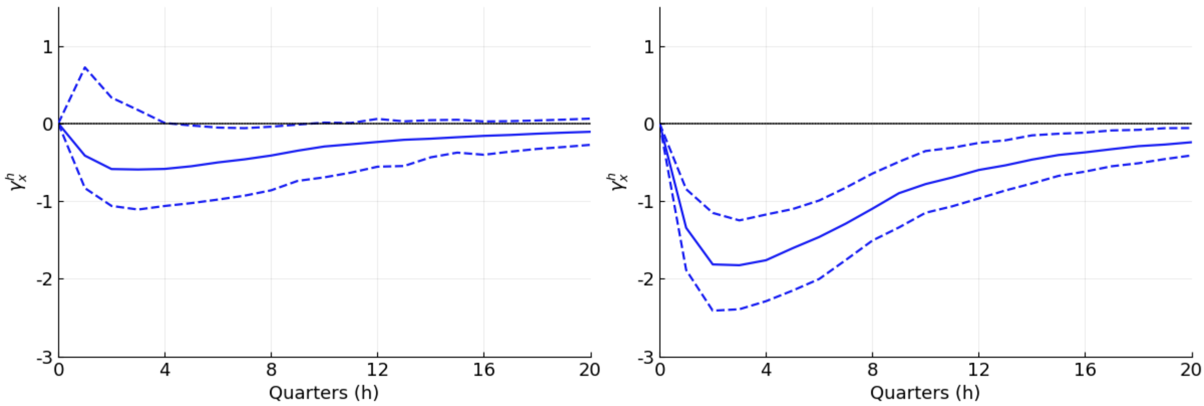
[41] The VAR generates policy rate response paths which "overshoot" when the effects dissipate after 2 years. Yet these rate deviations from pre-shock values are not statistically significantly different from zero (Figure B.7 in Appendix B.6). Thus, I impose that once r^m and r^b have returned to their steady state values, they stay there.

[42] This is roughly the number of individual firms included in the estimations of Section 2 in any given quarter.

[43] The empirical results of Section 2 are robust to controlling for log *net* assets instead of total assets. Without controlling for size in the model, all the main results survive and the estimates of differences between firms' responses are both statistically and economically more significant.

in modeling with $k_{i,t}$ referring to the capital stock in place *at the beginning* of t. Therefore, at $h = 0$, capital is predetermined and cannot respond by definition. To make an exact comparison of the model estimates below with Figures 1 and 2, one should shift the empirical estimates of γ_h^x "right" by one quarter.

Figure 6 depicts the estimates of γ_h^x from the baseline regressions which separately control for only leverage or liquid asset holdings in the general equilibrium monetary policy shock experiment. Panel 6a shows that after a contractionary shock, firms with higher leverage tend to contract their capital stocks relatively more. As in the data, the differences in shock sensitivity explained by leverage are just barely statistically significant at the 95% level, with the significance appearing about 5 quarters after the shock. A 10 pp increase in leverage is associated with an approximately 0.06 pp stronger contraction in the firm's capital stock at peak.



(a) x = leverage (b) x = –liquid asset ratio

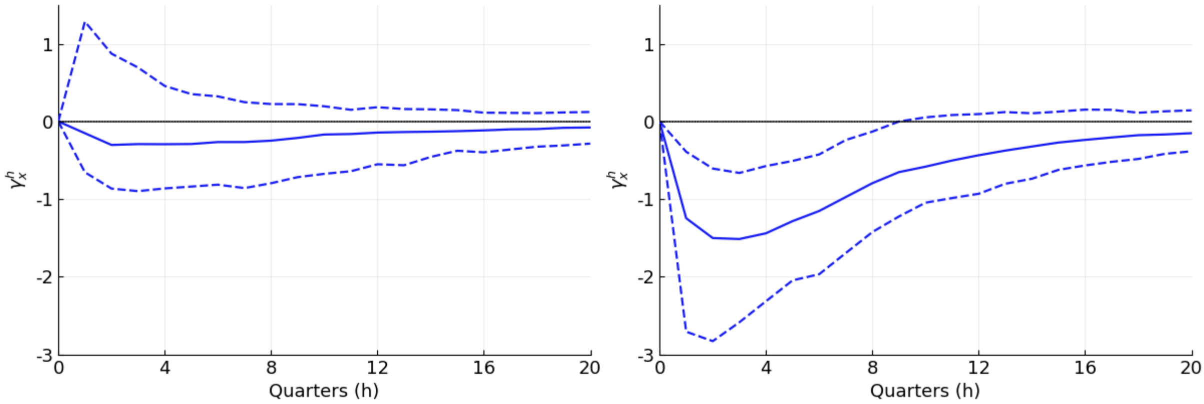
Figure 6: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings, separate regressions, general equilibrium response in model economy

Notes: Median point estimates and 2.5th and 97.5th percentiles for $\hat{\gamma}_h^x$ from estimating specification (A.7), with $\mathcal{X}^s = \{x\}$, controlling for size, from model simulated data on 500 samples of 2,000 firms.

Similarly, panel 6b illustrates that the contractionary monetary policy shock causes firms with low liquid asset holdings to cut back on investment by considerably more. And the differences remain statistically significant well after the interest rates have returned to their steady state values. At the peak, a 10 pp decrease in the liquid asset ratio is associated with a 0.185 pp more intense contraction in the capital stock – slightly below half the quantitative effect seen in the empirical estimates of Section 2.

As the model does not feature aggregate capital adjustment costs or planning lags to generate slower capital stock dynamics, the differences between firms appear at shorter horizons compared to the data. Nontheless, it is noteworthy that the differences between firms' capital stocks exhibit more sluggish dynamics than the actual interest rate shock paths in Figure B.8 in Appendix B.6. This can be explained by the fact that the monetary policy shock also has heterogeneous effects on the firms' net worth – a slow-moving state variable fundamental in an environment with financial frictions. This echoes a central idea empasized by Bernanke and Gertler (1989) reincarnated in the cross-section of firms: not only do financial frictions and net worth dynamics add persistence to the aggregate economy's response to aggregate shocks, but they can also make the differences between agents' behavior more slow-moving.

Figure 7 displays the estimates of γ_h^x from the regression jointly controlling for leverage and the liquid asset ratio. As in the empirical estimates, leverage loses any statistically significant explanatory power it had in the separate regression. While the statistical and economic significance of liquid asset holdings in explaining response heterogeneity is weakened to some extent, they still predict nontrivial differences in firms' investment dynamics after the shock. During the year after an unexpected 25 bp increase in the policy rate, a firm with a 10 pp lower liquid asset ratio is expected to contract its capital stock by about 0.15 pp more.



(a) x = leverage (b) x = –liquid asset ratio

Figure 7: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings, joint regression, general equilibrium response in model economy

Notes: Median point estimates and 2.5th and 97.5th percentiles for $\hat{\gamma}_h^x$ from estimating specification (A.7), with $\mathcal{X}^s = \mathcal{X}$, controlling for size, from model simulated data on 500 samples of 2,000 firms.

On top of the heterogeneous exposure to real interest rate fluctuations, the firms' investment is also differentially affected by the drop in cash flows caused by an increase in markups due to lower aggregate demand. Financially unconstrained firms with low leverage and high cash holdings are not directly affected by the fall in cash flows since they can cut back on dividend payments and the accumulation of their cash buffers to keep investment from dropping. For most financially constrained firms, the available liquid funds, including current cash flows, are essential in determining investment. The firms issuing new debt subject to a binding borrowing constraint cannot afford as much of the capital stock to serve as collateral and must reduce their borrowing, whereas the firms not tapping into the debt market must finance their investments with the liquidity provided by their cash flows and buffers. I assess the importance of this cash flow channel in Appendix A.8 by switching it off. In addition, the Appendix explains why firms with higher leverage could potentially exhibit relatively *higher* capital accumulation in the short run after a contractionary monetary shock, with the relation flipping in sign over the medium run – as suggested by the empirical results of Section 2.

4.2.3 Heterogeneity of Responses in the Absence of Issuance Costs

In this section, I demonstrate why a direct application of a conventional framework with heterogeneous firms and borrowing constraints, such as the Khan and Thomas (2013) model, does not allow to explain key features of the findings presented in Section 2, and why breaking the equivalence between cash and negative debt on a firm's balance sheet is needed. To do so, I repeat the analysis above for the special case model with $\bar{c}_B = 0$ and long-term debt is liquid.

First, I recalibrate the liquid debt specification given all the targets seen in Table A.1 in Appendix A.5, except the frequency of debt issuance since there is one less parameter to be determined. The resulting internally calibrated parameter values are $\left[k_0, \bar{\zeta}, \theta, g_q\right]$=[0.213, 0.0306, 0.630, 0.027].[44] Note that the convex capital adjusment costs are considerably higher than in the baseline calibration because the relatively high frequency of investment rates above 0.2 must now be generated by incentives to spread investment spurts across time due to real frictions instead of the frictions introduced by debt issuance costs.

Figure 8 presents the estimates of γ_h^x from the joint regression in the general equilibrium monetary policy shock experiment under liquid debt. The differences compared to the corresponding estimates from the baseline model seen in Figure 7 are apparent. Most importantly, controlling for liquid asset holdings, high leverage retains considerable negative predictive power for firms' capital accumulation after a contractionary monetary policy shock, with very high statistical significance. Because debt is liquid, every firm with nonzero debt is continuously "attached to" the debt market, actively responding to borrowing rates, in turn making leverage a strong predictor of sensitivity to borrowing cost fluctuations. As discussed in Section 4.1.2, because debt is liquid and the borrowing rate is higher than the lending rate, firms do not simultaneously borrow and hold cash. Therefore, the cross-sectional distribution of firms is "L-shaped" in the (leverage, liquid asset ratio)-space, with firms positioned along the axes, having either zero cash or zero long-term debt. So even though "cash is negative debt" from a firm's balance sheet perspective and there is a clear negative relation between debt and cash held, the cross-sectional distribution of liquid asset ratios and leverage does not feature perfect multicollinearity. This allows both financial variables to retain explanatory power in a joint linear regression.[45]

5 Aggregate Implications of Fixed Issuance Costs

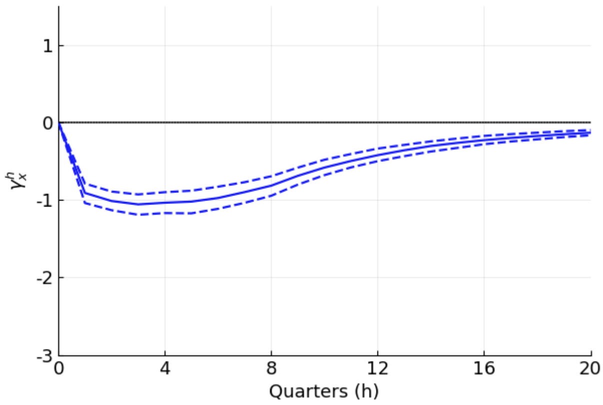
The above has shown that the introduction of fixed long-term debt issuance costs allows an otherwise conventional framework of heterogeneous firms and borrowing constraints to rationalize the stylized empirical findings of Section 2. In what is to follow, I investigate the implications of such costs for the macroeconomy, both regarding the misallocation and output losses generated in a stationary equilibrium, and changes to the transmission mechanisms of aggregate shocks.

5.1 Losses due to Fixed Issuance Costs in Stationary Equilibrium

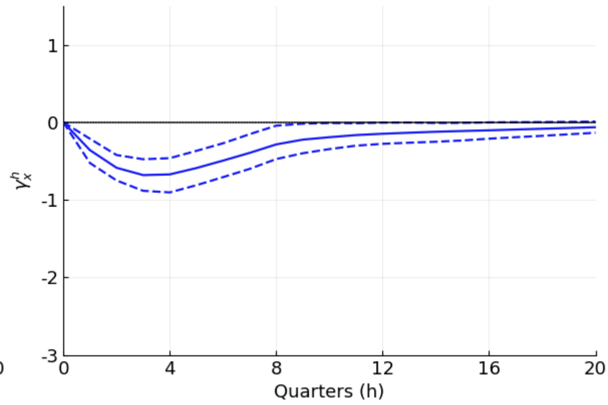
The coexistence of borrowing constraints and fixed debt issuance costs slows down the growth of younger firms with high marginal products of capital. The fixed nature of the costs keeps

[44] This calibration yields an aggregate debt-to-capital ratio of 31.9%, slightly below the target of 32.4%. Reducing the distance requires further increases in θ with the other parameters barely changing. Doing so only works to enhance the differences that I discuss below in comparison to the fixed issuance cost specification.

[45] To ensure that these inconsistencies with the empirical findings are not caused by the recalibration of parameters instead of the liquidity of long-term debt, I also repeat the exercise by simply imposing $\bar{c}_B = 0$ in the baseline calibration covered in Section 3.3, reaching similar conclusions.



(a) $x =$ leverage



(b) $x =$ –liquid asset ratio

Figure 8: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings, joint regression, general equilibrium response without fixed debt issuance costs
Notes: Median point estimates and 2.5th and 97.5th percentiles for $\hat{\gamma}_h^x$ from estimating specification (A.7), with $\mathcal{X}^s = \mathcal{X}$, controlling for size, from model simulated data on 500 samples of 2,000 firms.

firms from continuously raising external finance and the LTV constraint constricts the amount of funding acquired from a single visit to the debt market, eliminating the possibility of growing to the optimal scale quickly. Capital being prevented from flowing to firms with high marginal products of capital is a source of misallocation, leading to losses in output and aggregate productivity. In addition, the binding financial constraints restrict the flow of resources from the saving household to the firm sector as a whole, effectively impairing the technology of capital accumulation and depressing the scale of the economy.

Table 2 reports the relative changes in the steady state values of aggregates if debt issuance costs were to be eliminated by setting $\bar{c}_B = 0$ in the baseline calibration. Aggregate investment, output, and consumption would increase notably. Yet the improvement in measured TFP is considerably smaller. This suggests that the increase in the scale of the economy is in large part induced by the increased flow of resources into the firm sector as a whole, and not as much from the reallocation of capital within the firm sector.

Table 2: Relative changes in aggregates from eliminating fixed debt issuance costs

Variable	**Change**
Output	1.27%
Investment	3.49%
Consumption	0.78%
Measured TFP	0.10%

Notes: Measured TFP$\equiv Y_{SS}/\left(K_{SS}^{\alpha} n_{SS}^{\nu}\right)$, with Y_{SS}, K_{SS}, and n_{SS} the aggregate output, capital, and labor.

The relatively small effects on misallocation, as compared to the losses in aggregate output can be explained by the nature of the added financial friction. Namely, the introduction of fixed debt issuance costs does not necessarily affect the choices of firms with the highest marginal productivities of capital. Their growth opportunities imply large benefits of raising external finance, inducing them to pay the cost and borrow either way. Rather, the firms whose marginal returns to capital barely exceed the interest rate on corporate debt are the ones whose behavior is most affected by the cost, and they step away from debt markets as a result.

Figure A.7 in Appendix A.12 illustrates this idea by plotting the cross-sectional densities of marginal productivites of capital in the stationary equilibria of the specifications with and without debt issuance costs. The two distributions agree on the share of firms with high marginal products – high-TFP entrants issue debt at almost any cost, quickly taking advantage of their growth opportunities. It is firms with lower marginal products (low-TFP entrants and high-TFP incumbents) for whom the benefits of paying issuance costs are not as high and for whom the no-cost specification implies continued faster growth than under the baseline model. Therefore, unlike standard borrowing constraints or default risk which mostly tend to affect the most productive, small firms in conventional heterogeneous-firm macro-finance models, the fixed issuance cost is a friction that more significantly weighs on the choices of medium-sized firms. This explains why the cost can have potentially large effects on aggregate outcomes.

5.2 Cash Flow Sensitivity of Investment and Effectiveness of Fiscal Stimulus

It is a well-established idea in the literature on household consumption that agents who face financial constraints are likely to exhibit high marginal propensities to consume out of transitory income fluctuations, compared to a permanent income consumer. More recently, Kaplan and Violante (2014) have pointed out that in a two-asset model with fixed transaction costs, households with relatively high levels of total wealth, who as if do not seem to be financially constrained, may also exhibit high marginal propensities to consume – the "wealthy hand-to-mouth". Such households exist because fixed transaction costs in adjusting a high-return, illiquid asset induces them to hold near-zero levels of *liquid* wealth, making their consumption sensitive to both expected and unexpected cash windfalls at the time of receipt.

Analogously, the notion that firms which face financial constraints should exhibit stronger sensitivity of investment to cash flows has received considerable attention in corporate finance. Starting with the work by Fazzari et al. (1988), there has been an active debate on whether firm-level regressions which indicate strong comovement between investment and cash flows should be used to infer the existence and severity of financing constraints.[46] The validity of such empirical regressions is not the focus of this paper. Rather, we know that in a structural model such as Khan and Thomas (2013), financially constrained firms increase their investment if, all else equal, they receive a cash windfall, especially when they are against a binding borrowing constraint. When talking about "cash windfalls" or "propensity to invest out of liquid income", I have in mind thought experiments in which a firm experiences a one-time increase in its liquid income, conditional on all other, persistent states of the firm, such as capital, TFP, or debt remaining unchanged.[47] A financially unconstrained firm in the model of Section 3 has a zero propensity to invest out of such cash windfalls.

The model studied in this paper emphasizes the idea that if firms face fixed transaction costs in raising external finance, then they do not need to be at a binding borrowing constraint to exhibit high sensitivity of investment to temporary cash flow shocks. Firms which have debt

[46] For example, Kaplan and Zingales (1997), Fazzari et al. (2000), Kaplan and Zingales (2000), Gomes (2001).

[47] The sources of such income fluctuations can be good realizations of ζ, one-time government transfers of funds, temporary drops in wages or markups, etc.

far below their LTV constraints but simultaneously choose to hold small cash buffers appear as firms with strong balance sheets, yet might at the margin exhibit a marginal propensity to invest of virtually unity – an exact analogue of the wealthy hand-to-mouth consumers of Kaplan and Violante (2014). The relevance of cash in predicting marginal propensities to invest is also supported by the findings Zwick and Mahon (2017) who estimate the effect of temporary tax incentives on investment in the form of accelerated depreciation schedules using a large sample of firm-level data from the IRS. They find that the investment of firms with low liquid asset holdings is more than twice as responsive as that of high cash firms. Moreover, Zwick and Mahon (2017) document that firms' investments respond to the policy only if it generates immediate cash flows, and not when these flows come solely in the future.

In the context of the model of Section 3, a straightforward way to determine "wealthy" firms with high marginal propensities to invest out of liquid income is to consider firms who are currently not issuing new long-term debt but are simultaneously not acquiring any cash nor paying dividends.[48] I refer to these firms as being at a "liquidity constraint" (LC) in order to contrast them with those actively raising new debt and being against a binding long-term debt borrowing constraint (BC). Because the LC firms are not actively raising external finance, they are funding their current investments with internal funds and by definition are not borrowing constrained.[49] Yet they invest all available sources of liquid funds, including cash flows from operations and any other cash windfalls, into capital.[50]

To assess the aggregate relevance of the wealthy firms with a high marginal propensity to invest in the model, I compute the fraction of firms at the LC and the aggregate capital held by them in the stationary equilibrium. I compare these to the corresponding fractions at the BC, and repeat the exercise for the calibration discussed in Section 4.2.3 in which issuance costs are absent yet borrowing constraints are still in place. Because of the spread in the borrowing and lending interest rates, $r^b_{SS} > r^m_{SS}$, there also exists a well-defined notion of wealthy firms with a high marginal propensity to invest in the absence of issuance costs. These are firms who are at the kink with zero debt and zero cash while paying no dividends, and thus invest any marginal unit of cash flows into capital. I refer to these as the LC firms of the $\bar{c}_B = 0$ specification.

Table 3 reports the fractions of firms and capital at the two constraints from the baseline calibrations with $\bar{c}_B > 0$ (as calibrated in Section 3.3) and $\bar{c}_B = 0$ (as in Section 4.2.3). It also includes the results when $\bar{c}_B$ is simply set to 0 in the baseline calibration (as in Section 5.1) for reference. In the model with fixed debt issuance costs, the fraction of capital held by firms who face a binding borrowing constraint is about 7.6%. However, a third of aggregate capital is in the hands of firms who are currently not raising new debt while not acquiring cash nor paying dividends. All these firms would invest an extra dollar of liquid funds in capital. And this can lead to significant implications for the transmission of aggregate shocks which affect cash flows.

The fact that the recalibration with $\bar{c}_B = 0$ features higher convex adjustment costs on capital explains the counterintuitive result between the first two lines of Table 3 that without

[48] I take the likelihood of a firm setting $m' = 0$ and $div = 0$ while the constraints $m' \geq 0$ and $div \geq 0$ are *not binding* to be zero.

[49] More generally, one could think of a binding $m' \geq 0$ restriction as a binding "short-term" borrowing constraint.

[50] In the case of a model in which firms must hold a minimal cash buffer to finance operations or working capital needs, such as the extension presented in Appendix A.11, these statements regarding $m' = 0$ would have to be reclassified as liquid funds acquired over and above the minimal cash buffer required.

