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Corporate Investment and Cash Holdings under Financing Shocks

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Abstract

This paper investigates the extent to which corporate cash holdings protect firms from the adverse consequences of shocks to their borrowing cost. It develops a dynamic model of corporate investment and financing decisions subject to real and financial frictions. The calibrated model matches the substantial levels of corporate cash holdings across the firm size distribution and replicates the untargeted negative relationship between firm size and investment rates and cash holdings. Cash holdings help firms sustain investment when access to debt becomes costly or restricted. However, a shock to corporate borrowing conditions resembling the one seen in the Global Financial Crisis can significantly contract aggregate investment, especially by firms with lower cash holdings. These results highlight the capacity of shocks to corporate credit spreads to cause economic contractions, even in a context where firms hold cash buffers with the purpose of self-insuring against such shocks.

Resume

Dette working paper undersøger, i hvilken udstrækning virksomhedernes kontantbeholdninger beskytter dem mod stigende låneomkostninger. I working paper udvikles en dynamisk model for virksomhedernes investeringer og finansieringsbeslutninger, der tager højde for finansielle friktioner. Den kalibrerede model er i stand til at forklare de betydelige kontantbeholdninger på tværs af virksomheder samt at replikere det negative forhold mellem virksomhedernes størrelse, investeringer og kontantbeholdninger. Kontantbeholdninger kan bidrage til, at virksomhederne opretholder deres investeringer, når adgangen til gældsfinansiering bliver dyr eller begrænses. Dog kan væsentlige forringelser af virksomhedernes lånevilkår, som set under den globale finanskrise, betyde lavere aggregeret investeringsaktivitet, i særdeleshed for virksomheder med mindre kontantbeholdninger. Disse resultater viser, hvordan stød til virksomhedernes kreditspænd kan medføre nedgang i den makroøkonomiske aktivitet, selv i tilfælde hvor virksomhederne holder kontanter for at sikre sig mod konsekvenserne af sådanne økonomiske stød.

Key words

Refinancing risk; Risk management

JEL classification

G31; G32

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The author alone is responsible for any remaining errors.

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This paper investigates the extent to which corporate cash holdings protect firms from the adverse consequences of shocks to their borrowing costs. It develops a dynamic model of corporate investment and financing decisions subject to real and financial frictions. The calibrated model matches the substantial levels of corporate cash holdings across the firm size distribution and replicates the untargeted negative relationship between firm size and investment rates and cash holdings. Cash holdings help firms sustain investment when access to debt becomes costly or restricted. However, a shock to corporate borrowing conditions resembling the one seen during the Global Financial Crisis can significantly contract aggregate investment, especially by firms with low cash holdings. These results highlight the capacity of shocks to corporate credit spreads to cause economic contractions, even in a context where firms hold cash buffers with the purpose of self-insuring against such shocks.

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1 Introduction

A common approach in the macroeconomic analysis of firms' investment under financial constraints is the focus on net debt, which entails the consideration of cash holdings as negative debt. However, Eisfeldt and Muir (2012) document that many firms simultaneously raise external funds and build up cash buffers, thereby raising questions about this common assumption. In fact, corporate cash holdings have been growing among US corporations during the last decades and are important across all firm size categories, and especially so for small firms (Figure 1). Evidence in Gilchrist and Zakrajšek (2012) documents the existence of shocks to corporate credit spreads not directly attributable to changes in credit risk and with an important impact on aggregate corporate investment. This paper investigates whether cash holdings can effectively protect firms against such shocks.