Table 3: Percentage of firms and capital at borrowing (BC) and liquidity constraints (LC) in steady states of specifications with and without debt issuance costs

Model	**At BC**		**At LC**	
	Firms	Capital	Firms	Capital
$\bar{c}_B > 0$, baseline	15.4	7.6	30.0	29.4
$\bar{c}_B = 0$, recalibration	7.1	5.8	1.1	1.4
$\bar{c}_B = 0$, in baseline	14.2	11.0	1.7	2.2

Notes: Firm defined to be at BC $\iff$ $(1 + r^b_{SS})b' = \theta k'$. At LC in $\bar{c}_B > 0$ model $\iff$ do not pay c_B and $m' = 0$ and $div = 0$. At LC in $\bar{c}_B = 0$ model $\iff$ $b' = 0$ and $m' = 0$ and $div = 0$. The fraction of capital is measured as the beginning-of-period capital stock held by the corresponding firms.

issuance costs, the share of aggregate capital held by firms rushing to the borrowing constraint is not higher than in the baseline. This is verified by setting $\bar{c}_B = 0$ in the baseline calibration, as shown in the last line.[51] Nontheless, Table 3 shows that in the baseline model, the relative importance of firms and capital at the LC is considerably higher than of those at the BC.

Table 3 also provides another perspective on the discussion of Section 5.1 regarding the fixed issuance costs mostly affecting the behavior of moderately productive, medium-size firms. Comparing the first and third lines of the Table shows that simply abolishing debt issuance costs from the model does not significantly increase the amount of aggregate capital directly constrained by the BC. The intuition behind this is pointed out in Section 5.1: if a firm has strong enough incentives to raise external finance that it would borrow up to the LTV constraint in the absence of debt issuance costs, then its incentives will also justify the payment of the cost to access debt markets. And the issuance costs mostly affect firms who in the absence of the costs would not be at the BC in the first place.

The above establishes that a considerable fraction of aggregate capital in the baseline model is held by firms who exhibit high marginal propensities to invest out of liquid income. And it raises the question of how debt issuance costs affect the sensitivity of aggregate investment to shocks to the firm sector, especially to cash flows. To illustrate the implications of the heightened aggregate marginal propensity to invest for business cycle dynamics in the most straightforward manner, I study the economy's response to an unexpected government transfer, financed by lump sum taxation on the household and paid out to the corporate sector, in an equal amount to each firm.[52] As a benchmark, I suppose that nominal final good prices remain fixed and monetary policy is passive.[53] I also assume that the intermediation cost ϕ^I remains at its steady state level throughout. I compare the response of the baseline economy to that of the recalibrated model without debt issuance costs.

Figure 9 presents the aggregate impulse responses to a government transfer of the size of 0.1% of the respective economies' aggregate capital stock to each firm. In both models, the transfer

[51]The general equilibrium effect of higher wages due to an increase in steady state consumption and the wealth effect in labor supply explains why the mass of firms at the borrowing constraint does not increase. If one set $\bar{c}_B = 0$ in partial equilibrium while keeping wages unchanged, the share of firms and capital at the BC would be 16.4% and 11.6%, respectively.

[52]This is essentially one of the shocks employed by Bernanke et al. (1999) to exemplify the strength of the financial accelerator mechanism in their workhorse model.

[53]In a world with flexible prices or partially sticky prices and a Taylor rule, the shock would have smaller aggregate effects because real interest rates would increase, dampening the boom in investment.

increases firms' available liquid funds and net worth, allowing the financially constrained ones to expand investment immediately. The rise in investment demand is accommodated by a drop in markups $\mathcal{M}_0$, leading to an expansion in aggregate production and labor. And the drop in markups in turn provides firms with higher cash flows, allowing them to further increase investment. The wealth injection also partially crowds out aggregate borrowing shown by the response of long-term debt outstanding B. Note that for firms at a binding borrowing constraint, the transfer potentially crowds *in* borrowing by allowing them to acquire more collateral. Because the shock helps financially constrained firms with higher marginal productivities of capital to invest more, also the measured aggregate TFP improves slightly, but the effect is quantitatively very small. Due to the absence of aggregate capital adjustment costs, investment responds in an erratic manner. Aggregate capital increases at the time of the transfer and starts a reversion to its steady state immediately thereafter, implying below-average investment after the initial upsurge. Inverse markups comove with investment demand, inducing similar dynamics in aggregate output and labor. Because monetary policy is passive and prices rigid, interest rates and consumption do not respond.

The size of the responses with and without fixed debt issuance costs exhibits considerable differences. The impact effects on aggregate output, labor, and investment are about three times larger in the case with issuance costs since a significant fraction of capital is held by firms with high marginal propensities to invest. Because of the volatile movements and overshooting after the impact responses in aggregate flows, it is most apt to evaluate the effects of the stimulus on capital accumulation directly based on the paths of aggregate capital. The main message remains unchanged: the relative increase in the capital stock in the baseline is about three times larger at impact and remains elevated for a prolonged period after the shock.

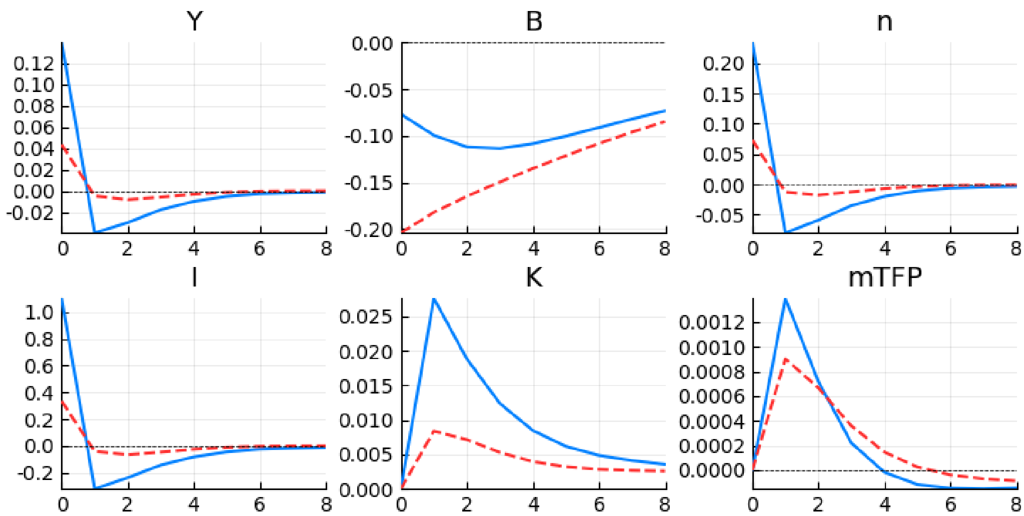


Figure 9: Impulse responses of model aggregates to government transfer

Notes: Impulse responses of output (Y), long-term debt outstanding (B), labor (N), investment (I), capital stock (K), and measured TFP ($mTFP$) to transfer of 0.1% $\times K$; all in percentage deviations from steady state values. Blue solid: baseline model calibration, red dashed: calibration without debt issuance costs. Horizontal axis: quarters since shock.

This simple exercise illustrates the potential of fixed debt issuance costs to amplify the effects of shocks to firms' cash flows by increasing the corporate sector's aggregate marginal propensity to invest out of liquid income. Disturbances that provide the corporate sector with relatively more liquid income induce the financially constrained ones to increase demand for investment. And general equilibrium forces will then determine the relevance of this amplification mechanism for aggregates. Although relaxing the assumptions of fixed prices and passive monetary policy would dampen the overall responsiveness of the real aggregates both with and without debt issuance costs, nontrivial differences between the two specifications very likely remain.

6 Conclusion

In this paper I have studied the relevance of firm balance sheet liquidity in the transmission of monetary policy to investment. Employing firm-level panel data and identified monetary policy shocks, I document that firms with high leverage and firms with low liquid asset holdings exhibit relatively slower fixed capital growth after unexpected policy rate increases. Controlling for liquid asset holdings, leverage does not predict significant heterogeneity in investment responsiveness while balance sheet liquidity remains highly relevant. I develop a general equilibrium model of heterogeneous firms that introduces long-term debt financing and fixed debt issuance costs in a conventional framework with collateral constraints. The fixed issuance costs generate an endogenous disconnect of firms from the borrowing costs currently prevalent in the debt market. A firm's balance sheet liquidity dominates leverage in predicting debt issuances and sensitivity to corporate debt rates, allowing the model to explain the empirical findings.

The introduction of fixed issuance costs gives rise to firms who are not borrowing constrained and have relatively high net worth but exhibit large marginal propensities to invest out of liquid income. In the model studied, such firms are relatively large and plentiful, considerably increasing the corporate sector's aggregate marginal propensity to invest. This has implications for the conduct of policy aiming to promote investment. For example, the efficacy of fiscal policy and investment subsidies could be increased by targeting firms with the highest liquidity needs, instead of blanket transfers or targeting those with high leverage. Yet further empirical work in addition to the abundant corporate finance literature on investment cash flow sensitivities is needed to identify such firms and assess their relevance for the macroeconomy. Accounting for the liquidity provided by lines of credit in addition to cash holdings is one imperative step.

In further developments of the theory, it would also be insightful to endogenize the credit spread faced by the firms in the model. This could be done with an additional layer of financial frictions on the financial intermediary. A standard costly state verification (CSV) friction (Townsend, 1979) as employed by Bernanke et al. (1999) would generate a non-zero steady state spread between the borrowing and lending rates. Because the intermediary holds long-term debt claims while financing itself with short-term deposits, in response to an unexpected policy rate increase the return of the intermediary's assets falls due to debt price drops while the liabilities are unchanged. The relative net worth of the intermediary drops and based on the conventional forces at play in the CSV problem, the spread between the returns on holding long-term debt and liquid assets increases.

References

Acharya, V. V., H. Almeida, and M. Campello (2007). Is cash negative debt? A hedging perspective on corporate financial policies. *Journal of Financial Intermediation 16*(4), 515–554.

Acharya, V. V., S. A. Davydenko, and I. A. Strebulaev (2012). Cash Holdings and Credit Risk. *The Review of Financial Studies 25*(12), 3572–3609.

Almeida, H., M. Campello, and M. S. Weisbach (2004). The Cash Flow Sensitivity of Cash. *The Journal of Finance 59*(4), 1777–1804.

Altinkiliç, O. and R. S. Hansen (2000). Are There Economies of Scale in Underwriting Fees? Evidence of Rising External Financing Costs. *The Review of Financial Studies 13*(1), 191–218.

Bachetta, P., K. Benhima, and C. Poilly (forthcoming). Corporate Cash and Employment. *American Economic Journal: Macroeconomics*.

Bates, T. W., K. M. Kahle, and R. M. Stulz (2009). Why do US firms hold so much more cash than they used to? *The Journal of Finance 64*(5), 1985–2021.

Bazdresch, S. (2013). The role of non-convex costs in firms' investment and financial dynamics. *Journal of Economic Dynamics & Control 37*(5), 929–950.

Begenau, J. and J. Salomao (2018, April). Firm Financing over the Business Cycle. Working Paper.

Bernanke, B. and M. Gertler (1989). Agency Costs, Net Worth, and Business Fluctuations. *American Economic Review 79*(1), 14–31.

Bernanke, B., M. Gertler, and S. Gilchrist (1996). The Financial Accelerator and the Flight to Quality. *The Review of Economics and Statistics 78*(1), 1–15.

Bernanke, B., M. Gertler, and S. Gilchrist (1999). The Financial Accelerator in a Quantitative Business Cycle Framework. In *Handbook of Macroeconomics*, Volume 1, pp. 1341–1393. Amsterdam: North Holland.

Bernanke, B. S. and K. N. Kuttner (2005). What Explains the Stock Market's Reaction to Federal Reserve Policy? *Journal of Finance 60*(3), 1221–1257.

Bolton, P., H. Chen, and N. Wang (2014, November). Debt, taxes, and liquidity. Working Paper.

Bougheas, S., P. Mizen, and C. Yalcin (2006). Access to external finance: Theory and evidence on the impact of monetary policy and firm-specific characteristics. *Journal of Banking & Finance 30*(1), 199–227.

Buera, F. and S. Karmakar (2018). Real Effects of Financial Distress: The Role of Heterogeneity. Working Paper.

Caggese, A. (2007). Financing constraints, irreversibility, and investment dynamics. *Journal of Monetary Economics 54*(7), 2102–2130.

Carlstrom, C. T. and T. S. Fuerst (1997). Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis. *American Economic Review 87*(5), 893–910.

Chodorow-Reich, G. (2014). The Employment Effects of Credit Market Disruptions: Firm-level Evidence from the 2008-9 Financial Crisis. *The Quarterly Journal of Economics 129*(1), 1–59.

Choi, J., D. Hackbarth, and J. Zechner (2017, August). Corporate Debt Maturity Profiles. Working Paper.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy 113*(1), 1–45.

Cloyne, J., C. Ferreira, M. Froemel, and P. Surico (2018, December). Monetary Policy, Corporate Finance and Investment. NBER Working Paper No. 25366.

Cloyne, J., C. Ferreira, and P. Surico (forthcoming). Monetary Policy when Households have Debt: New Evidence on the Transmission Mechanism. *Review of Economic Studies*.

Cochrane, J. and M. Piazzesi (2002). The Fed and Interest Rates: A High Frequency Identification. *American Economic Review Papers and Proceedings 92*(2), 90–101.

Colla, P., F. Ippolito, and K. Li (2013). Debt specialization. *The Journal of Finance 68*(5), 2117–2141.

Cook, T. and T. Hahn (1989). The effect of changes in the federal funds rate target on market interest rates in the 1970s. *Journal of Monetary Economics 24*(3), 331–351.

Cooley, T. F. and V. Quadrini (2001). Financial Markets and Firm Dynamics. *American Economic Review 91*(5), 1286–1310.

Cooley, T. F. and V. Quadrini (2006). Monetary Policy and the Financial Decisions of Firms. *Economic Theory 27*(1), 243–270.

Crouzet, N. (2018). Aggregate Implications of Corporate Debt Choices. *The Review of Economic Studies 85*(3), 1635–1682.

Crouzet, N. and N. R. Mehrotra (2018, January). Small and Large Firms over the Business Cycle. Working Paper.

Doms, M. and T. Dunne (1998). Capital Adjustment Patterns in Manufacturing Plants. *Review of Economic Dynamics 1*(2), 409–429.

Drechsler, I., A. Savov, and P. Schnabl (2017). The deposits channel of monetary policy. *The Quarterly Journal of Economics 132*(4), 1819–1876.

Edwards, A. K., L. E. Harris, and M. S. Piwowar (2007). Corporate Bond Market Transaction Costs and Transparency. *The Journal of Finance 62*(3), 1421–1451.

Ehrmann, M. and M. Fratzscher (2004). Taking Stock: Monetary Policy Transmission to Equity Markets. *Journal of Money, Credit and Banking 36*(4), 719–737.

Eisfeldt, A. L. and T. Muir (2016). Aggregate external financing and savings waves. *Journal of Monetary Economics 84*, 116–133.

Faulkender, M. (2005). Hedging or Market Timing? Selecting the Interest Rate Exposure of Corporate Debt. *The Journal of Finance 60*(2), 931–962.

Fazzari, S. M., R. G. Hubbard, and B. C. Petersen (1988). Financing Constraints and Corporate Investment. *Brookings Papers on Economic Activity 1*, 141–195.

Fazzari, S. M., R. G. Hubbard, and B. C. Petersen (2000). Investment-Cash Flow Sensitivities are Useful: A Comment on Kaplan and Zingales. *The Quarterly Journal of Economics 115*(2), 695–705.

Gaiotti, E. and A. Generale (2002). Does Monetary Policy Have Asymmetric Effects? A Look at the Investment Decisions of Italian Firms. *Giornale degli Economisti e Annali di Economia 61*(1), 29–59.

Gamba, A. and A. Triantis (2008). The Value of Financial Flexibility. *The Journal of Finance 63*(5), 2263–2296.

Gertler, M. and S. Gilchrist (1994). Monetary Policy, Business Cycles and the Behavior of Small Manufacturing Firms. *The Quarterly Journal of Economics 109*(2).

Gertler, M. and P. Karadi (2015). Monetary Policy Surprises, Credit Costs, and Economic Activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

Gilchrist, S., D. López-Salido, and E. Zakrajšek (2015). Monetary Policy and Real Borrowing Costs at the Zero Lower Bound. *American Economic Journal: Macroeconomics 7*(1), 77–109.

Gilchrist, S., J. W. Sim, and E. Zakrajšek (2014, April). Uncertainty, Financial Frictions, and Investment Dynamics. Working Paper.

Gilchrist, S. and E. Zakrajšek (2012). Credit Spreads and Business Cycle Fluctuations. *American Economic Review 102*(4), 1692–1720.

Giroud, X. and H. M. Mueller (2017). Firm Leverage and Unemployment during the Great Recession. *Quarterly Journal of Economics 132*(1), 271–316.

Gomes, J. F. (2001). Financing Investment. *American Economic Review 91*(5), 1263–1285.

Gomes, J. F., U. Jermann, and L. Schmid (2016). Sticky Leverage. *American Economic Review 106*(12), 3800–3828.

Gorodnichenko, Y. and M. Weber (2016). Are Sticky Prices Costly? Evidence from the Stock Market. *American Economic Review 106*(1), 165–199.

Gürkaynak, R. S., B. Sack, and E. T. Swanson (2005). Do Actions Speak Louder than Words? The Response of Asset Prices to Monetary Policy Actions and Statements. *International Journal of Central Banking 1*(1), 55–93.

Hanson, S. G. and J. C. Stein (2015). Monetary policy and long-term real rates. *Journal of Financial Economics 115*(3), 429–448.

Hennessy, C. A. and T. M. Whited (2007). How Costly is External Financing? evidence from a Structural Estimation. *The Journal of Finance 62*(4), 1705–1745.

Ippolito, F., A. K. Ozdagli, and A. Perez-Orive (2018). The transmission of monetary policy through bank lending: The floating rate channel. *Journal of Monetary Economics 95*, 49–71.

Jarocinski, M. and P. Karadi (2018, June). Deconstructing Monetary Policy Surprises – The Role of Information Shocks. Working Paper.

Jeenas, P. (2018). Monetary Policy Shocks, Financial Structure, and Firm Activity: A Panel Approach. Working Paper.

Jermann, U. and V. Quadrini (2012). Macroeconomic Effects of Financial Shocks. *American Economic Review 238–271*(102), 1.

Jordà, O. (2005). Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review 95*(1), 161–182.

Kaplan, G. and G. L. Violante (2014). A Model of the Consumption Response to Fiscal Stimulus Payments. *Econometrica 82*(4), 1199–1239.

Kaplan, S. N. and L. Zingales (1997). Do Investment-Cash Flow Sensitivities Provide Useful Measures of Financing Constraints? *The Quarterly Journal of Economics 112*(1), 169–215.

Kaplan, S. N. and L. Zingales (2000). Investment-Cash Flow Sensitivities Are Not Valid Measures of Financing Constraints. *The Quarterly Journal of Economics 115*(2), 707–712.

Karabarbounis, L. and B. Neiman (2013). The Global Decline of the Labor Share. *The Quarterly Journal of Economics 129*(1), 61–103.

Kashyap, A. K., O. A. Lamont, and J. C. Stein (1994). Credit Conditions and the Cyclical Behavior of Inventories. *The Quarterly Journal of Economics 109*(3), 565–592.

Khan, A., T. Senga, and J. K. Thomas (2014). Default Risk and Aggregate Fluctuations in an Economy with Production Heterogeneity. Working Paper.

Khan, A. and J. K. Thomas (2008). Idiosyncratic Shocks and the Role of Nonconvexities in Plant and Investment Dynamics. *Econometrica 76*(2), 395–436.

Khan, A. and J. K. Thomas (2013). Credit Shocks and Aggregate Fluctuations in an Economy with Production Heterogeneity. *Journal of Political Economy 121*(6), 1055–1107.

Kiyotaki, N. and J. Moore (1997). Credit Cycles. *Journal of Political Economy 105*(2), 211–248.

Kuttner, K. (2001). Monetary policy surprises and interest rates: Evidence from the Fed funds futures market. *Journal of Monetary Economics 47*(3), 523–544.

Leary, M. T. and M. R. Roberts (2005). Do Firms Rebalance Their Capital Structures? *The Journal of Finance 60*(6), 2575–2619.

Leland, H. E. (1994). Corporate Debt Value, Bond Covenants, and Optimal Capital Structure. *The Journal of Finance 49*(4), 1213–1252.

Leland, H. E. (1998). Agency Costs, Risk Management, and Capital Structure. *The Journal of Finance 53*(4), 1213–1243.

Mertens, K. and M. O. Ravn (2013). The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States. *American Economic Review 103*(4), 1212–1247.

Mongey, S. and J. Williams (2017, January). Firm Dispersion and Business Cycles: Estimating Aggregate Shocks Using Panel Data. Working Paper.

Nakamura, E. and J. Steinsson (2018). High Frequency Identification of Monetary Non-Neutrality: The Information Effect. *Quarterly Journal of Economics 133*(3), 1283–1330.

Nikolov, B., L. Schmid, and R. Steri (2017, May). Dynamic Corporate Liquidity. Working Paper.

Nikolov, B. and T. M. Whited (2014). Agency Conflicts and Cash: Estimates from a Dynamic Model. *The Journal of Finance 69*(5), 1883–1921.

Oliner, S. D. and G. D. Rudebusch (1996). Is There a Broad Credit Channel for Monetary Policy? *Economic Review - Federal Reserve Bank of San Francisco 1*, 3–13.

Opler, T., L. Pinkowitz, R. Stulz, and R. Williamson (1999). The determinants and implications of corporate cash holdings. *Journal of Financial Economics 52*(1), 3–46.

Opler, T. C. and S. Titman (1994). Financial Distress and Corporate Performance. *The Journal of Finance 49*(3), 1015–1040.

Ottonello, P. and T. Winberry (2019). Financial Heterogeneity and the Investment Channel of Monetary Policy. Working Paper.

Peersman, G. and F. Smets (2005). The Industry Effects of Monetary Policy in the Euro Area. *The Economic Journal 115*(503), 319–342.

Ramey, V. A. (2016). Macroeconomic Shocks and Their Propagation. *Handbook of Macroeconomics 2*, 71–162.

Rauh, J. D. and A. Sufi (2010). Capital Structure and Debt Structure. *The Review of Financial Studies 23*(12), 4242–4280.

Riddick, L. A. and T. M. Whited (2009). The Corporate Propensity to Save. *The Journal of Finance 64*(4), 1729–1766.

Rigobon, R. and B. Sack (2004). The impact of monetary policy on asset prices. *Journal of Monetary Economics 54*(8), 1553–1575.

Romer, C. D. and D. H. Romer (2004). A New Measure of Monetary Shocks: Derivation and Implications. *American Economic Review 94*(4), 1055–1084.

Rouwenhorst, K. G. (1995). Asset pricing implications of equilibrium business cycle models. In T. F. Cooley (Ed.), *Frontiers of Business Cycle Research*, pp. 294–330. Princeton, NJ: Princeton University Press.

Sharpe, S. A. (1994). Financial Market Imperfections, Firm Leverage, and the Cyclicality of Employment. *American Economic Review 84*(4), 1060–1074.

Sharpe, S. A. and G. Suarez (2015). Why isn't Investment More Sensitive to Interest Rates: Evidence from Surveys. Working Paper.

Stock, J. H. and M. W. Watson (2012). Disentangling the channels of the 2007-09 recession. *Brookings Papers on Economic Activity 42*(1), 81–135.

Stock, J. H. and M. W. Watson (2018). Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments. *Economic Journal 28*(610), 917–948.

Townsend, R. M. (1979). Optimal Contracts and Competitive Markets with Costly State Verification. *Journal of Economic Theory 21*(2), 265–293.

Wieland, J. and M.-J. Yang (2017, February). Financial Dampening. Working Paper.

Winberry, T. (2018, October). Lumpy investment, business cycles, and stimulus policy. Working Paper.

Xiao, J. (2018, May). Capital Allocation and Investment Dynamics in Credit Crises. Working Paper.

Young, E. R. (2010). Solving the incomplete markets model with aggregate uncertainty using the Krusell–Smith algorithm and non-stochastic simulations. *Journal of Economic Dynamics and Control 34*(1), 36–41.

Zwick, E. and J. Mahon (2017). Tax Policy and Heterogeneous Investment Behavior. *American Economic Review 107*(1), 217–248.

Online Appendix

A Model Appendix

A.1 Reformulation of Long-Term Debt

This Appendix shows how a long-term debt contract with a fixed geometrically decaying coupon sold at a discount price can be rewritten as one in which the issuer chooses the total real funds raised and thereafter pays the implied one-period real interest rates alongside a pricipal payment. I present the derivation for the case of a bond with a nominally denominated coupon. For a bond with coupons dictating payments in the final good, the derivation is analogous.

Let the underlying debt contract on one unit of debt sold in t stipulate that in $t+1$ the firm repays a coupon of $(1-\gamma)$ nominal units' worth of the final good, $\gamma(1-\gamma)$ in $t+2$, $\gamma^2(1-\gamma)$ in $t+3$, etc. Let q_t be the nominal price of a unit of such debt raised in t, and $b^n_{i,t+1}$ the total number of units of long-term debt that firm i exits period t with. Consider a firm entering period t with $b^n_{i,t}$ units of debt, thus obliged to pay a coupon of $(1-\gamma)b^n_{i,t}$ nominal units' worth. For generality, I will allow for changes in the price level, denoting the nominal price of the numeraire as P_t.

If the firm chooses not to adjust its debt, then as *real* expenditures, it must cover the real coupon payment $(1-\gamma)\frac{b^n_{i,t}}{P_t}$, and it carries forward the debt outstanding $b^n_{i,t+1} = \gamma b^n_{i,t}$.

If the firm chooses to adjust its debt, then its real expenditures must cover the current real coupon payment, and it can raise funds from new debt issuances (or debt repurchases) $b^n_{i,t+1} - \gamma b^n_{i,t}$, written altogether as the real net inflow of funds:

$$-(1-\gamma)\frac{b^n_{i,t}}{P_t} + \frac{q_t}{P_t}\left[b^n_{i,t+1} - \gamma b^n_{i,t}\right]$$

Define the real market value of firm i's debt leaving period t, as $\tilde{b}_{i,t+1} \equiv \frac{q_t}{P_t} b^n_{t+1}$, and the implicit one-period real gross return on the long-term debt between periods $t-1$ and t as $(1+r^b_t) \equiv \frac{1-\gamma+\gamma q_t}{q_{t-1}}\frac{P_{t-1}}{P_t}$. Also, define the adjusted fraction of real principal not repaid as $\tilde{\gamma}_t \equiv \frac{q_t}{q_{t-1}}\frac{P_{t-1}}{P_t}\gamma$.

Given these redefinitions, one can consider the problem of a firm who enters period t with $\tilde{b}_{i,t} = \frac{q_{t-1}}{P_{t-1}} b^n_{i,t}$, its real market value of debt at the end of $t-1$. Given the underlying debt contract, if the firm is not reissuing debt, then the net inflows from debt simply include the coupon payment:

$$-(1-\gamma)\frac{b^n_{i,t}}{P_t} = -\frac{1-\gamma}{q_{t-1}}\frac{P_{t-1}}{P_t}\tilde{b}_{i,t} = -\left[1 + r^b_t - \tilde{\gamma}_t\right]\tilde{b}_{i,t}$$

where the last equality follows from the definitions of $(1+r^b_t)$ and $\tilde{\gamma}_t$. And the real market value of the firm's debt outstanding going forward is:

$$\tilde{b}_{i,t+1} = \frac{q_t}{P_t} b^n_{i,t+1} = \frac{q_t}{P_t}\gamma b^n_{i,t} = \gamma\frac{q_t}{q_{t-1}}\frac{P_{t-1}}{P_t}\tilde{b}_{i,t} = \tilde{\gamma}_t \tilde{b}_{i,t}$$

And if the firm chooses to adjust its debt, then the net real inflow of funds will be:

$$-(1-\gamma)\frac{b^n_{i,t+1}}{P_t}+\frac{q_t}{P_t}\left[b^n_{i,t+1}-\gamma b^n_{i,t}\right]=-\frac{1-\gamma+\gamma q_t}{q_{t-1}}\frac{P_{t-1}}{P_t}\frac{q_{t-1}}{P_{t-1}}b^n_{i,t}+\frac{q_t}{P_t}b_{i,t+1}=-(1+r^b_t)\tilde{b}_{i,t}+\tilde{b}_{i,t+1}$$

In the main text, I use $b_{i,t}$ in place of $\tilde{b}_{i,t}$ to denote the real market value of firm i's debt leaving period t. And $\gamma_t=\frac{q_t}{q_{t-1}}\gamma$ instead of the notation $\tilde{\gamma}_t$, given that there is no inflation.

A.2 Discussion of Key Assumptions

The following discusses the implications of and rationale behind some of the key modeling assumptions made.

Exogenous exit of firms. As is common in the macroeconomics literature on firms' financial frictions, it is necessary to ensure that firms do not save themselves out of any financial constraints they might be facing in order for the frictions to be relevant in equilibrium. This is achieved by assuming that exiting firms are replaced by entrants which cannot immediately reach their optimal scale of production using internal net worth.

Cash flow shocks ζ. The ζ-shock captures transitory disturbances to a firms' profitability and cash flows in a manner uncorrelated with investment opportunities characterized by persistent TFP z. That is, unfavorable realizations of ζ combined with high z create situations in which disinvestment of capital to raise liquid funds is suboptimal, generating a motive to acquire precautionary cash holdings. $\bar{\zeta}$ also provides a natural lever in calibration, allowing to match desired targets of the firms' aggregate cash holdings. In the baseline calibration of $\chi=\frac{\alpha}{1-\nu}$, a cash flow shock of the functional form ζk^{χ} could be thought of as arising from idiosyncratic TFP consisting of a persistent and a mean-one transitory i.i.d. component $\left(z\tilde{\zeta}\right)^{1-\nu}$.

Fixed debt adjustment costs. The introduction of fixed costs in debt issuance allows the model to generate features of firm-level debt and cash management behavior observed empirically, absent from an analogous model otherwise. For example, as documented by Bazdresch (2013), based on various measures of lumpiness, Compustat firms' net debt issuances tend to be more concentrated on a small fraction of observations in comparison to a normal distribution, even more so than investments in productive capital. Moreover, the correlation between cash accumulation and net debt issuance is *positive* in the data. Such features would be difficult to rationalize with a model in which debt was perfectly liquid, especially if borrowing rates were higher than the returns on cash. More importantly, non-convex transaction costs in financial adjustment give rise to firms which are at times endogenously disconnected from debt markets. This represents the notion that not all firms are actively responding to fluctuations in corporate debt rates, especially if they have abundant cash reserves and are not planning to borrow in the near future, as documented by Sharpe and Suarez (2015).

The stochastic nature of the costs captures the idea that otherwise similar firms could have varying opportunities of raising debt at any given point in time due to unmodeled differences in characteristics and the circumstances faced in financial management. The continuous distribution of costs generates smoothness of firms' aggregate policy functions, useful in clearing markets when solving for general equilibrium. The assumption that the adjustment cost can be covered by shareholders ensures that the optimal decision of debt adjustment follows a simple cutoff policy, allowing for computational efficiency. The calibrated costs are very small in magnitude and would thus not induce considerable effects on available funds if financed internally.

Corporate debt as a geometrically decaying fixed coupon. The most common types of debt instruments used by Compustat firms covered by the Capital IQ Capital Structure database are senior bonds and notes.[54] And the most common corporate bonds are noncallable, nonputable, nonconvertible straight bonds with fixed coupons (Edwards et al., 2007). Most of non-bank debt has fixed rates, while bank debt which accounts for less than 40% of Compustat firms' debt, tends to have floating rates (Ippolito et al., 2018). Thus, modeling long-term corporate debt with coupon payments that do not respond to changes in market interest rates should capture the characteristics of the majority of Compustat firms' long-term debt.[55] Although a geometrically decaying coupon does not exactly match the payment profile of a fixed rate straight bond, it allows to maintain computational tractability.

I abstract from distinguishing between different maturities of firms' debt. Unsecured, liquid short-term borrowing could be introduced by setting the lower bound on liquid asset holdings to $m' \geq -\bar{m}$ for some $\bar{m} > 0$. This would shift the reference point for the lowest level of (net) liquid asset holdings but not change anything of substance in the economics of the firms' problem. Compustat firms' short-maturity debt outstanding is considerably smaller than their long debt, so a recalibration of the model would retain a prominent role for the latter.[56] To model a notion of credit lines with interest rates different from the returns on cash and long-term debt, one could assume the "return" on $m' < 0$ to be different from the return on $m' > 0$.

Non-negative dividends. The assumption that incumbent firms cannot raise equity is common in the macro-finance literature, allowing for a less computationally intensive solution of the firm's problem. Furthermore, it proxies for the fact documented in empirical corporate finance that the costs related to equity issuances are significantly larger than those for debt issuance, as for example documented by Altinkiliç and Hansen (2000). Also, equity issuance is more infrequent and lumpier than debt issuance for Compustat firms (Bazdresch, 2013).

Pass-through financial intermediary. I employ the concept of a financial intermediary who faces an exogenous intermediation cost in order to parsimoniously introduce a difference between the interest rates at which firms can borrow and the returns they earn on their liquid savings. Empirically, such a spread arises because corporate debt governs a non-zero spread over policy rates, even at the safest credit rating levels. In addition, as I document in more detail below, the corporate sector's liquid asset portfolio contains non-interest-bearing assets, in turn generating a spread between policy rates and returns to firms' liquid asset holdings. Moreover, to compare firms' responses to a monetary policy shock in the data and the model, introducing the spread allows to ensure that the firms in the model face similar fluctuations in relevant rates as they do empirically – such as the non-trivial increase in the excess bond premium after unexpected policy rate hikes (Gertler and Karadi, 2015). And if nominal rates increase, losses from holding non-interest-bearing assets go up as well. In Section 6 I discuss

[54]A positive amount outstanding is reported by about two thirds of firm-year observations with non-zero debt between 2002 and 2009, as documented by Colla et al. (2013)

[55]Faulkender (2005) studies a sample of 275 debt issuances from 133 firms in the chemical industry and finds that after incorporating interest rate swaps, 68% of all debt issuances were at fixed rates.

[56]The empirical results seen in Section 2 also hold for the financial conditioning variables of *long-term leverage* and *liquid assets net of short debt*, instead of the leverage and liquid assets employed.

how one can endogenize such a spread between the borrowing and lending rates, including its positive comovement with monetary policy shocks, by introducing an additional layer of financial frictions between the financial intermediary and its depositors.

No inflation. I abstract from fluctuations in inflation to focus on the main transmission channel of interest which relies on firms having heterogeneous exposure to *real* borrowing costs due to varying balance sheet positions. Also, given that I aim to ensure that the interest rates in the model economy follow empirically plausible paths after a monetary policy shock, the estimates from a vector autoregression that I employ suggest no statistically significant fluctuations in inflation in response to an identified monetary policy shock, as seen in Appendix B.6. Moreover, the computation of a perfect foresight transition path under fixed prices is slightly less cumbersome, which is helpful given that solving the model is computationally demanding due to the large dimensionality of the idiosyncratic state space.

This assumption does not claim that movements in inflation would be inconsequential in such a model. In the case of nominally denominated long-term debt contracts, fluctuations in inflation would matter for the firms on top of any movements in real prices and interest rates, as pointed out by Gomes et al. (2016), and lead to heterogeneous effects on firms due to their different levels of indebtedness. However, similarly as dampening the effects of real borrowing cost fluctuations, fixed debt issuance costs would diminish the influence of inflation on firms through long-term debt prices because non-adjusters only care about inflation insofar that it affects their real coupon payments. The introduction of inflation dynamics is an essential next step in developing the model.

No aggregate capital adjustment costs. In models of the financial accelerator mechanism, it is common to assume convex adjustment costs on aggregate capital, introduced through a separate capital production sector. This induces a positive relation between the price of capital and aggregate investment and sets in motion the financial accelerator mechanism (Bernanke et al., 1999). The costs also act as a dampening force on the quantity of aggregate investment, leading to smoothed investment behavior across time. To focus on the specific transmission channel of heterogeneous exposure to borrowing costs and demonstrate its potency, I suppose that the real price of capital is fixed at unity and the financial accelerator mechanism is not operative. However, this comes with the caveat that the resulting equilibrium dynamics of aggregate investment exhibit abrupt behavior and the differences in firms' capital stock accumulation appear at an earlier horizon than seen in the empirical results of Section 2. The illiquidity of firm-level capital is not enough to smooth aggregate investment across time.

A.3 Additional Details and Derivations in Baseline Model

A.3.1 Characterizing Financially Unconstrained Firms

In this Appendix I discuss how to solve for the optimal capital and debt policies of a firm which does not face a non-negativity constraint on dividends, the minimum savings policy, and how to determine idiosyncratic states in which a firm is financially unconstrained.

Unconstrained firm behavior. Consider the recursive problem of a firm which does not face a non-negativity constraint on dividends. Let the beginning-of-period value function of such a firm be denoted $V_{0,t}^u$ – the analogue of the general $V_{0,t}$. And for brevity, let the debt adjustment decision be implicitly captured by the firm's choice of b'. The Bellman equation of an unconstrained firm can be written as:

$$
\begin{aligned}
V_{0,t}^u(k,a,b,z) =& \eta \upsilon_t \left\{ y_t^p(k,z) + p_k^-(1-\delta)k + a - (1+r_t^b)b \right\} \\
&+ (1-\eta)\mathbb{E}_{c_B} \left\{ \max_{k',m',b'} \left[\upsilon_t \left(div - c_B \mathbb{1}\left\{ b' \neq \gamma_t b \right\} \right) + \beta \mathbb{E}_{z',\zeta'} \left[V_{0,t+1}^u \left(k',a',b',z' \right) |z \right] \right] \right\}
\end{aligned}
$$

subject to

$$
\begin{aligned}
div \leq& y_t^p(k,z) - (1+r_t^b)b + b' + a - m' - k' + (1-\delta)k - AC(k',k) \\
b' \geq& 0; \quad a' = \left(1 + r_{t+1}^m\right) m' - \zeta' k'^{\chi}
\end{aligned}
$$

I am not explicitly writing the non-negativity constraint $m' \geq 0$ since it is not binding, given that the unconstrained firm is indifferent between financial savings and dividends. And I am directly abstracting from the borrowing constraint which does not bind for the unconstrained firm because $r_{t+1}^b > r_{t+1}^m$ implies it would only want to *decrease* its debt whevever adjusting.

Using the budget constraint at equality to plug in for div, it is clear that $V_{0,t}^u$ is *linear* in a, with a slope of υ_t. Thus, because $\beta \frac{\upsilon_{t+1}}{\upsilon_t}(1 + r_{t+1}^m) = 1$ in equilibrium, and $\mathbb{E}[\zeta'] = 0$, one can study the unconstrained firm's choices of capital and debt at $m' = a' = 0$ without loss of generality. Also, because the only relevant remaining constraint of $b' \geq 0$ does not affect the firm's choice of k', the firm can split the problem into separately choosing the optimal k' and b'. Define the auxiliary value functions $v_{0,t}^u$ and $W_{0,t}^u$ which denote the beginning-of-period values associated with the firm's production and capital investment activities, and its debt management activities, respectively:

$$
\begin{aligned}
v_{0,t}^u(k,z) =& \upsilon_t \left[y_t^p(k,z) + \eta p_k^-(1-\delta)k \right] \qquad \text{(A.1)} \\
&+ (1-\eta) \max_{k'} \left\{ \upsilon_t \left[-k' + (1-\delta)k - AC(k',k) \right] + \beta \mathbb{E}_{z'} \left[v_{0,t+1}^u \left(k',z' \right) |z \right] \right\} \\
W_{0,t}^u(b) =& -\upsilon_t \left(1 + r_t^b \right) b + (1-\eta)\mathbb{E}_{c_B} \left\{ \max_{b' \geq 0} \left\{ \upsilon_t \left[b' - c_B \mathbb{1}\left\{ b' \neq \gamma_t b \right\} \right] + \beta W_{0,t+1}^u \left(b' \right) \right\} \right\} \qquad \text{(A.2)}
\end{aligned}
$$

These two Bellman equations form the basis of solving for the unconstrained firm's capital and debt policies, which I denote as $k_{t+1}^u(k,z)$ and $b_{t+1}^u(b,c_B)$, and solve for numerically. The optimal debt repayment policy is a function of the c_B drawn by the firm – a simple cutoff policy. Given that an adjusting unconstrained firm necessarily sets $b' = 0$, one can determine this cutoff, denoted $\hat{c}_{B,t}^u(b)$, based on the above formulation by equalizing the values of setting $b' = \gamma_t b$ versus setting $b' = 0$ while paying c_B:

$$
\upsilon_t \gamma_t b + \beta W_{0,t+1}^u(\gamma_t b) = -\upsilon_t c_B \Rightarrow \hat{c}_{B,t}^u(b) = -\left[\gamma_t b + \upsilon_t^{-1} \beta W_{0,t+1}^u(\gamma_t b) \right]
$$

where I also employ the fact that $W_{0,t}^u(0) = 0$ by optimality. Because the firm owners' equilibrium discount rate is lower than the effective interest paid on long-term debt, $b > 0$ implies that $\hat{c}^u_{B,t}(b) > 0$. And one can elaborate upon the debt policy:

$$b^u_{t+1}(b, c_B) = \begin{cases} 0 & \text{if } c_B \leq \hat{c}^u_{B,t}(b) \\ \gamma_t b & \text{otherwise} \end{cases}$$

For ease of notation in what is to follow, I will also denote these continuation debt policies as $b^{u,A}_{t+1}(b)$ and $b^{u,N}_{t+1}(b)$, respectively, referring to the end of period debt outstanding *conditional* on the extensive margin adjustment decision of an unconstrained firm.

Having solved for the unconstrained firm's policies $k^u_{t+1}(k, z)$ and $b^u_{t+1}(b, c_B)$, and the implied value functions $v^u_{0,t}(k, z)$ and $W^u_{0,t}(b)$, one can infer the beginning-of-period value of an unconstrained firm in idiosyncratic state (k, a, b, z) at time t as:

$$V^u_{0,t}(k, a, b, z) = \upsilon_t a + v^u_{0,t}(k, z) + W^u_{0,t}(b)$$

Because the return to liquid assets inside the firm is equal to the discount rate of the firm's shareholders, an unconstrained firm is indifferent between retaining earnings and paying out dividends. Thus, to pin down the firms' equilibrium savings behavior, I follow Khan and Thomas (2013) and assume that, without loss of generality, all unconstrained firms follow a minimum savings policy, retaining exactly as little cash inside the firm as possible to fund the policies $k^u_{t+1}(k, z)$ and $b^u_{t+1}(b, c_B)$ forever after, with the non-negativity constraint on dividends never binding.

Solving for the minimum savings policy of unconstrained firms means determining the liquid asset holdings that a firm entering period t in idiosyncratic state (k, a, b, z) and following $k^u_{t+1}(k, z)$ and $b^u_{t+1}(b, c_B)$ must hold at the end of the period, so that it can afford following $k^u_{t+1+j}(k, z)$ and $b^u_{t+1+j}(b, c_B)$, for $j \geq 1$, without ever violating the non-negativity constraint on dividends. I denote this required level of savings as $\underline{m}^E_{t+1}(k, b, z)$, for either period t extensive margin decision $E \in \{A, N\}$.[57] In general, an unconstrained firm in state (k, a, b, z) may choose to repay its debt or not, depending on the c_B it draws. And the firm's debt obligations going forward, determined by this debt repayment decision, then naturally dictate the required savings it needs. A more indebted firm must have higher savings to afford coupon payments or potential debt repayment if future repayment costs happen to be low, while engaging in optimal investment behavior. Because of this, one must determine a minimum required level of savings for *either* potential extensive margin decision that a firm might take in period t.

I solve for the minimum savings policy recursively. In doing so, for ease of exposition, it is helpful to explicitly consider the four possible pairs of sequential extensive margin decisions an unconstrained firm might take: $\{(E, E')|E, E' \in \{A, N\}\}$.[58] One can then write down the full recursive formulation of $m^{E,E'}_{t+1}(k, b, z_i)$ – the end-of-period-t cash holdings by a firm entering in state (k, b, z_i), required to afford unconstrained investment and the minimum savings policy in $t+1$, for any potential realization of z', conditional on making the extensive margin decision E

[57] Because a is liquid by definition, the required savings going forward are independent of the firm's incoming level of a.

[58] Based on the fact that an unconstrained firm always wants to repay its debt in full whenever possible, the combination (A, A) will never happen in equilibrium. I take this into account below.

in t and E' in $t+1$:

$$\underline{m}_{t+1}^{E,E'}(k,b,z_i) = \left(1+r_{t+1}^m\right)^{-1}\Bigg\{ -\tilde{y}_{t+1}^{E,E'}(k,b,z_i) + \max_{\{z_j|\pi_{ij}>0\}}\Bigg[-y_t^p\left(k_{t,i}^u(k),z_j\right) + k_{t+1,ij}^u(k) + AC\left(k_{t+1,ij}^u(k), k_{t,i}^u(k)\right) + \max\left\{0, \underline{m}_{t+2}^{E'}\left(k_{t,i}^u(k), b_t^{u,E}(b), z_j\right)\right\}\Bigg]\Bigg\}$$

where

$$\tilde{y}_{t+1}^{E,E'}(k,b,z_i) \equiv (1-\delta)k_{t,i}^u(k) - \left(1+r_{t+1}^b\right)b_t^{u,E}(b) + b_{t+1}^{u,E'}\left(b_t^{u,E}(b)\right) - \bar{\zeta}\left[k_{t,i}^u(k)\right]^\chi$$

$$k_{t,i}^u(k) \equiv k_{t+1}^u(k,z_i)$$

$$k_{t+1,ij}^u(k) \equiv k_{t+2}^u\left(k_{t+1}^u(k,z_i),z_j\right)$$

Given this, one can finally determine, for $E \in \{A,N\}$:

$$\underline{m}_{t+1}^E(k,b,z) = \begin{cases} \underline{m}_{t+1}^{E,A}(k,b,z) & \text{if } G\left(\hat{c}_{B,t+1}^u\left(b_{t+1}^{u,E}(b)\right)\right) = 1 \\ \underline{m}_{t+1}^{E,N}(k,b,z) & \text{if } G\left(\hat{c}_{B,t+1}^u\left(b_{t+1}^{u,E}(b)\right)\right) = 0 \\ \max\left\{\underline{m}_{t+1}^{E,A}(k,b,z), \underline{m}_{t+1}^{E,N}(k,b,z)\right\} & \text{otherwise} \end{cases}$$

That is, if the firm knows with certainty that it will repay its debt in $t+1$, or that will certainly not do so, it only needs to worry about the savings needed for the corresponding contingency. Otherwise it needs to be ready to afford the optimal unconstrained policies in either contingency.

The set of functions $\left(n_t, k_{t+1}^u, b_{t+1}^{u,E}, \underline{m}_{t+1}^E, \hat{c}_{B,t}^u\right)$ with $E \in \{A,N\}$, then fully characterizes the optimal behavior of a firm which never faces a binding non-negativity constraint on its dividends. And its implied dividends in period t, contingent on the debt adjustment decision $E \in \{A,N\}$, are given as the residual:

$$div_t^{u,E}(k,a,b,z) = y_t^p(k,z) - \left(1+r_t^b\right) + b_{t+1}^{u,E}(b) + a - \underline{m}_{t+1}^E(k,b,z) - k_{t+1}^u(k,z) + (1-\delta)k - AC\left(k_{t+1}^u(k,z),k\right)$$

Constrained firm behavior. Given the unconstrained policies determined above, one can establish whether a firm which finds itself in state (k,a,b,z) at the beginning of period t, and is not assigned to exit, is financially unconstrained, willing to pay dividends, and can follow the unconstrained policies forever after. Analogously as in Khan and Thomas (2013), this can simply be done based on the resulting current period dividends implied by following the unconstrained policies. If a firm can follow the unconstrained investment, debt, and minimum savings policies, while its implied dividends are non-negative, then it must by definition be financially unconstrained, as its savings will ensure that it will never face a binding equity issuance constraint again.

However, there is an extra subtlety one must be careful with due to the extensive margin debt repayment decision contingent on a firm's c_B realization. Namely, it might happen that at a state (k,a,b,z), for some realizations of c_B the firm can follow the unconstrained policies while for others not. That is, in general one could have $div_t^{u,A}(k,a,b,z) < 0$ while $div_t^{u,N}(k,a,b,z) \geq 0$ or vice versa. To allow for a clear partition of the space $\mathbf{S}$ into "constrained" and "unconstrained" states, and not have to explicitly deal with such specific "in-between" states, I suppose that the firms follow a slightly more conservative savings policy than potentially necessary for an absolute minimum savings policy. That is, I treat a firm in the economy as financially unconstrained if it can follow the unconstrained policies for *either* extensive margin debt adjustment decision. Note that this is again without loss of generality because a firm is *always* willing to keep savings inside the firm instead of paying them out as dividends.[59] And thus it is also optimal for a firm to refrain from paying dividends until it reaches an idiosyncratic state in which both $div^{u,A} \geq 0$ and $div^{u,N} \geq 0$. In other words, I designate a firm in state (k,a,b,z) to behave as financially unconstrained in period t and onwards if $div_t^{u,A}(k,a,b,z) \geq 0$ and $div_t^{u,N}(k,a,b,z) \geq 0$. If that is the case, $V_{0,t}(k,a,b,z) = V_{0,t}^u(k,a,b,z)$, and the firm adopts the unconstrained policies from period t onwards. Otherwise, the firm sets dividends in period t to 0 and solves the problem given by (5)–(8) for k' and b', with m' as the residual. I solve the constrained firm's problem using numerical methods and interpolation of the firm's value function, discussed in detail in Appendix A.13.

A.3.2 Price Setting and Final Good Production

The final good firm's optimization gives rise to the demand curve, for $j \in [0,1]$:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t$$

which retailers take as given. If prices were flexible, the retailers would maximize their profits by choosing prices $p_{j,t}$:

$$\begin{aligned} \max_{p_{j,t}, y^w_{j,t}} \; & p_{j,t} y_{j,t} - (1-\tau_w) P^w_t y^w_{j,t} \\ \text{s.t.} \quad & y_{j,t} = \left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t \\ & y^w_{j,t} \geq y_{j,t} \end{aligned}$$

And one would get the conventional optimal static markup over marginal costs set by firm j as:

$$\frac{p_{j,t}}{P^w_t} = \frac{\varepsilon}{\varepsilon - 1}(1-\tau_w)$$

Thus, I suppose that $\tau_w = \frac{1}{\varepsilon}$ and in the stationary equilibrium, gross markups equal 1.

Along transition paths, the prices $p_{j,t}$ are fixed at some steady state level $\bar{P}$, so the retailers accommodate their demand forthcoming at this price and earn the real profits:

$$\Xi^r_t \equiv \left[1 - (1-\tau_w)\frac{P^w_t}{\bar{P}}\right] Y_t$$

[59] Also, in the stationary equilibrium of the baseline calibration, only a fraction of 0.04% of firms are in such states at any point in time.

A.3.3 Law of Motion for the Distribution of Firms

Let the function F denote the cumulative distribution function of ζ. The firms' policy functions then imply a law of motion for the distribution of firms, for all $(\mathcal{A}, z_j) \in \mathcal{S}$:

$$\begin{aligned}\mu_{t+1}(\mathcal{A}, z_j) =&(1-\eta)\int_{\mathbf{S}}\int_{\zeta}\Big\{G\left(\hat{c}_{B,t}(k,a,b,z_i)\right)\Gamma_t^A(\mathcal{A},k,a,b,z_i,\zeta)\\&+\left[1-G\left(\hat{c}_{B,t}(k,a,b,z_i)\right)\right]\Gamma_t^N(\mathcal{A},k,a,b,z_i,\zeta)\Big\}\pi_{ij}F(d\zeta)\mu_t(dk,da,db,dz_i)\\&+\eta\bar{\pi}_j\int_{\zeta}\mathbb{1}\left\{(k_0,-\zeta k_0^{\chi},0)\in\mathcal{A}\right\}F(d\zeta) \qquad \text{(A.3)}\end{aligned}$$

where, for $E \in \{A, N\}$:

$$\Gamma_t^E(\mathcal{A},k,a,b,z_i,\zeta) \equiv$$

$$\equiv \mathbb{1}\Big\{\Big(k_{t+1}^E(k,a,b,z_i),(1+r_{t+1}^m)m_{t+1}^E(k,a,b,z_i)-\zeta\left[k_{t+1}^E(k,a,b,z_i)\right]^{\chi},b_{t+1}^E(k,a,b,z_i)\Big)\in\mathcal{A}\Big\}$$

A.4 Equilibrium Definition

Given fixed prices, the monetary authority can control the real rate on liquid assets directly, and the intermediation costs are exogenous. The equilibrium relevant for monetary policy shock exercises can thus be defined as follows.

Definition 1. *A* perfect foresight fixed price equilibrium *in this economy, given an initial distribution μ_0 of firms over idiosyncratic states and paths for the real liquid assets rate r_{t+1}^m and the intermediation cost ϕ_{t+1}^I, is given by the set of functions and quantity and price paths $V_{0,t}(k,a,b,z)$, $n_t(k,a,b,z)$, $\left\{k_{t+1}^E(k,a,b,z), b_{t+1}^E(k,a,b,z), m_{t+1}^A(k,a,b,z)\right\}_{E\in\{A,N\}}$, $\hat{c}_{B,t}(k,a,b,z)$, c_t^h, n_t^h, m_{t+1}^h, $\Lambda_{t+1}^h(k',a',b',z')$, B_{t+1}, D_{t+1}, υ_t, w_t, M_{t+1}, q_t, γ_t, r_t^b, $\mathcal{M}_t$, $\mu_t(k,a,b,z)$ such that:*

1. *the value function $V_{0,t}$ solves (5)–(8), and n_t, $\hat{c}_{B,t}$, $\left\{k_{t+1}^E, b_{t+1}^E, m_{t+1}^E\right\}$, for $E \in \{A,N\}$, are the associated policy functions;*

2. *the intermediary earns zero profits in expectation, i.e. (11) holds, and its lending is fully financed with deposits: $B_{t+1} = D_{t+1}$;*

3. *the stochastic discount factor is given by $M_{t+1} = \beta\frac{\upsilon_{t+1}}{\upsilon_t}$, with $\upsilon_t = \left(c_t^h\right)^{-1}$, and it satisfies (10), and the labor supply condition (9) holds;*

4. *r_t^b and γ_t are consistent with long-term debt prices: $(1+r_t^b) = \dfrac{1-\gamma+\gamma q_t}{q_{t-1}}$, $\gamma_t = \gamma\dfrac{q_t}{q_{t-1}}$;*

5. *the distribution of firms evolves as implied by (A.3);*

6. *the final good market clears:*

$$
\begin{aligned}
c_t^h = \int_{\mathbf{S}} \Big\{ & z^{1-\nu} k^{\alpha} \left[n_t(k,a,b,z) \right]^{\nu} \\
& - (1-\eta) G\left(\hat{c}_{B,t}(k,a,b,z)\right) \left[k_{t+1}^A(k,a,b,z) + AC\left(k_{t+1}^A(k,a,b,z),k\right) \right] \\
& - (1-\eta)\left(1 - G\left(\hat{c}_{B,t}(k,a,b,z)\right)\right) \left[k_{t+1}^N(k,a,b,z) + AC\left(k_{t+1}^N(k,a,b,z),k\right) \right] \\
& + (1-\eta)(1-\delta)k + \eta \left[p_k^-(1-\delta)k - k_0 \right] \Big\} \mu_t(dk,da,db,dz)
\end{aligned}
$$

where $AC(k',k)$ *is defined by* (3)*;*

7. *the labor market clears:* $n_t^h = \int_{\mathbf{S}} n_t(k,a,b,z)\mu_t(dk,da,db,dz)$*;*

8. *the equity market clears:* $\Lambda_{t+1}^h(k',a',b',z') = \mu_{t+1}(k',a',b',z')$ *for each* $(k',a',b',z') \in \mathbf{S}$*;*

9. *the long-term debt market clears:*

$$
\begin{aligned}
B_{t+1} = (1-\eta) \int_{\mathbf{S}} \Big\{ & G\left(\hat{c}_{B,t}(k,a,b,z)\right) b_{t+1}^A(k,a,b,z) \\
& + \left[1 - G\left(\hat{c}_{B,t}(k,a,b,z)\right) \right] b_{t+1}^N(k,a,b,z) \Big\} \mu_t(dk,da,db,dz)
\end{aligned}
$$

10. *the deposits market clears by Walras' law:*

$$
\begin{aligned}
D_{t+1} = m_{t+1}^h + (1-\eta) \int_{\mathbf{S}} \Big\{ & G\left(\hat{c}_{B,t}(k,a,b,z)\right) m_{t+1}^A(k,a,b,z) \\
& + \left[1 - G\left(\hat{c}_{B,t}(k,a,b,z)\right) \right] m_{t+1}^N(k,a,b,z) \Big\} \mu_t(dk,da,db,dz)
\end{aligned}
$$

It is also useful to clarify how the interest rates r_t^m, r_t^b, and the debt price q_t are determined along the perfect foresight equilibrium path and in response to any unexpected shocks. Since there is no inflation and monetary policy is assumed to set the rate on liquid assets going forward, it is always the case that at time t, r_{t+1}^m is determined. Given ϕ_{t+1}^I, it must then be the case that the expected one period return on holding long-term debt for the intermediary is $r_{t+1}^b = r_{t+1}^m + \phi_{t+1}^I$, and the price of debt q_t adjusts accordingly.

If at time $t+1$ any unexpected shocks are realized, agents' optimal behavior and the government policies going forward dictate new equilibrium paths for r_{t+j+1}^m, r_{t+j+1}^b, and q_{t+j} for $j \geq 1$, among all other equilibrium outcomes. Yet q_t, r_{t+1}^m and ϕ_{t+1}^I are predetermined. This means that the impact response of q_{t+1} generates a response in r_{t+1}^b and the return on holding long-term debt is not fixed in response to any aggregate shocks. For example, a monetary policy announcement at time $t+1$ which increases real rates going forward induces a drop in q_{t+1} and r_{t+1}^b, generating losses for the intermediary holding the long-term debt.

A.5 Further Details on Calibration and Summary

As stated in Section 3.3, I determine the calibrated steady state spread ϕ_{SS}^I between the implicit one-period borrowing rate and the lending rate $r_{SS}^b - r_{SS}^m$ by decomposing it into the sum of a risk-free corporate borrowing spread over an implicit policy rate r^f and the policy rate over the effective real return on firms' liquid assets. As the spread on the risk-free corporate borrowing rate over the policy rate, I target the average of the Bank of America Merrill Lynch U.S. Corporate AAA Option-Adjusted Spread between 1997Q1–2007Q4 of about 69 bp. I derive the $r^f - r^m$ target spread using the Flow of Funds Accounts data on the U.S. nonfinancial corporate sector's aggregate balance sheet to construct a representative liquid asset portfolio. I assume that all components of the liquid asset portfolio earn the implicit policy rate, except *Checkable deposits and currency* to which I impose a zero nominal return. Time-averaged over the 1990Q1–2007Q4 period, checkable deposits and currency accounted for approximately 25.5% of the aggregate corporate sector's liquid portfolio.[60] Assuming an implicit empirical inflation rate of 2% and the implied nominal rate on liquid assets of 4%, this yields the annual spread of $r^b - r^m = 0.0069 + \frac{0.255}{1-0.255} \times 0.04 = 0.0206$.

The exact parameter values used in the baseline calibration of the model and their corresponding targets and sources are reported in Table A.1.[61] I employ the discrete approximation of the steady state distribution of firms μ_{SS} in computing the model equivalents of all of the moments, so there is no explicit simulation nor sampling variation involved in matching the targets.

Table A.1: Calibrated parameter values and calibration targets

Parameter	Value	Target / Source
Externally calibrated		
β	$1.02^{-1/4}$	2% annual real rate (r^m_{SS})
ϕ^I_{SS}	51.5×10^{-4}	206 bp spread, Flow of Funds Accounts
α, ν	0.255, 0.595	Gilchrist et al. (2014)
ρ_z, σ_z	0.80, 0.15	Gilchrist et al. (2014)
δ	0.025	average I/K
γ	0.933	4 year maturity
η	0.088	Xiao (2018), BED
p_k^-	0.85	macro + corporate finance estimates
Internally calibrated		
k_0	0.211	$= 0.24K$ (**model: 0.24**)
$\bar{\zeta}$	0.0238	aggregate cash/capital = 7.2% (**7.2%**)
θ	0.622	aggregate debt/capital = 32.4% (**32.6%**)
$\bar{c}_B$	0.0094	$\text{freq}(\Delta_\gamma b/k > 0.01)\vert_{k<q_{75}(k)} = 0.244$ (**0.242**)
g_q	0.005	$\text{freq}(i_a/k > 0.2) = 0.247$ (**0.246**)

Notes: $\Delta_\gamma b$ refers to new issuances of long-term debt, i_a to annual gross investment.

[60] The complete decomposition of the nonfinancial corporate sector's average liquid asset portfolio for the 1990Q1–2007Q4 period can be seen in Table B.1 of Appendix B.5. Because of the high right-skewness in the firms' size distribution in the data, the aggregate corporate sector's portfolio of liquid asset holdings is likely to capture the average portfolio of the public Compustat firms reasonably well. For example, among Compustat firms, the top 10% in terms of net assets size held on average about 67% of the total firms' cash and short-term investments during 1990–2007.

[61] As, for example, done by Gilchrist et al. (2014), I set the linear disutility parameter of labor supplied so that the real wage in the steady state is normalized to an arbitrary constant, in this case 1.85, chosen so that financially unconstrained firms fluctuate around a capital stock of 1.

A.6 Firm Life Cycle

Figure A.1 illustrates how the life cycle of a firm in the steady state of the economy looks like. The top panel plots the paths of its capital stock k, market value of debt outstanding b, and cash holdings m. The bottom panel depicts various financial ratios: debt-to-capital $l \equiv b/k$, cash-to-capital m/k, financial wealth ratio $fw/k \equiv \left[\left(1+r_{SS}^{m}\right)m - \left(1+r_{SS}^{b}\right)b\right]/k$, and the probability of debt adjustment $G\left(\hat{c}_{B,SS}\left(k,x,b,z\right)\right)$ denoted "$P(Ba)$". I assume that in every period the firm gets the same productivity realization and a transitory shock of $\zeta = 0$. I also suppose that it faces the average debt issuance cost $\bar{c}_B/2$ in every period except in $t = 6$ when it draws an issuance cost below its issuance cutoff threshold.

In $t = 1$ at entry, the firm issues a large amount of debt, acquires leverage up to its LTV constraint, and invests the proceeds. However, because of convex costs, it smooths investment by also acquiring some cash at issuance. In $t = 2$ it spends most of this cash on investments and retains a near-zero cash buffer, growing through retained earnings. The bottom panel shows how the probability of debt issuance drops from around 0.8 to slightly above 0.1 immediately after the initial issuance. Given that the expected returns to capital remain relatively high, the probability of issuances stays elevated until in quarter 6 the firm gets a lucky draw of a low issuance cost. This triggers a new debt issuance, making the firm lever up and simultaneously acquire a cash buffer.

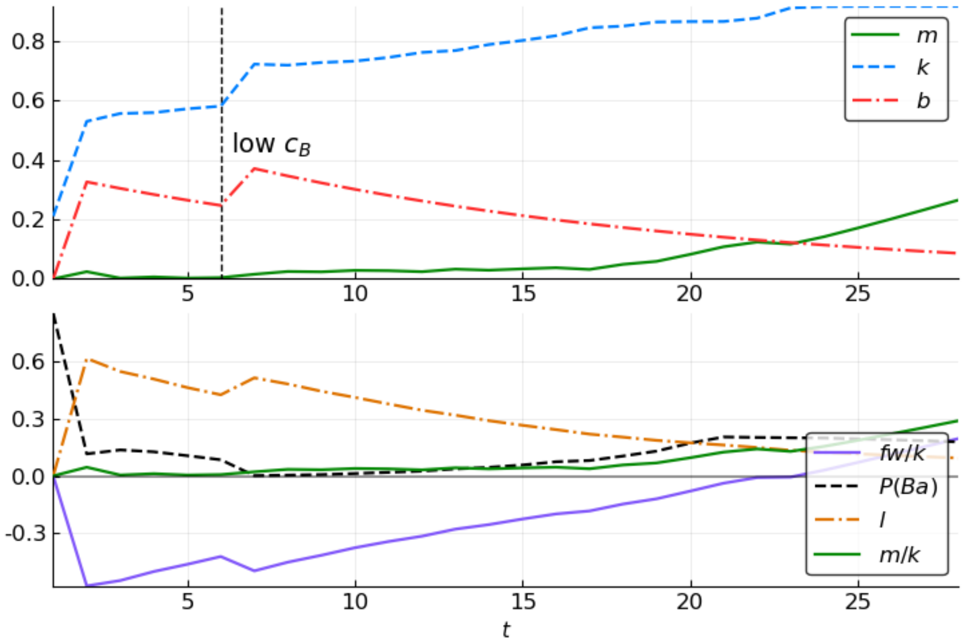


Figure A.1: Example of firm life cycle

Notes: Example of life cycle of a firm in stationary equilibrium, given $\zeta = 0$, $z = z_2$, $c_{B,6} \approx 0$, $c_{B,t} = \bar{c}_B/2$ else. Horizontal axis: age (in quarters).

To see how the idea of cash holdings being a better predictor of debt issuances than leverage surfaces within one firm across time, compare the firm's financial position at the beginning of quarters 4 and 8. Entering $t = 4$, the firm has a nontrivial probability of visiting the debt market, high productivity of capital, and in accordance with this, is holding a cash buffer of virtually zero. After the second issuance, at the beginning of $t = 8$, the firm has reached an optimal scale of production given the high interest rate on debt, its probability of debt issuance has fallen to zero, and its cash buffer is larger than in the previous periods. Yet the firm's leverage is virtually identical at the beginning of the two periods under consideration.

After debt issuance in $t = 6$, the firm continues to grow through retained earnings while making its scheduled coupon payments and deleveraging as a result. If the firm survives long enough to reach the optimal scale of production as governed by the owners' discount rate, it starts building a larger cash buffer to be able to grow out of financial constraints and be ready for future investment opportunities arriving as favorable draws of productivity z. Also, note that after $t \approx 9$ the debt adjustment probability starts increasing slowly. This does not reflect debt *issuance* but debt *repayment*. Because the implicit one period rate on long-term debt is higher than the firm owner's discount rate, the firm would like to repay its debt principal early once it has gathered a sufficient amount of net worth to finance operations near the optimal scale.

During the ages of approximately $t = 7, \ldots, 18$, the firm's cash buffer is not too high, while its probability of debt issuance is zero. This implies that the firm's investment is relatively responsive to cash flow shocks even though its leverage considerably below the maximal LTV ratio. If there is an unexpected drop in cash flows, the firm is unlikely to find it worthwhile to go to the debt market in order to raise liquidity. Instead, it uses its cash buffer to cover the shortfall, and if the buffer is not large enough or the firm wants to retain a liquidity buffer going forward, it must pull back on its investment. It is in such idiosyncratic states that the firm behaves analogously to a "wealthy hand-to-mouth" consumer, exhibiting a high marginal propensity to invest out of cash flows. See Section 5.2 for further discussion.

A.7 Replicating Empirical Panel Regressions in the Model

This Appendix provides details in how I identify and estimate γ_h^x from model simulated data in order to replicate the empirical exercises of Section 2. Since the empirical approach does not filter the firm-quarters included in the panel based on any specific firm characteristics, apart from data availability and dropping outliers, I also conduct the model experiments based on representative samples from the stationary distribution of firms.[62] To ensure that the firms' states, such as leverage and the liquid asset ratio are chosen by the firms endogenously and are not a result of the assumptions on entrants' portfolios, I sample firms conditional on being at least one quarter old.

In the following, I discuss how one can utilize the option of computing counterfactuals with and without realized monetary policy shocks in identifying and estimating γ_h^x from model simulated data. Recall that the key empirical regression specification to be estimated at horizon h, given a monetary policy shock at t, has the following structure, for the financial conditioning

[62] In order to measure firm fixed effects more precisely, the empirical approach does leave out firms which appear in the panel for less than 40 quarters, but this does not preclude young firms from being included in the regressions in any given quarter t (unless the firm entered the sample later than 40 quarters before the end of the sampling period; yet in robustness tests I have verified that such a sampling bias is not driving the results). Moreover, because in the model the probability of exit is independent of any firm characteristics, only including firms which survive for at least 40 quarters after the shock experiment would simply select a random sample from the already random sample of the population of firms.

variable x under consideration:

$$\log(k_{i,t+h}) - \log(k_{i,t}) = f_{i,h} + d_{h,t+h} + \beta_h^x x_{i,t-1} + \gamma_h^x x_{i,t-1}\varepsilon_t^m + u_{i,t+h} \tag{A.4}$$

I am omitting the indication of industry-time fixed effects as there is no industry dimension in the model. For brevity of exposition of the argument, I am also leaving out other covariates, such as firm size, from (A.4) and focusing on the regression specification in which only one financial conditioning variable x is included. For time-indexing the firm's capital stock, I now follow the timing convention used in the model with $k_{i,t}$ referring to the capital stock in place *at the beginning* of t. The timing of other variables is unchanged compared to (1).

Under the scenario of a "one unit" monetary policy shock occurring at time t, $\varepsilon_t^m = 1$, and (A.4) becomes:

$$\log(k_{i,t+h}^{\varepsilon}) - \log(k_{i,t}) = f_{i,h} + d_{h,t+h}^{\varepsilon} + (\beta_h^x + \gamma_h^x)\, x_{i,t-1} + u_{i,t+h}^{\varepsilon} \tag{A.5}$$

where $k_{i,t+h}^{\varepsilon}$ is firm i's capital stock at the beginning of period $t+h$ in the scenario of the one unit monetary policy shock, $d_{h,t+h}^{\varepsilon}$ captures the aggregate fluctuations in capital accumulation induced by the shock, and $u_{i,t+h}^{\varepsilon}$ reflects any idiosyncratic variation in capital accumulation not explained by firm fixed effects or heterogeneity in $x_{i,t-1}$. In the absence of a monetary policy shock in the same quarter t, $\varepsilon_t^m = 0$, and (A.4) reads:

$$\log(k_{i,t+h}^{SS}) - \log(k_{i,t}) = f_{i,h} + d_{h,t+h}^{SS} + \beta_h^x x_{i,t-1} + u_{i,t+h}^{SS} \tag{A.6}$$

I denote the outcomes in the absence of the shock with the "SS" label because in the experiment, I consider unexpected monetary policy announcements which hit the economy in the stationary equilibrium.

Taking the difference between (A.5) and (A.6), one gets:

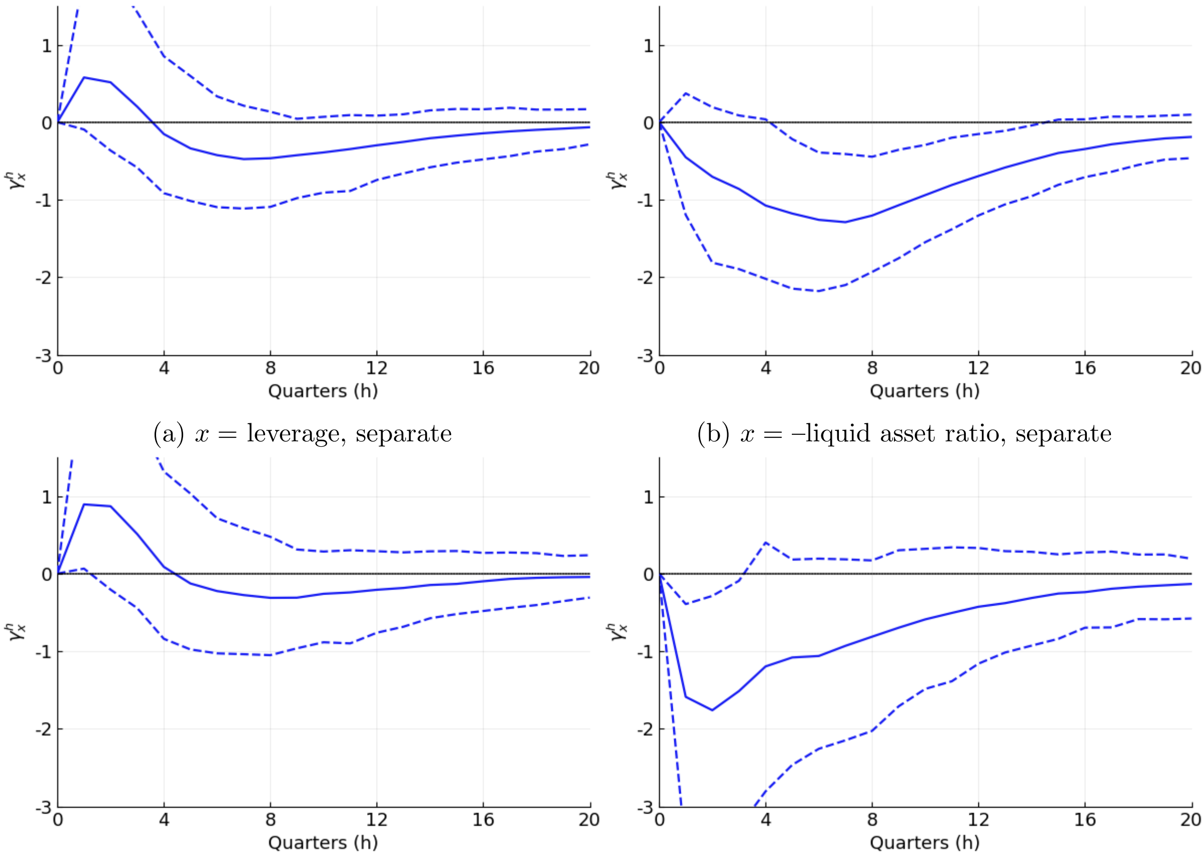
$$\log(k_{i,t+h}^{\varepsilon}) - \log(k_{i,t+h}^{SS}) = \hat{d}_{h,t+h} + \gamma_h^x x_{i,t-1} + \hat{u}_{i,t+h}$$

where $\hat{d}_{h,t+h} \equiv d_{h,t+h}^{\varepsilon} - d_{h,t+h}^{SS}$ and $\hat{u}_{i,t+h} \equiv u_{i,t+h}^{\varepsilon} - u_{i,t+h}^{SS}$. (A.7) has the natural implication that one can identify and estimate γ_h^x in the model by simply comparing each firm's capital stock h quarters after the monetary policy shock under the shock scenario to that under the counterfactual no-shock scenario, and regressing these differences on the financial conditioning variable of interest. In general, given controls $W_{i,t-1}$ and the possibility of controlling for both leverage and liquid asset holdings, in the model I estimate:

$$\log(k_{i,t+h}^{\varepsilon}) - \log(k_{i,t+h}^{SS}) = \hat{d}_{h,t+h} + \Omega_h' W_{i,t-1} + \sum_{x \in \mathcal{X}^s} \gamma_h^x x_{i,t-1} + \hat{u}_{i,t+h} \tag{A.7}$$

A.8 Model Regression Estimates in Partial Equilibrium

To illustrate the relevance of New Keynesian demand effects arising from fluctuations in the markup $\mathcal{M}_t$, Figure A.2 presents the estimates of γ_h^x from a partial equilibrium experiment in which the real interest rates r^m and r^b respond as in the general equilibrium of the baseline model while $\mathcal{M}_t$ is fixed at its steady state level.[63] The estimates show that in qualitative terms, the differences between firms' investment responses to the monetary policy shock are largely similar to those in the general equilibrium case, indicating that both high leverage and low liquid asset holdings tend to predict stronger contractions and the former effect, although weak and statistically significant only at the 90% level, disappears in the joint regression. However, both statistically and economically, the explained differences are less significant, implying that the results seen in Figures 6 and 7 are a combination of "direct" interest rate effects and "indirect" general equilibrium effects working through a demand channel affecting firms' cash flows.



(a) x = leverage, separate

(b) x = –liquid asset ratio, separate

(c) x = leverage, joint

(d) x = –liquid asset ratio, joint

Figure A.2: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings, separate and joint regressions, partial equilibrium response in model economy

Notes: Median point estimates and 2.5th and 97.5th percentiles for $\hat{\gamma}_h^x$ from estimating specification (A.7), with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d), controlling for size, from model simulated data on 500 samples of 2,000 firms.

In addition, there is a key difference compared to the general equilibrium results in that in the absence of aggregate demand effects, higher leverage tends to be associated with a *higher* capital stock in the short run after the contractionary shock's impact. And exactly as documented in the empirical results of Section 2, this effect becomes stronger in the joint regression. The positive association between leverage and investment in the short run after an increase in real interest

[63]Although I am also allowing the real wage to move in this quasi-partial equilibrium exercise, the marginal effect of these movements on the firms is *expansionary* and small. The real wage drops by about 0.15% at shock impact and then reverts to steady state.

rates can be attributed to the fact that high leverage firms are more likely to either be against a binding borrowing constraint, when issuing, or investing most of their available cash flows into capital when not issuing new debt. Essentially, the mechanism emphasized by Ottonello and Winberry (2019) is especially potent in this model because the borrowing constraint is a "hard" one – a firm borrowing up to a binding LTV constraint is virtually unaffected by marginal fluctuations in interest rates. Even though the higher implied interest payments (lower long-term debt prices) shrink the maximal amount of debt a firm can raise, all else equal, this effect is quantitatively minuscule compared to the sensitivity of a firm who is effectively "at an Euler equation" for capital accumulation. This mechanism is overshadowed in general equilibrium by the cash flow effect.

As time passes and interest rates return to their pre-shock levels, the effects on the capital stocks of relatively less financially constrained low-leverage firms dissipate because their investment is more directly determined by the lending rate. On the other hand, firms which had high leverage at the time of the shock are unlikely to all have grown out of their financial constraints at these longer horizons. And at least some of them issue new debt at the time of elevated interest rates, incurring larger borrowing costs and potentially scaling back their operations. Their net worth is directly hurt by this. So the investment of firms with high leverage at the time of the shock remains depressed due to their depleted net worth, providing an explanation for the non-monotonic predictions of leverage regarding capital accumulation. This is another example of the ideas discussed in Section 4.2.2, by which financial frictions can induce long-lasting differences between firms due to slow-moving net worth dynamics.

A.9 Model Regression Estimates with Demeaned Explanatory Variables

Figure A.3 presents the estimates for the key regression coefficients of interest, γ_h^{liq}, estimated based on data generated by the model of Section 3 when employing observed within-firm variation in the liquid asset ratios. And it compares the coefficients to the estimates when not demeaning the liquid asset ratios, corresponding to the coefficients studied in Section 4.2 – my actual coefficients of interest.[64] The median firm in the Compustat sample that I employ in the estimations of Section 2 is observed for 57 quarters. I compute the firms' average liquid asset ratios in the model based on samples of 60 quarters. Given that variation in firms' liquid asset ratios is also generated by other idiosyncratic and aggregate shocks in the data not present in the model, I consider this to be a conservatively long sample period.

The estimates show that the coefficients γ_h^{liq} based on the within-firm demeaned measures of liquid asset ratios are considerably biased in comparison to the coefficients of interest based on the non-demeaned ratios. The firms' liquid asset holdings exhibit nontrivial persistent differences due to life cycle dynamics and the fact that the realized persistent idiosyncratic TFP levels can dictate significantly different optimal liquid asset holdings for firms within the same age cohort. For example, old financially unconstrained firms with low TFP hold large buffer stocks of liquid assets to finance investment spurts whenever good TFP draws arrive, whereas high-productivity unconstrained firms have no need for such buffers. The shorter the model

[64] For presenting the idea in the most straightforward way, I am not controlling for the cross-term of firm size and the monetary shock, as I have in other regressions in the data and the model.

sample employed for within-firm demeaning, the larger the difference with the baseline estimates becomes. For example, with a sample length of 40 quarters the median estimates of γ_h^{liq} are all higher than -0.5 and the upper bound of the plotted confidence intervals is above 0.1 at every horizon h.

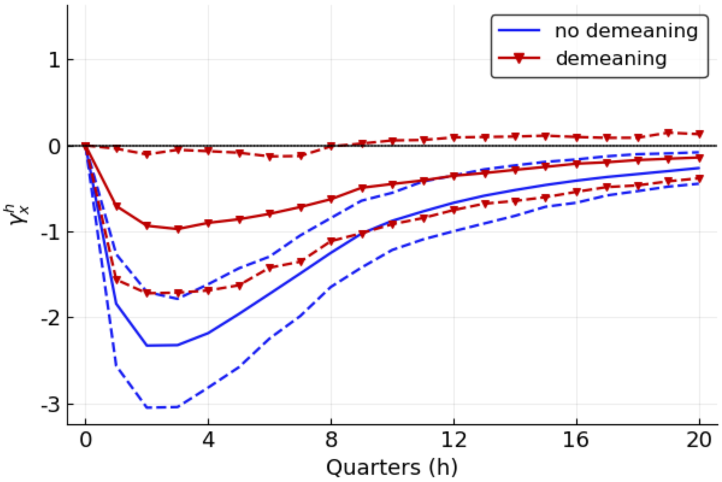


Figure A.3: Coefficient estimates for heterogeneity in responses of capital accumulation based on within-firm demeaned and non-demeaned measures of liquid asset ratios

Notes: Median point estimates and 2.5th and 97.5th percentiles for $\hat{\gamma}_h^{liq}$, from the model analogues of the specifications

$$\log(k_{i,t+h}) - \log(k_{i,t}) = f_{i,h} + d_{h,t+h} + \beta_h^{liq} x_{i,t-1} + \gamma_h^{liq} \tilde{x}_{i,t-1} \varepsilon_t^m + u_{i,t+h}$$

with $\tilde{x}_{i,t-1} = x_{i,t-1}$ ("no demeaning") or $\tilde{x}_{i,t-1} = x_{i,t-1} - \bar{x}_i$ ("demeaning"), $x_{i,t-1}$ the liquid assets to assets ratio of firm i at the end of $t-1$, and $\bar{x}_i$ the sample mean of $x_{i,t}$ over time. Estimated based on general equilibrium model-simulated data on 500 samples of 2,000 firms and 60 quarters.

A.10 A Real Version of the Baseline Model

This Appendix formulates and discusses a real version of the baseline model studied in the main text, and conducts a real interest rate shock exercise by introducing unexpected disturbances to the representative household's preferences.

Given that Section 3 presents the baseline model with a New Keynesian structure already in real terms, recasting it as a fully real economy is straightforward. Let the long-term debt contracts now dictate coupon payments in units of the final good, with the same geometrically decaying profile as described in Section 3.1.1. Because no nominal rigidities are needed, the layers of retailers and a final good producer can be dropped, so $\Xi_t^r = 0$, and one can assume that the heterogeneous firms directly produce the homogeneous final good using the decreasing returns to production function (2). With the final good still used as the numeraire, the real price of the firms' output and the gross markup are trivially 1 at every point in time. The government's monetary policy and subsidies to retailers are also obsolete, so $T_t = 0$, $\forall t$.

Most importantly, suppose that the household's momentary utility in period t includes the exogenous preference shifter ϵ_t, so the Bellman equation for its lifetime utility can be written as:

$$\mathcal{V}_t^h\left(m^h, \Lambda^h\right) = \max_{c, n^h, m^{h\prime} \geq 0, \Lambda^\prime} \left\{\epsilon_t\left(\log c - \psi n^h\right) + \beta \mathcal{V}_{t+1}^h\left(m^{h\prime}, \Lambda^{h\prime}\right)\right\}$$

subject to the budget constraint presented in Section 3.1.2, with $\Xi_t^r = T_t = 0$. Thus the household's stochastic discount factor becomes:

$$M_{t+1} \equiv \beta \frac{\epsilon_{t+1}}{\epsilon_t} \left(\frac{c_{t+1}^h}{c_t^h}\right)^{-1}$$

And the labor supply condition (9) is unchanged. Let ϵ_{SS} be normalized to 1. Given the assumptions made, the baseline economy with a New Keynesian structure and the real specification have identical stationary equilibria.

To generate and compute the general equilibrium response to an interest rate shock experiment with the same equilibrium paths for r^m and r^b as in the baseline model in Section 4.2, redefine the household's marginal utility value of the final good in period t as $\upsilon_t \equiv \epsilon_t \left(c_t^h\right)^{-1}$. This means that $M_{t+1} = \beta \frac{\upsilon_{t+1}}{\upsilon_t}$, and the labor supply condition can be written as:

$$w_t = \frac{\psi}{\upsilon_t} \epsilon_t$$

Therefore, given a transition path for ϕ^I and υ, the only change in a firm's problem compared to the baseline specification is that the real price of its production is 1 but the real wage is affected by ϵ_t.

Given that $M_{t+1}\left(1 + r_{t+1}^m\right) = 1$ holds in equilibrium, a desired equilibrium path for r^m directly implies a path for υ. Finding an equilibrium in which r^m follows a given path thus involves finding a path of ϵ such that the final goods market clears at the implied $c_t^h = \epsilon_t / \upsilon_t$ in every period along the transition while firms behave optimally. And the resulting ϵ path is the required household preference shock which yields the desired r^m path along the transition in general equilibrium.

Figure A.4 presents the real model's estimation results on firms' response heterogeneity, with 90% confidence intervals, in a general equilibrium monetary policy experiment with the real borrowing and lending rate paths depicted in Figure B.8 in Appendix B.6.

A.11 A Specification with "Fixed Cost" Shocks and Cash-in-Advance Constraints

The baseline model studied in the main text of this paper features some stark predictions regarding firms' liquid asset holdings, for example implying that many growing firms hold *zero* cash buffers. This Appendix discusses an alternative specification of the baseline model which leads to a less extreme distribution of liquid asset holdings across firms and allows to generate a negative unconditional cross-sectional correlation between firms' size and liquid asset ratios, as observed in the data. At the same time, the underlying economic mechanisms under examination in the baseline model remain largely unchanged, and the model can replicate the empirical results of Section 2 virtually as well as the baseline. The main goal of this Appendix is to

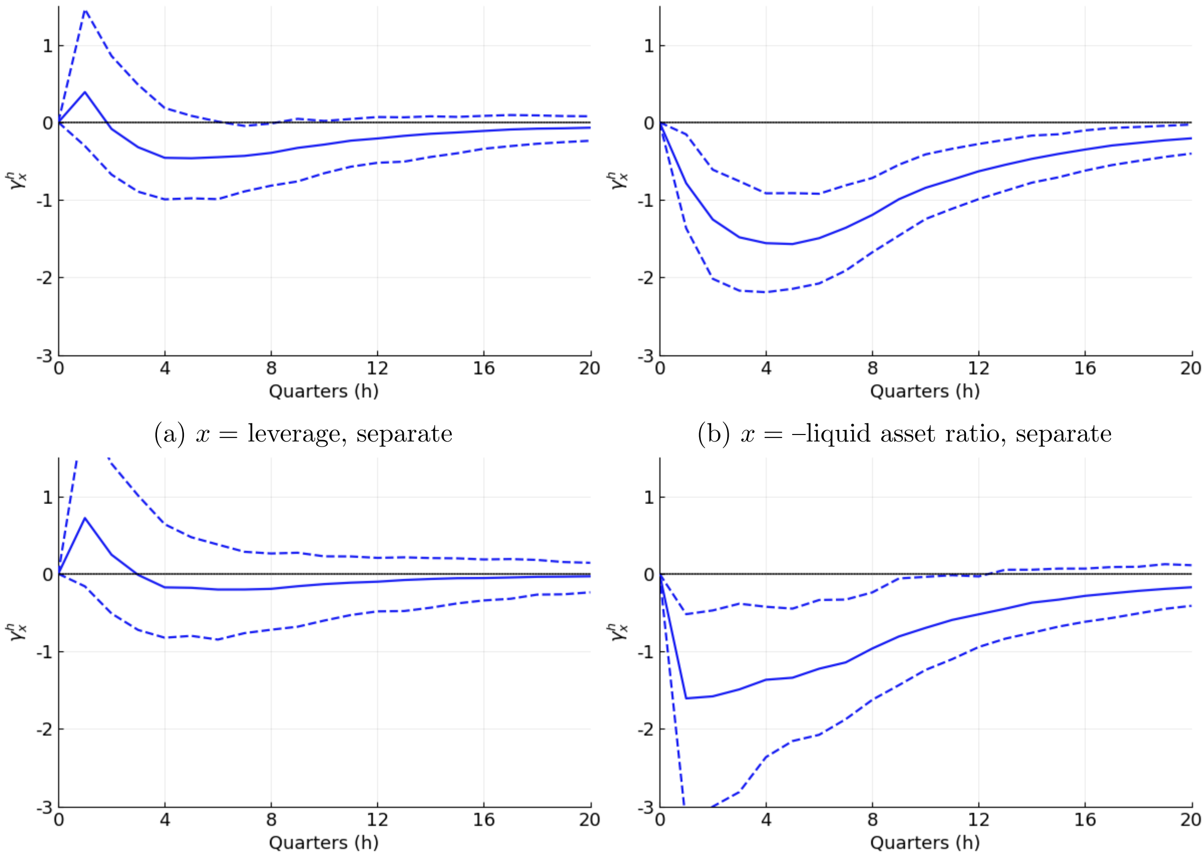


Figure A.4: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings, separate and joint regressions, general equilibrium response in real economy specification

Notes: Median point estimates and 5th and 95th percentiles for $\hat{\gamma}_h^x$ from estimating specification (A.7), with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d), controlling for size, from model simulated data on 500 samples of 2,000 firms.

argue in the simplest manner that one could introduce additional motives for firms to hold cash into the baseline without changing the forces that allow firms' liquid asset holdings to explain heterogeneous investment responses to monetary policy shocks.

Suppose now that $\chi = 0$, meaning that all firms are hit by temporary cash flow shocks of the same size in *absolute* terms. Furthermore, suppose that each operating firm leaving period t must be ready to cover a fraction ϕ_ζ of the worst realization of ζ in $t+1$ in cash held between t and $t+1$. That is, each firm must hold at least $m' \geq \phi_\zeta \bar{\zeta}$ overnight.[65] I will refer to this as a naive cash-in-advance (CIA) constraint.

In what is to follow, I argue that the CIA constraint shifts the "reference point" of zero cash holdings in the baseline to $\phi_\zeta \bar{\zeta}$ in the extension, while leaving the predictions that observed variation in firms' liquid asset ratios has for debt issuance and investment policies largely unchanged. To see this, first decompose a firm's cash holdings into the component $\phi_\zeta \bar{\zeta}$ and a

[65] One could think of this requirement arising from a "transactional motive" to hold cash, in contrast to the "precautionary motive" under analysis in the baseline model in the main text.

"precautionary component" $\hat{m}$ over and above it:

$$m = \hat{m} + \phi_\varsigma \bar{\zeta}$$

The terms in the firm's period t budget constraint which contain cash can then be written as:

$$(1 + r_t^m)\, m - m' = (1 + r_t^m) \left(\hat{m} + \phi_\varsigma \bar{\zeta}\right) - \left(\hat{m}' + \phi_\varsigma \bar{\zeta}\right) = (1 + r_t^m)\, \hat{m} - \hat{m}' + r_t^m \phi_\varsigma \bar{\zeta}$$

At the same time, the remainder of the firm's problem and its budget constraint remain virtually unchanged. The relevant non-negativity constraint on cash holdings now simply becomes $\hat{m} \geq 0$. Therefore, given a small r_t^m, the firm's problem in now choosing $\hat{m}'$ is almost the same as choosing m' in the baseline model without the CIA constraint.

The firm's cash-to-capital ratio can then be rewritten as:

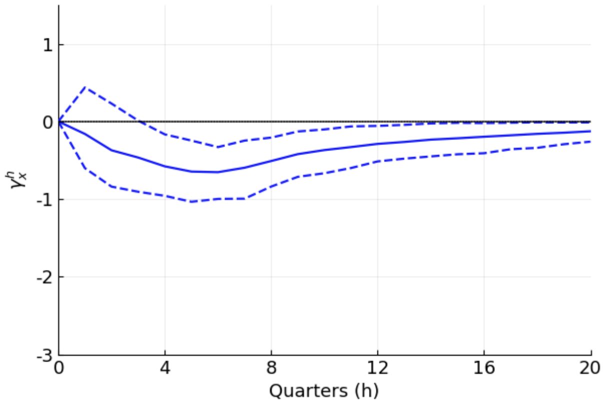
$$\frac{m}{k} = \frac{\hat{m}}{k} + \phi_\varsigma \bar{\zeta} k^{-1}$$

This means that, if all firms were to choose $\hat{m}$ in an identical manner as they choose m in a model without the CIA constraint, the addition of the constraint has simply introduced into the firms' liquid asset ratios a "transactional component" which is decreasing in firm size, inducing a negative unconditional correlation between size and the liquid asset ratio. Moreover, if one controls for firm size in the estimation of (A.7), this transactional component in the liquid asset ratio does not obscure the model's ability to replicate the empirical results of Section 2.

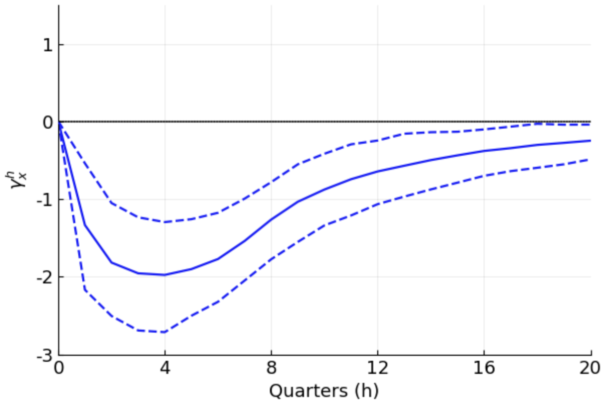
To show this, I calibrate the extended model, targeting the aggregate debt-to-capital ratio, the entrants' relative size, and the frequency of annualized lumpy investment as presented in Table A.1 in Appendix A.5. In addition, I target the frequency of debt issuance for firms smaller than the median firm in the cross section (0.255), and the unconditional cross-sectional correlations between log-sales and the debt-to-capital ratio (-0.083), and between log-sales and the cash-to-capital ratio (-0.273).[66] The resulting parameter values are $\left[k_0, \bar{\zeta}, \theta, \bar{c}_B, g_q, \phi_\varsigma\right]$=[0.280, 0.0231, 0.743, 0.0129, 0.006, 0.944].[67] The estimation results of $\hat{\gamma}_h^x$ from conducting a monetary policy exercise in general equilibrium, as described in Section 4.2, can be seen in Figure A.5. Apart from leverage retaining slight statistical significance in predicting response heterogeneity in the joint regression, the CIA specification does as well as the baseline in matching the empirical stylized facts of Section 2.

[66] In this specification, I assume that entrants start with an initial capital stock k_0 and also cash holdings $m_0 = \phi_\varsigma \bar{\zeta}$.

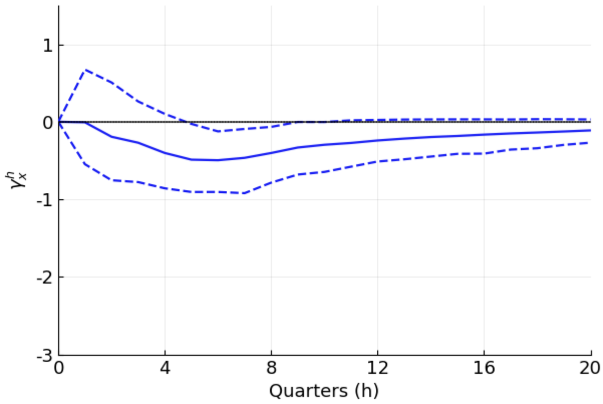
[67] The parametrization cannot hit all the targets perfectly, and rather is the outcome of minimizing the distance between the vector of targets and model moments.



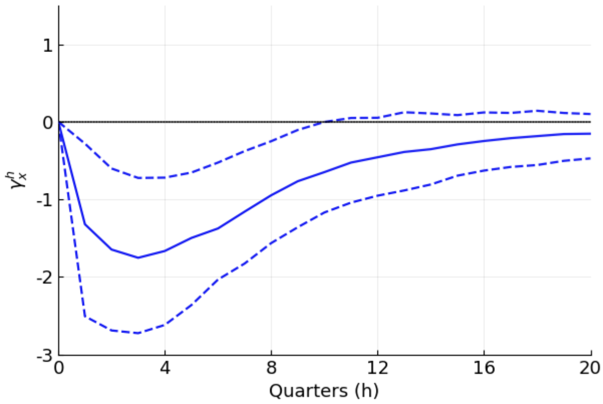
(a) x = leverage, separate



(b) x = –liquid asset ratio, separate



(c) x = leverage, joint



(d) x = –liquid asset ratio, joint

Figure A.5: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings, separate and joint regressions, general equilibrium response in specification with CIA constraint

Notes: Median point estimates and 2.5th and 97.5th percentiles for $\hat{\gamma}_h^x$ from estimating specification (A.7), with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d), controlling for size, from model simulated data on 500 samples of 2,000 firms.

A.12 Additional Figures

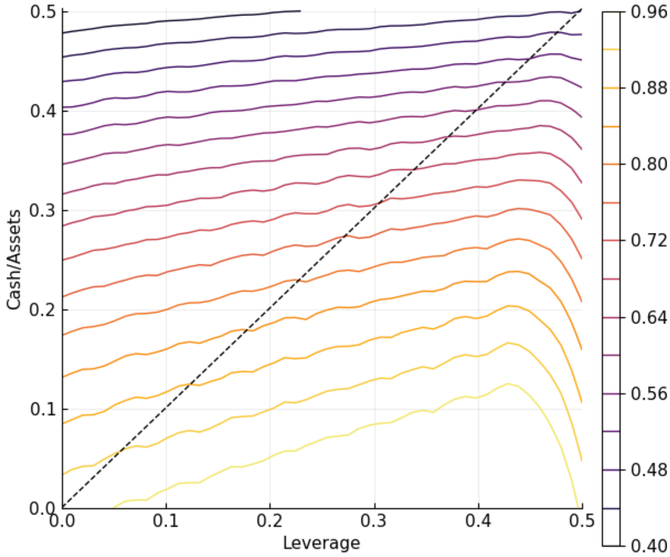


Figure A.6: Isolines of debt issuance probability, fixing balance sheet size

Notes: Isolines of debt issuance probability, given $(m+k) = 0.85$, $z = z_4$, as a function of leverage and cash-to-assets ratio, based on policy functions in the stationary equilibrium. Black dashed line: portfolio combinations implying zero net financial wealth. Right hand scale: color-probability correspondences.

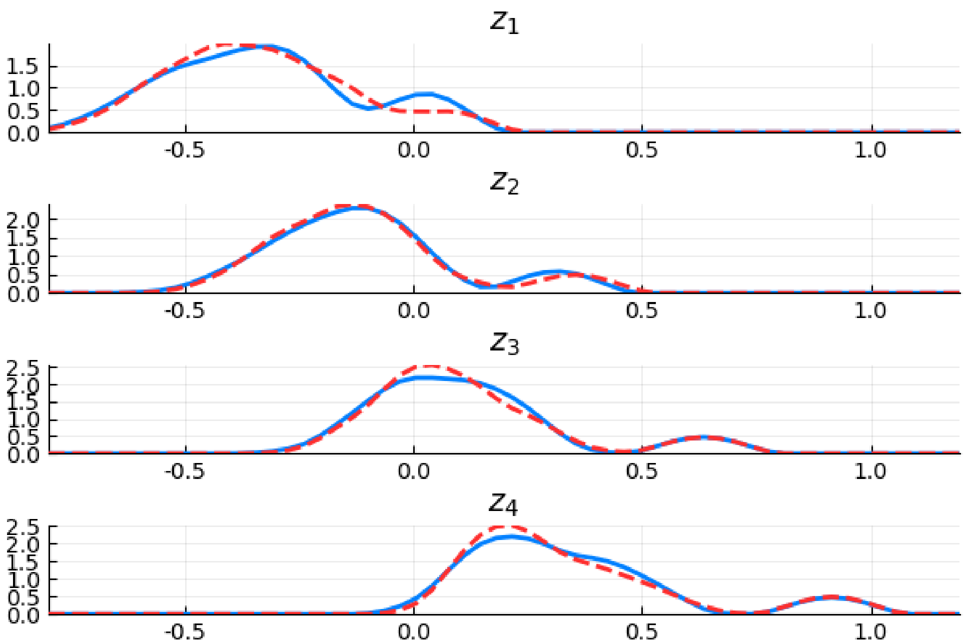


Figure A.7: Cross-sectional densities of log marginal products of capital, conditional on $z_i \in \mathbf{Z}$; blue – baseline calibration, red dashed – baseline calibration with $\bar{c}_B = 0$

Notes: Log marginal products of capital demeaned with population average log marginal product in corresponding model. Densities based on sample of 50,000 firms in stationary distribution of model, computed using the Average Shifted Histograms method.

A.13 Computational Details

This Appendix provides details on the computational methods that I apply in solving the models in this paper. I solve the firm's problem by value function iteration, both in steady state and along transition paths. To solve for the economy's transition paths after the revelation of unexpected shocks, I employ a shooting algorithm, using backward iteration to obtain policy functions and forward iteration on the distribution of firms across the idiosyncratic state space to compute aggregate objects. In steady state, this translates to iteration until the convergence of the value functions and the stationary distribution of firms, ensuring final good market clearing. I discretize the distribution of firms over the idiosyncratic state space using the nonstochastic simulation approach following Young (2010).

Firm's problem and value function iteration. For the computation of firms' value functions and policies, I define the idiosyncratic state space over the states $(k, \tilde{a}, l, z)$, where $\tilde{a}$ stands for $\tilde{a} \equiv \theta k + (1 + r^m) m - \zeta k^\chi - \left(1 + r^b\right) b$, and $l \equiv b/k$. Using as one of the states a variable which can be used to infer the firm's net financial wealth $(1 + r^m) m - \zeta k^\chi - \left(1 + r^b\right) b$, instead of simply the liquid financial wealth a, is convenient because the problem of a firm adjusting debt does not depend on the incoming debt level over and above the net financial wealth, as seen in problem (7). This allows to solve the problem of such a firm on the smaller space over $(k, \tilde{a}, z)$. I include θk in the definition of $\tilde{a}$ because the firms' admissible choices imply a natural lower bound of zero for feasible values of $\tilde{a}$.[68] I use unequally spaced grids over $(k, \tilde{a}, l)$ with more points around areas in which the firm's value function exhibits more curvature: low values of k and $\tilde{a}$, and high values of l. Because of decreasing returns, borrowing constraints, and employing the minimum savings policy given bounded idiosyncratic shocks, firms' optimal choices of (k', m', b') are bounded and I ensure that the maximal values of the grids are high enough for firms not to ever exceed them. I use 55, 70, and 35 points along the k, $\tilde{a}$, and l grids, respectively. In computing expectations over ζ, I employ 7 equidistant points over its support.

Following the discussion in Section 3.2.1 and the steps outlined in Appendix A.3.1, I first solve for the unconstrained policies of capital and debt based on the recursions (A.1) and (A.2), respectively, employing value function iteration and interpolation of $v^u_{0,t}$ and $W^u_{0,t}$ outside the gridpoints of the discretized state space.[69] Given the capital and debt policies, I solve for the minimum savings policy $\underline{m}^{E,E}_{t+1}$, with $E \in \{A, N\}$, over the discretized (k, b, z_i) space, using the recursion outlined in Appendix A.3.1, also using interpolation to evaluate $\underline{m}^{E,E}_{t+1}$ outside gridpoints. Altogether, these policies characterize the unconstrained firm behavior on the whole discretized idiosyncratic state space. Given the implied unconstrained policies, one can determine in which states in the space the firm is unconstrained and impose that the firm's value and policies at these points are the unconstrained ones. On all other points, the firm solves the full problem (5)–(8), setting $div = 0$.

In solving the full firm problem, the key object of interest is the expected continuation value

[68] Although one must keep in mind that the ζ-shocks can take firms' $\tilde{a}$ below zero.

[69] For precision, I solve the unconstrained firm's problem using the first order conditions for k' directly, approximating the derivative of $v^u_{0,t}$ with respect to k.

function:

$$V_t^e(k,\tilde{a},l,z) \equiv \mathbb{E}_{z',\zeta'}\left[\hat{V}_{0,t}\left(k,\tilde{a}-\zeta k^{\chi},l,z'\right)|z\right]$$
$$\text{with } \hat{V}_{0,t}\left(k,\tilde{a},l,z\right) \equiv V_{0,t}\left(k,\tilde{a}-\theta k+\left(1+r_t^b\right)kl,kl,z\right)$$

with $V_{0,t}$ satisfying (5). Taking V_{t+1}^e and the unconstrained firm's solution in t as given, one can solve for $\hat{V}_{0,t}$ on the subset of the discretized individual state space for which the firm is financially constrained, based on the system (5)–(8) while setting $div = 0$. Combining the unconstrained and constrained values for $\hat{V}_{0,t}$, one can then integrate to determine the values of V_t^e on the discretized space. To evaluate value functions outside of the gridpoints, I use cubic interpolation over the k-dimension, and linear interpolation over the $\tilde{a}$ and l dimensions using tensor product spline approximation.

I solve the firm's optimization problems using golden search, allowing for a fully nonlinear global solution under several occasionally binding constraints. When solving for the constrained firm's bivariate choice (k',b'), I use nested golden search, choosing k' conditional on b' in an "inner optimization loop".[70] In steady state, I iterate on the firm's problem until the convergence of V_t^e on the discretized grid. Along the transition path, I simply use backward iteration.

Transition paths after unexpected shocks. Given that all the shocks that I consider are temporary, after a shock is revealed in $t=0$, there is some $\tilde{T}$ after which all exogenous variables have returned to their initial values and the economy starts its transition back to steady state. I suppose that for some $T>\tilde{T}$, the economy is "close enough" to the steady state. In backwards iterations, the value functions and prices applicable in T are then those from steady state.

In the baseline economy with rigid nominal prices, one must find the path of the aggregate markup which yields final good market clearing along the transition. In order to find the equilibrium path for the markups, I start from an initial guess, solve the firm's problem by backward iteration, and iterate the economy forward starting from the steady state distribution. Depending on the implied path of excess demand in the final good market, I update the guess for markups and repeat. In the real economy presented in Appendix A.10, I do the same, but instead iterating over the required path of the household's preference shock ϵ in order to find the shock conformable with final good market clearing and the path for the marginal utility of consumption $\upsilon = \epsilon c^{-1}$, as implied by the desired equilibrium lending rate path.

[70] To check that the results are not affected by multiple local optima in which the golden search method might get stuck, I have inspected the inner and outer objective functions visually. They appear unimodal. In addition, taking the converged steady state value function as the continuation, I have solved the firm's problem with a simulated annealing approach robust to local optima without any noticeable gains in the values achieved.

B Data Appendix

B.1 Compustat Data for Panel Regressions

This Appendix details the steps taken to construct the variables and select the sample of Compustat firm-quarters employed in the regression estimations of (1) and the computation of the model's calibration targets.

B.1.1 Sample Selection

I apply the same steps of sample selection as in Jeenas (2018). I exclude all firm-quarters for which:

1. The firm is not incorporated in the United States.
2. The firm is in the financial industry (SIC code between 6000 and 6999) or utilities (SIC between 4900 and 4999)
3. The measurements of *Total assets* (Compustat data item 44, $ATQ_{i,t}$), *Property, Plant and Equipment (Net)* (item 42, $PPENTQ_{i,t}$), *Sales* (item 2, $SALEQ_{i,t}$), *Total Inventories* (item 38, $INVTQ_{i,t}$) are missing or not positive.[71]
4. The measurements of *Debt in Current Liabilities* (item 45, $DLCQ_{i,t}$), *Total Long-Term Debt* (item 51, $DLTTQ_{i,t}$) and *Cash and short-term investments* ($CHEQ_{i,t}$, item 38) are missing or negative.
5. All firm-quarters before a firm's first observation of *Property, Plant and Equipment (Gross)* (item 118, $PPENTQ_{i,t}$) in the full quarterly Compustat dataset.

After computing the yearly moving averages for leverage and liquid asset ratios and before estimating (1), I drop all firms which are observed between 1990Q1–2007Q4 for less than 40 quarters.

B.1.2 Construction of Variables

I construct the key variables employed in Section 2 as follows.

1. To construct a measure of the firms' *fixed capital stocks*, I use a perpetual inventory method, as is commonly done for Compustat data, as for example by Mongey and Williams (2017). I measure the initial value of firm i's capital stock as the earliest available entry of $PPEGTQ_{i,t}$, and then iteratively construct $k_{i,t}$ from $PPENTQ_{i,t}$ as

$$k_{i,t+1} = k_{i,t} + PPENTQ_{i,t+1} - PPENTQ_{i,t}$$

2. I define *leverage* as total debt divided by $ATQ_{i,t}$, with total debt computed as the sum of debt in current liabilities and total long-term debt ($DLCQ_{i,t} + DLTTQ_{i,t}$).

[71] The main implications of Figures 1 and 2 are robust to including firm-quarters with zero inventories.

3. I measure the *liquid asset ratio* as $CHEQ_{i,t}/ATQ_{i,t}$.

4. *Net assets* are defined as $ATQ_{i,t} - CHEQ_{i,t}$.

5. *Entrants' relative size:* For each of the years between 1990–2007, I determine the firms which were indicated to have had an IPO in that year, compute their average size in that year's last quarter relative to the average firm's size in net assets, and then take the time-average of this relative size time series.[72]

6. *Investment rates:* For computing the frequency of lumpy investment, I use the annual Compustat database of U.S. incorporated nonfinancial firms to measure investment on a yearly basis, as is more common in the investment literature. I measure investment rates as the ratio of capital expenditures (item 128, $CAPX_{i,t}$) to lagged capital stock, constructed based on the perpetual inventory method. I exclude all firm-years with non-measured or non-positive total assets. I am also excluding Compustat firms with net property, plant, and equipment of less than \$1M at any point during the sample. In the model sample, I include firms conditional on being least one year old to alleviate the effects of firms' fast growth at entry. I employ balanced panels with lengths of 15 years, with the annual Compustat panel drawn between 1990–2004.

Whenever the deflating of variables is necessary, such as for the measures of gross and net fixed capital used in the perpetual inventory method, I deflate them using the implied price index of gross value added in the U.S. nonfarm business sector (BEA-NIPA Table 1.3.4 Line 3).

B.2 Additional Panel Regression Estimates and Comparison to Ottonello and Winberry (2019)

In what is to follow, I point out the differences between my empirical approach and results and those of Ottonello and Winberry (2019). Among other proxies for default risk, they study how leverage explains firms' heterogeneous capital accumulation responses to monetary policy shocks identified using high-frequency data on federal funds futures. Regarding the predictive power of leverage, their specification finds statistically significant heterogeneity in capital accumulation at shock-impact and the year after that, with the analogues in my estimates seen in Panels 1a and 2a, at $h \leq 4$, indicating that higher leverage predicts stronger capital growth in response to contractionary shocks. Ottonello and Winberry (2019) do not find a "flip" in the sign when they demean firms' financial positions at the firm level, which I discuss further below.

As pointed out in a previous version of this paper and by Ottonello and Winberry (2019), measuring leverage using a four-quarter rolling mean helps in finding statistically significant evidence of higher-leverage firms contracting their capital stocks by relatively more over the medium run in response to a contractionary monetary shock. Figure B.1 compares the estimates for γ_h^{lev} from the separate regression specification of (1) when firm leverage at the end of t is measured as the past year's rolling mean versus the actual measured level of leverage at the end of t.

[72] I conduct the computation on a yearly, rather than a quarterly basis because in some quarters, the sample includes only a relatively small number of IPOs which can potentially lead to observations influenced by the size of a few very large firms.

First, while it is true that in specification (1) the coefficient estimates for γ_h^x become insignificant at the two and three year horizons when not using the rolling mean of leverage, the induced changes in the point-estimates are relatively small. Second, as pointed out in Jeenas (2018), the linearity imposed by (1) on the marginal effect of leverage in predicting firms' responsiveness is restrictive and not borne out by the data, diminishing the informativeness of the specification.

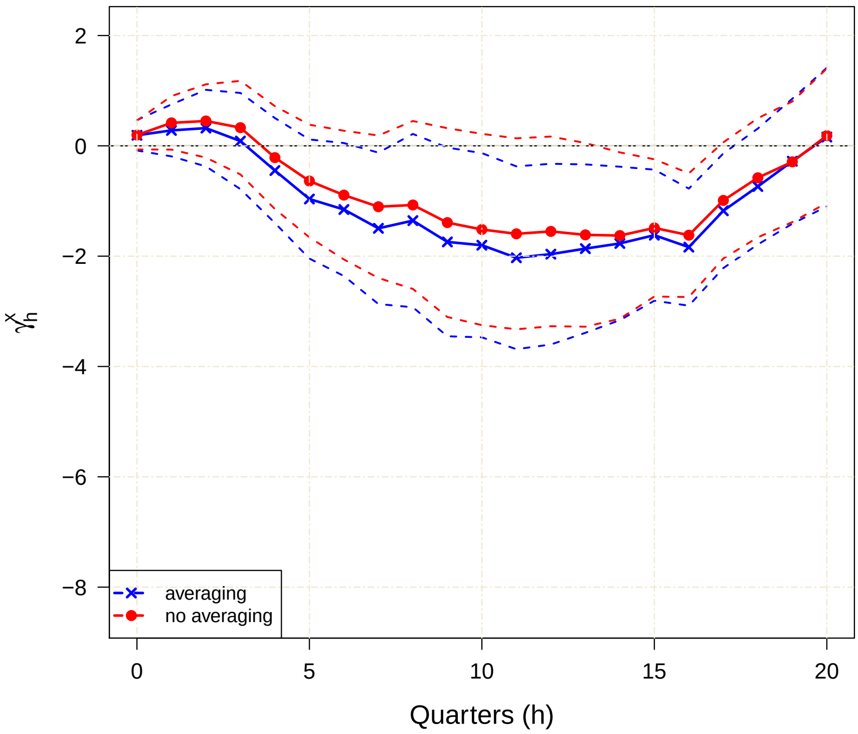


Figure B.1: Comparing heterogeneity in responses of capital accumulation conditional on leverage and its four-quarter rolling mean
Notes: Point estimates and 95% confidence intervals for γ_h^x from estimating specification (1), with $\mathcal{X}^s = \{lev\}$. Leverage $x_{i,t-1}$ measured as the leverage at the end of quarter $t-1$ ("no averaging"), and as the past four-quarter rolling mean ("averaging"). Dropping observations in the top 1% of the leverage and average leverage cross-sectional distributions by quarter. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

Figure B.2 employs the baseline specification used in Jeenas (2018). Instead of conditioning the heterogeneity in firms' capital stock responses on a financial variable $x_{i,t}$, the approach splits firms into groups based on their relative positions in the cross-section of variable x at the end of t. And it estimates differences in firms' responses conditional on membership in the groups, not averaging over the past year's observations of variable x. More specifically, in each quarter t, I split the sample of firms in the panel at the time, denoted $\mathcal{I}_t$, into groups based on quantiles of the explanatory variable x:

$$\mathcal{I}_t^{x,(a,b)} \equiv \left\{ i \in \mathcal{I}_t | x_{i,t} \in \left[q_{x,t}^a, q_{x,t}^b \right] \right\}$$

$q_{x,t}^a$ refers to the 100a-th percentile of variable x in the cross-section of firms in $\mathcal{I}_t$. For both leverage and the liquid asset ratio, I group together the firms below the 40th percentile, and the firms between the 40th and 80th percentiles. Based on the notation introduced, this yields the set of groups $\left\{\mathcal{I}_t^{x,(0,0.4)}, \mathcal{I}_t^{x,(0.4,0.8)}, \mathcal{I}_t^{x,(0.8,1.0)}\right\}$ in both the leverage and liquid asset ratio cross-sections, with $x \in \{lev, liq\}$. These cutoffs follow the approach in Jeenas (2018), motivated by the findings that based on finer splits using quintiles, the capital stocks of firms below the 40th percentile of the leverage distribution tend to behave similarly in response to monetary policy shocks, as for firms below the 40th percentile of the liquid asset ratios distribution.[73] The specification that I estimate is the corresponding analog of (1):

$$\begin{aligned}\Delta_h \log(k_{i,t+h}) = & f_{i,h} + d_{n,h,t+h} + \left(\Theta_h' + \varepsilon_t^m \Omega_h'\right) W_{i,t-1} + \\ & + \sum_{x \in \mathcal{X}^s} \sum_{j \in \mathbb{J}^x} \left(\beta_{j,h}^x + \alpha_{j,h}^x \Delta Y_{t-1} + \gamma_{j,h}^x \varepsilon_t^m\right) \times \mathbb{1}\left\{i \in \mathcal{I}_{t-1}^{x,j}\right\} + u_{i,h,t+h}\end{aligned} \tag{B.1}$$

$\mathbb{1}\left\{i \in \mathcal{I}_{t-1}^{x,j}\right\}$ is the indicator of firm i belonging in $\mathcal{I}_{t-1}^{x,j}$. In line with the approach taken in specification (1), I let the base level of the group indicator dummies for leverage be the lowest leverage group, and for liquid assets the highest group, implying the grouping indicator definitions $\mathbb{J}^{lev} \equiv \{(0.4, 0.8), (0.8, 1.0)\}$ and $\mathbb{J}^{liq} \equiv \{(0, 0.4), (0.4, 0.8)\}$. Also, to illustrate the robustness of the main results to the controlling for cyclical sensitivities employed by Ottonello and Winberry (2019), I add the cross-terms between the grouping indicators and lagged GDP growth ΔY_{t-1}. Θ_h, Ω_h, $\beta_{j,h}^x$, $\alpha_{j,h}^x$, and $\gamma_{j,h}^x$ are regression coefficients. As in the baseline specifications in Section 2, I control for firms' total book assets, $W_{i,t} = [\log(\text{size}_{i,t})]$. And as in Section 2, I multiply the $\Delta_h \log(k_{i,t+h})$ by 100 prior to estimation to present the coefficients $\gamma_{j,h}^x$ as directly referring to percentage point differences in capital growth across groups. Figure B.2 depicts the point estimates for $\gamma_{j,h}^x$, for $x \in \{lev, liq\}$, alongside the 90% confidence intervals, in both the separate and joint specifications of (B.1). The relative response of firms between the 40th and 80th percentiles of the cross-sectional distribution of leverage is similar to the response of firms with leverage above the highest quintile. And both of these groups reduce their capital significantly more than low-leverage firms in response to contractionary monetary policy shocks, both when grouping firms by simply the level of leverage or by the rolling mean of leverage. The predictive power of liquid assets remains statistically significant and superior to that of leverage when not using rolling means.

In addition, in their baseline analysis of firms' dynamic responses, Ottonello and Winberry (2019) focus on the explanatory power of within-firm variation in the financial variables of interest, demeaned using the observed average values of each firm's corresponding characteristics. The justification is that doing so would control for any permanent differences across firms. However, such a demeaning also eliminates persistent, and not necessarily permanent, differences between firms' financial positions, relevant for my analysis, and can alter the interpretation of the empirical results depending on the questions and mechanisms of interest at hand. Life cycle dynamics and persistent idiosyncratic shocks can generate persistent and potentially large differences in firms' financial positions, even when the firms are ex ante homogeneous. And this can lead to an imprecise estimation of "fixed effects" based on samples of similar length as my

[73] See Jeenas (2018) for a more detailed discussion and the results based on finer splits.

Compustat sample.

I illustrate this idea in Appendix A.9 based on simulated data from the model of Section 3. In the context of the model, within-firm demeaning of financial positions eliminates informative persistent variation in firms' characteristics relevant for the mechanisms under consideration, and it generates considerable biases in my main coefficients of interest. Because of this, I refrain from using within-firm demeaned financial characteristics when studying the heterogeneous effects of monetary policy shocks. And I prefer to focus on specification (1) which relies on within-industry variation, and the main results being robust to industry splits as fine as the SIC 3-digit level, as shown in Figure B.3 below.

As an alternative way to assess whether permanent differences between firms' financial positions could explain the response heterogeneity in Figures 1 and 2, I repeat the estimation of (1), for $x = lev$, by only including data from firms who have had both high and low leverage in the observed sample between 1990Q1–2007Q4. I define being high- or low-leverage in a given quarter based on whether a firm is above or below the cross-sectional median leverage in that quarter, respectively.[74] This ensures that firms who always have either high or low leverage are left out of the sample. And I repeat the same procedure for liquid asset holdings. The results can be seen in Figure B.4. While the coefficient estimates for leverage are statistically slightly weaker, now significant at the 90% level, they show that when only employing variation from firms who switch their status between high- and low-leverage across time, it is still the case that the ones with higher leverage at the time of a contractionary monetary policy shock tend to contract their capital stocks relative to others.

B.3 Panel Regression Estimates Conditional on Firm Age

Following Cloyne et al. (2018), I construct a proxy for firms' age as time since incorporation based on the Worldscope database. I consider the cutoff for being "younger" as 15 years. To show that the main empirical findings of Section 2 hold also when controlling for firm age, I repeat the estimation of (1), now allowing the response heterogeneity also to be explained by firms' age. Moreover, I allow the relevance of leverage and liquid asset holdings in explaining shock-responsiveness to differ between the older and younger groups. That is, γ_h^x can differ for firms who are younger versus older at the time of the shock. Figure B.5 presents the estimates for the coefficients on the cross-terms of ε_t^m and the financial variables of interest.[75]

B.4 Panel Regression Estimates with Romer and Romer (2004) Shocks

Figure B.6 presents the estimates for γ_h^x from the separate and joint regression specifications of (1) by employing measures of monetary policy shocks ε_t^m constructed using the approach of Romer and Romer (2004). More specifically, I use the shock series constructed by Ramey (2016)

[74] The findings are robust to using other definitions of "high-x" and "low-x", such as belonging to the top and bottom thirds or fourths of the cross-sectional distribution, for example.

[75] There still remain some differences in our results because Cloyne et al. (2018) are using a slightly different approach to shock-identification and they are studying heterogeneity in the responsiveness of firms' investment rates. If different groups of firms are investing at different rates before the shock, the heterogeneity of relative responses in the capital stock does not necessarily need to line up with the heterogeneity in percentage point responsiveness in investment rates.

and updated by Wieland and Yang (2017). I aggregate the monthly Romer-Romer shock series to quarterly by simply summing within quarter. As in the baseline approach, I normalize the ε_t^m series by its standard deviation between 1990Q1–2007Q4.

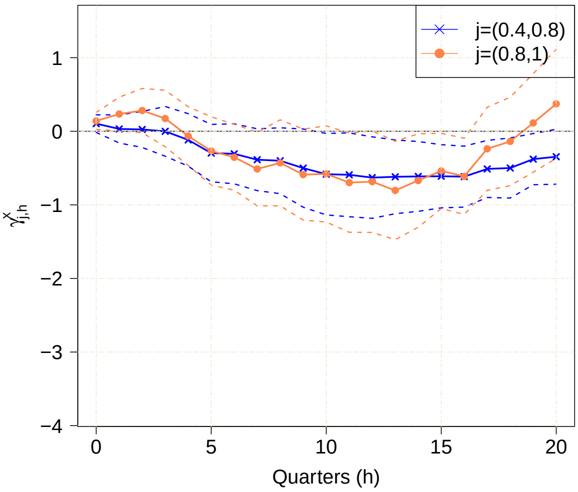
B.5 U.S. Corporate Liquid Asset Portfolio Shares

Table B.1 presents the composition of the U.S. nonfinancial corporate sector's liquid asset portfolio based on the Federal Reserve Board Flow of Funds Accounts data. The shares are computed as the time-averages of the respective shares in each quarter over 1990Q1–2007Q4. In choosing the types of instruments considered among the portfolio of liquid assets, I seek to follow the definition of Compustat's *Cash and Short-Term Investments* as closely as possible.

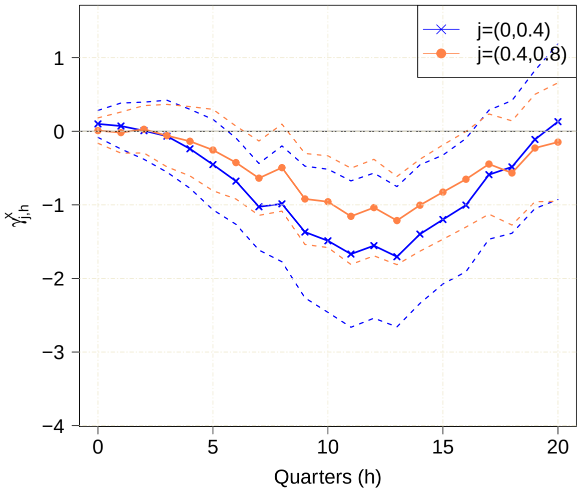
Table B.1: Asset shares in the US nonfinancial corporate sector's liquid assets portfolio

Asset	Share
Checkable deposits and currency	25.5%
Time and savings deposits	25.4%
Money market fund shares	21.3%
Security repurchase agreements	0.6%
Commercial paper	5.4%
Treasury securities	5.6%
Agency- and GSE-backed securities	1.9%
Municipal securities	5.1%
Mutual fund shares	9.2%

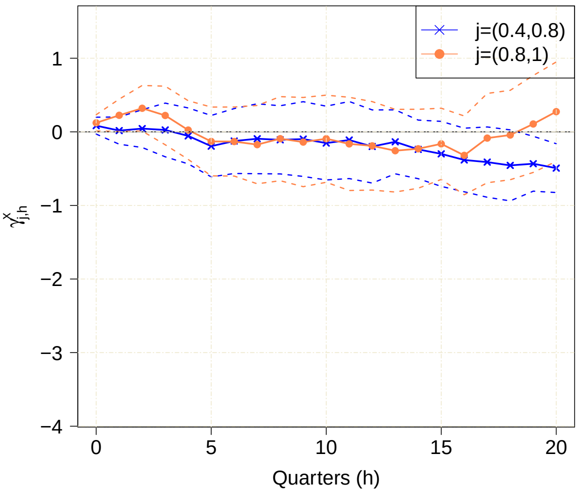
Source: Quarterly Flow of Funds Accounts, time-average shares over 1990–2007.



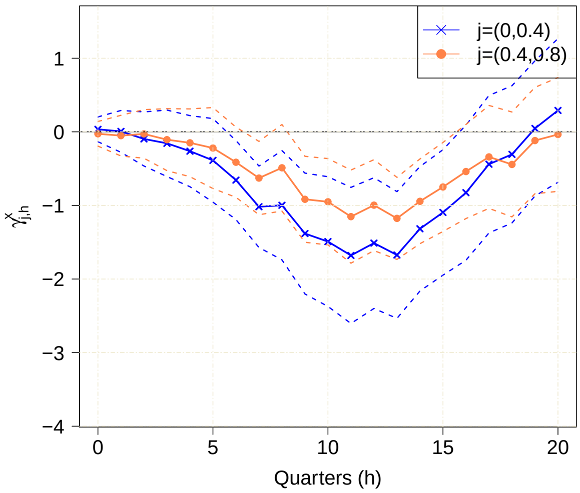
(a) x = leverage, separate



(b) $x = -$liquid asset ratio, separate



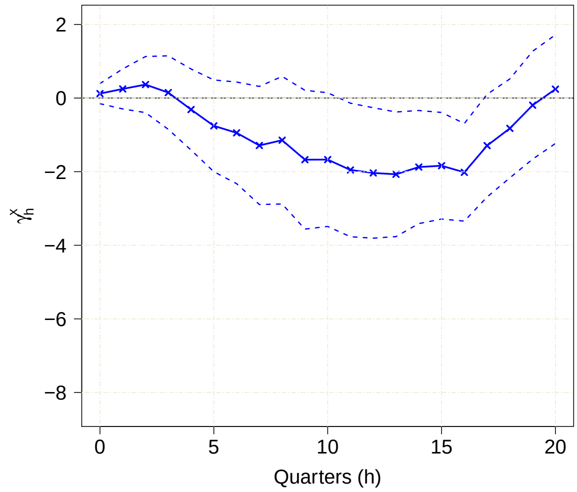
(c) x = leverage, joint



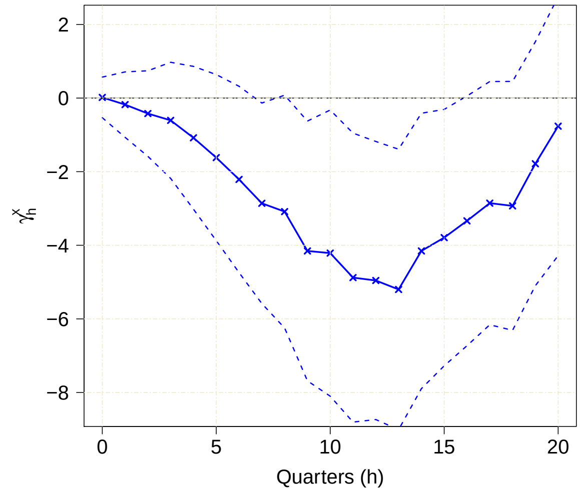
(d) $x = -$liquid asset ratio, joint

Figure B.2: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset ratio groupings in separate and joint regressions

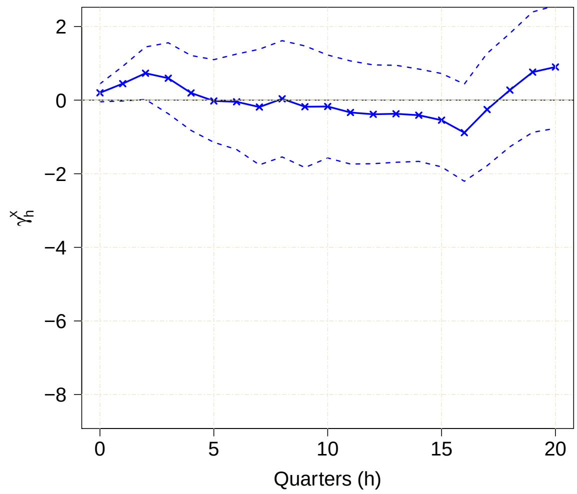
Notes: Point estimates and 90% confidence intervals for $\gamma^{x}_{j,h}$ from estimating specification (B.1), with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d). Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.



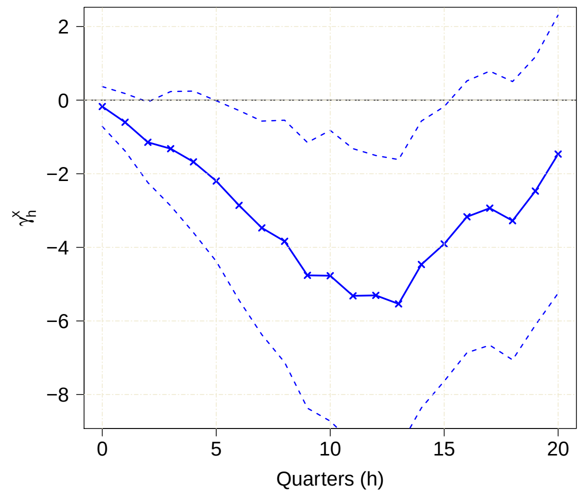
(a) $x =$ leverage, separate



(b) $x = -$liquid asset ratio, separate



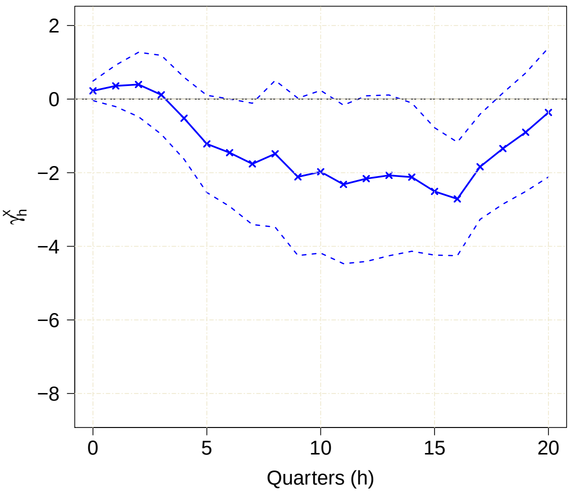
(c) $x =$ leverage, joint



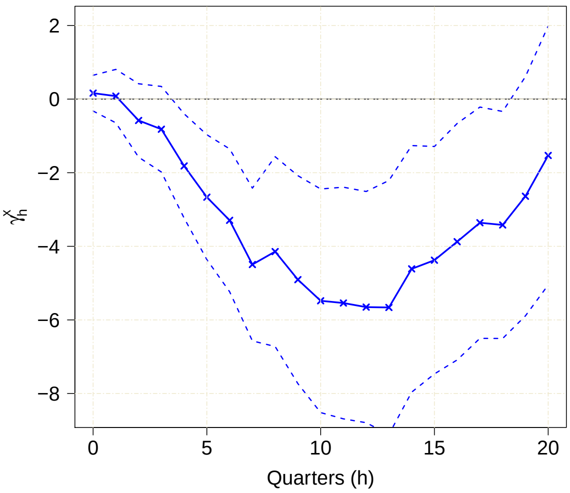
(d) $x = -$liquid asset ratio, joint

Figure B.3: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings in separate and joint regressions with SIC 3-digit industry-quarter fixed effects

Notes: Point estimates and 95% confidence intervals for γ_h^x from estimating specification (1), with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d), and $d_{n,h,t+h}$ constructed based on SIC 3-digit industries. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.



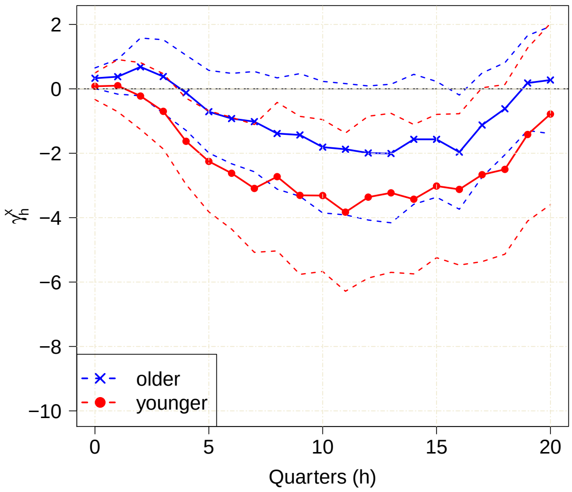
(a) x = leverage, separate



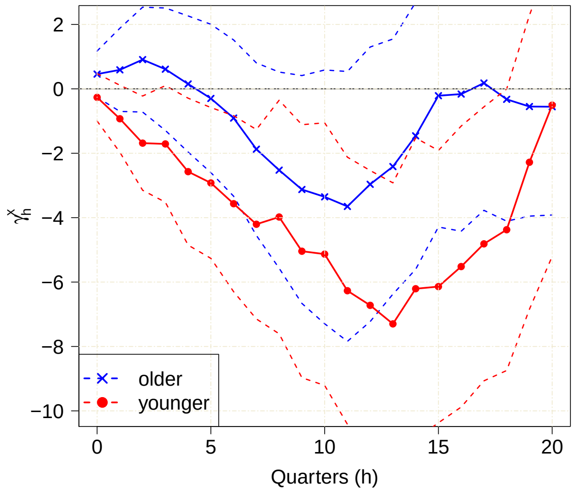
(b) $x = -$liquid asset ratio, separate

Figure B.4: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings in separate regressions, dropping firms with permanently high or low x

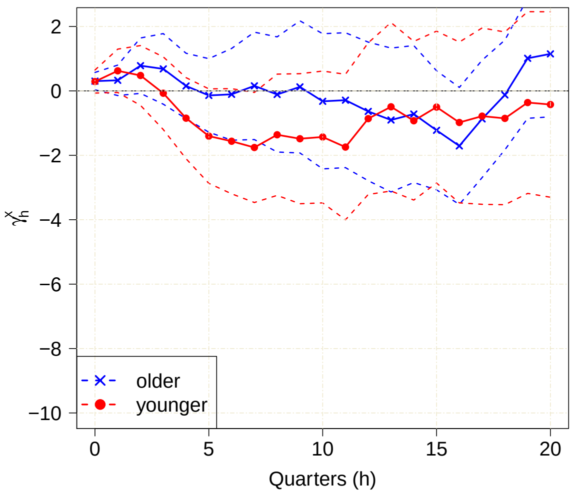
Notes: Point estimates and 90% confidence intervals for γ_h^x from estimating specification (1), with $\mathcal{X}^s = \{x\}$. The sample for estimating γ_h^x only includes firms which have been both above and below the cross-sectional median of x, at any point between 1990Q1–2007Q4. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.



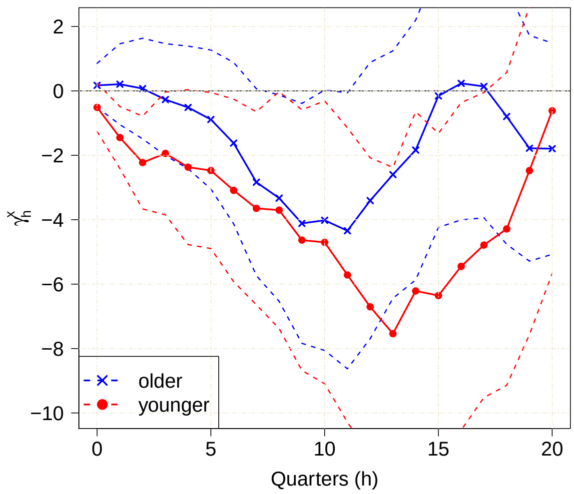
(a) $x =$ leverage, separate



(b) $x = -$liquid asset ratio, separate



(c) $x =$ leverage, joint



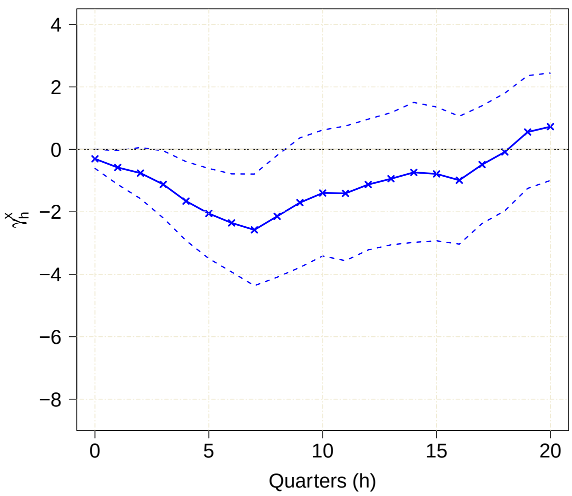
(d) $x = -$liquid asset ratio, joint

Figure B.5: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings in separate and joint regressions, by age

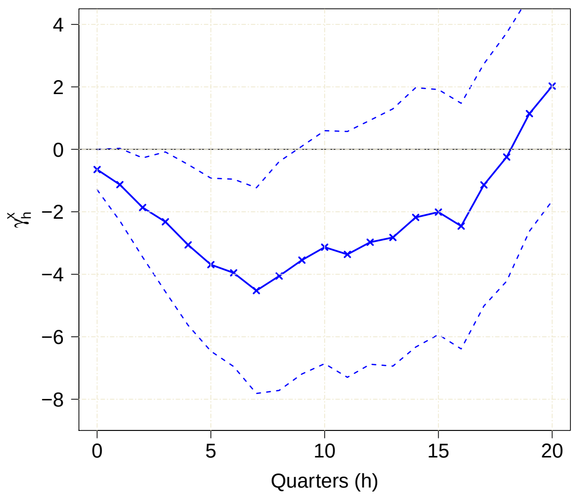
Notes: Point estimates and 95% confidence intervals for $\gamma^x_{h,o}$ and $\gamma^x_{h,y} \equiv \gamma^x_{h,o} + \gamma^x_{h,d}$ from estimating:

$$\begin{aligned}\Delta_h \log(k_{i,t+h}) =& f_{i,h} + d_{n,h,t+h} + \left(\Theta'_h + \varepsilon^m_t \Omega'_h\right) W_{i,t-1} + \\ &+ \sum_{x \in \mathcal{X}^s} \left[\beta^x_{h,o} + \gamma^x_{h,o}\varepsilon^m_t + \left(\beta^x_{h,d} + \gamma^x_{h,d}\varepsilon^m_t\right) \mathbb{1}^y_{i,t-1}\right] x_{i,t-1} + u_{i,h,t+h}\end{aligned}$$

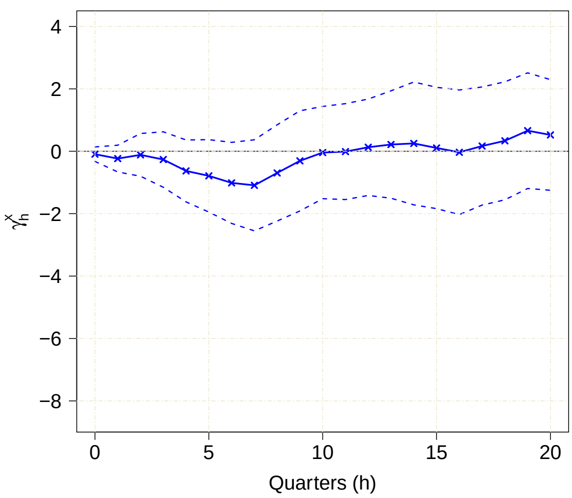
with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d), $W_{i,t} = [\log(\text{size}_{i,t}), \mathbb{1}^y_{i,t}]$. $\mathbb{1}^y_{i,t}$ is an indicator function that equals 1 if less than 15 years have passed since firm i's incorporation by quarter t. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.



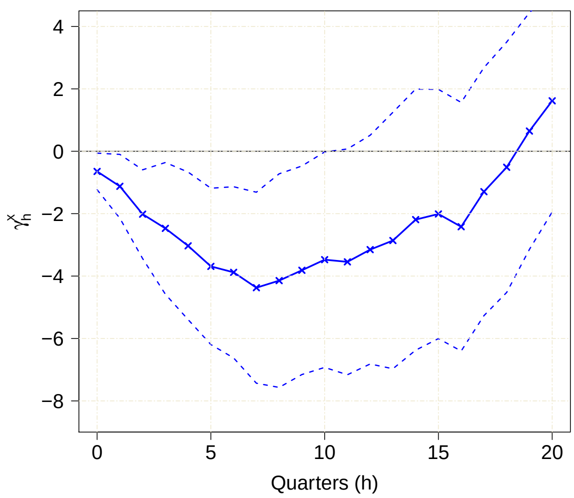
(a) x = leverage, separate



(b) x = −liquid asset ratio, separate



(c) x = leverage, joint



(d) x = −liquid asset ratio, joint

Figure B.6: Heterogeneity in responses of capital accumulation conditional on leverage and liquid asset holdings in separate and joint regressions with Romer and Romer (2004) shocks

Notes: Point estimates and 95% confidence intervals for γ_h^x from estimating specification (1), with $\mathcal{X}^s = \{x\}$ (a,b) and $\mathcal{X}^s = \mathcal{X}$ (c,d). Shocks ε_t^m constructed based on the Romer and Romer (2004) method. Confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

B.6 Vector Autoregression Estimation of Monetary Policy Shocks

To estimate the dynamic behavior of the policy rate and firms' borrowing rates in response to a monetary policy shock, I employ a structural VAR model in the market interest rates of main interest.

As for the dynamic panel regressions in Section 2, I identify the effects of structural monetary policy shocks in the VAR using as external instruments the high-frequency changes in the current month's fed funds futures prices.[76] The estimation approach builds on the methods developed by Stock and Watson (2012) and Mertens and Ravn (2013), and more specifically, the VAR specification and identification closely follows the work of Gertler and Karadi (2015). For more details on the structure of the VAR and the identification method, see Gertler and Karadi (2015) or the discussion in Jeenas (2018).

As Gertler and Karadi (2015), I make the distinction between the policy *indicator* and the policy *instrument*. The instrument of monetary policy is the current period short-term interest rate, which in the U.S. is the federal funds rate. However, as over time the conduct of monetary policy has started increasingly relying on forward guidance, the effects of which one would like the VAR to capture, one can use as the monetary policy indicator a government rate of a longer maturity than the policy instrument. Movements in such a policy indicator reflect both changes in the current funds rate and in the expectations about the future path of the funds rate.

To focus the estimation on the period under consideration in the empirical analysis of Section 2, I estimate the VAR using data only from the period of 1990Q1–2007Q4. To avoid overfitting, I include three key variables of importance, and consider lags up to $p = 2$. The aggregate series I include in the VAR are a monetary policy indicator, a measure of credit spreads, and a measure of price inflation. More specifically, as the policy indicator r^f I use the one-year Treasury constant maturity rate, as reported by the Federal Reserve Board. As the measure of credit spreads $r^b - r^f$ I employ the Gilchrist and Zakrajšek (2012) excess bond premium. For price inflation I use the log-growth in the seasonally adjusted consumer price index as reported by the BLS.

Figure B.7 presents the impulse responses and 95% confidence bands to a one standard deviation contractionary monetary policy shock as identified by the weighted external instruments $\bar{\varepsilon}_t^m$ constructed from current month federal funds futures price data.[77] The shock induces an approximately 30bp increase in the one-year rate which then slowly reverts to pre-shock levels after increasing slightly, reminiscent of the behavior of the fed funds rate in conventional monetary VARs such as estimated Christiano et al. (2005). As found by Gertler and Karadi (2015), the contractionary monetary shock causes a temporary yet persistent worsening of financial conditions evident in the heightened level of the excess bond premium. There are no statistically significant responses in price inflation, supporting the idea of disregarding inflation

[76]More specifically, like Gertler and Karadi (2015), I use weighted quarterly instruments of monetary policy shocks $\bar{\varepsilon}_t^m$ which take into account the exact time of realization within a quarter. The weighted measures tend to perform as slightly stronger instruments in the first stage regression of the VAR and they can be used because the identification assumptions for a VAR are weaker than those in local projections – see Stock and Watson (2018) for a discussion. See Jeenas (2018) for more detail on the construction of the weighted instruments.

[77]As Mertens and Ravn (2013) and Gertler and Karadi (2015), I use wild bootstrap to construct confidence bands valid under heteroskedasticity and strong instruments.

fluctuations in my study of the effects of monetary policy shocks. Scaling the responses so that the impact effect on the policy rate is 25 bp forms the basis for constructing borrowing and lending rate paths which agents in the model face after a monetary policy contraction. Following the discussion in Section 4.2.1, the resulting paths can be seen in Figure B.8.

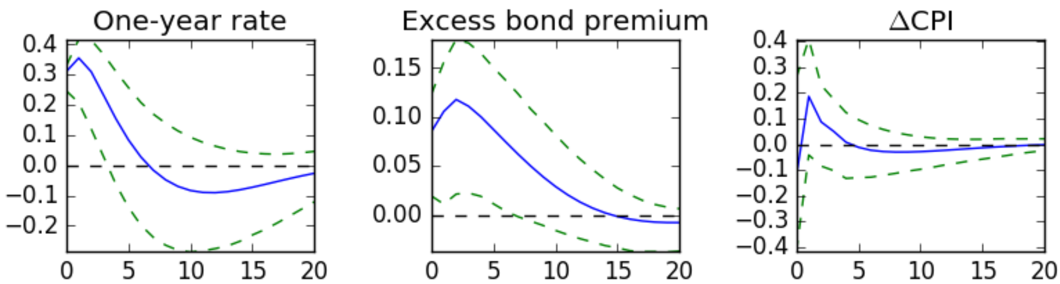


Figure B.7: Aggregate impulse responses to 1 sd monetary policy shock from 3-variable VAR
Notes: All in percentages, annualized. Horizontal axis: quarters after monetary shock. 95% confidence intervals from wild bootstrap.

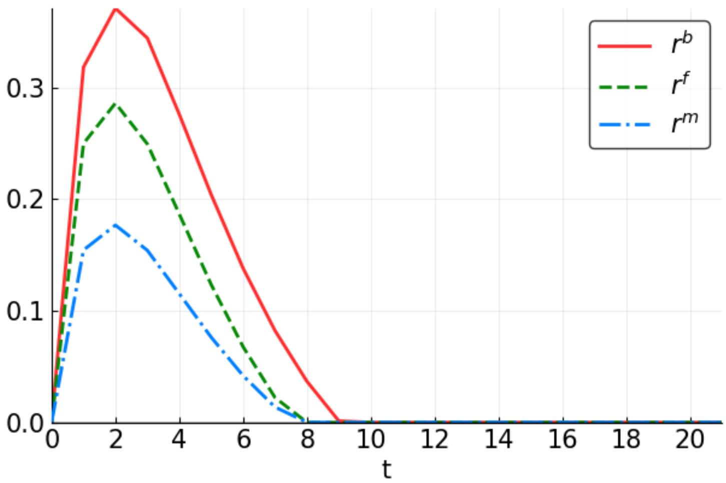


Figure B.8: Paths for the real borrowing rate, lending rate, and the reference policy rate along the monetary policy shock experiment path; in annualized percentage point deviations from steady state value