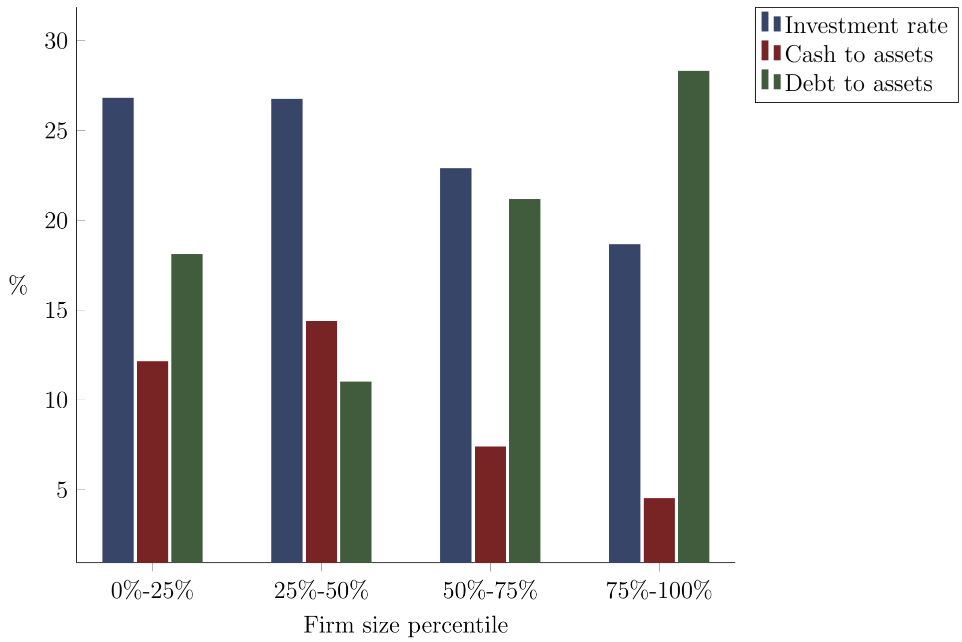

Figure 1: Investment and financing patterns by firm size

This figure presents median investment rates (left), cash ratios (middle) and leverage ratios (right) for the period 1980-2015 across four quantiles of the firm size distribution. Firm size is measured by total assets. Moments are based on non-financial, non-utility US firms in the annual Compustat database.

To this end, I develop a dynamic model of corporate investment and financing decisions in which cash holdings allow firms to smooth away shocks to their cost of external funding. This makes the model consistent with recent surveys of American and European CFOs, which document that investment by firms with ample cash buffers is less sensitive to changes in their borrowing costs (Sharpe and Suarez, 2015). After calibrating the model and showing its capacity to reproduce targeted and untargeted patterns in the data, I use it to evaluate the capacity of equilibrium cash buffers to help absorb a shock to external funding costs of the size observed during the Global Financial Crisis (GFC) of 2007-2009.

In the model, firms can draw on accumulated savings, sell capital and raise debt to finance payouts to shareholders and profitable investment opportunities, if they arise. While investment in physical capital is subject to adjustment costs, debt funding is limited by a collateral constraint and has a cost that varies over time. The variation in borrowing costs provides firms with incentives to build up liquidity buffers which can be used when the access to external debt funding becomes more costly. However, the insurance provided by the accumulated cash holdings comes at the cost of sacrificed dividends and/or larger leverage.

I calibrate the model to aggregate and microeconomic data so as to match key moments related to the investment and financing behavior of US firms in the Compustat database. Shocks to funding costs are calibrated to replicate the time-series variation in US average corporate credit spreads. The calibrated model reproduces untargeted relationships between firm size, leverage and investment such as those illustrated in Figure 1. Specifically, it generates investment rates and cash holdings that decline with firm size, as in the data. In the context of the model, small firms have persistent and more profitable investment opportunities. Due to the presence of convex capital adjustment costs firms prefer to smooth investment over time. Financial frictions hamper firms' ability to rely on debt to finance investment, especially in the case of small firms that lack net worth to finance it internally. The coexistence of real and financial frictions thus makes cash holdings especially valuable for small firms.[1]

[1]Relative to the workhorse model of firm dynamics by Khan and Thomas (2013), my model rationalizes the concurrent high investment and savings rates of small firms relative to their large counterparts. This makes the model consistent with evidence by Opler et al. (1999) and Bates, Kahle and Stulz (2009), who document that firms with low leverage and high cash ratios tend to be small, young, have little earnings, pay less dividends and be more likely to be financially constrained.

I use the model to assess the extent to which cash holdings help firms accommodate aggregate shocks to the cost of external financing and, as a result, reduce the implications of such shocks for aggregate investment. Equilibrium cash holdings provide some protection against financing shocks, but they are insufficient to shield the economy from the contractive implications of an aggregate shock to financial conditions such as that seen in the GFC. Aggregate investment contracts significantly and especially so among firms with lower liquidity buffers. These results are consistent with the mounting empirical evidence on the role of rises in corporate credit spreads in causing or amplifying economic contractions (Gertler and Lown, 1999; Gilchrist and Zakrajšek, 2012; Faust et al., 2013). Specifically, the analysis shows the capacity to generate such effects in a context where firms can hold cash buffers with the purpose of self-insuring against these shocks.

Related literature. This paper is related to several strands of the literature. One of these strands develops quantitative models of corporate investment and financing decisions in the presence of financial frictions. Relevant contributions include Gomes (2001), Cooley and Quadrini (2001), Cooley and Quadrini (2006), Khan and Thomas (2013), Gilchrist, Sim and Zakrajšek (2014), Crouzet (2017), Begenau and Salomao (2018), Xiao (2018), and Bacchetta, Benhima and Poilly (2019). The impact of financial shocks on firms' investment and financing decisions was emphasized by Jermann and Quadrini (2012), who show that financial shocks (combined with productivity shocks and financial frictions) are necessary to explain the observed cyclical movements in external financing. Financial shocks also play a role in the models of Eisfeldt and Muir (2012), Bolton, Chen and Wang (2011), and Eisfeldt and Muir (2016), who consider stochastic financing opportunities, in Hugonnier, Malamud and Morellec (2014), who consider credit supply shocks, and in González-Aguado and Suarez (2015), who consider changes in the short-term, risk-free interest rate. I contribute to these studies by allowing for cash holdings and exploring their capacity to smooth (but not fully remove) the impact of external funding cost shocks on aggregate investment.

The modeling of firm financing and investment decisions that I adopt is similar to that found in the dynamic corporate finance literature by Hennessy and Whited (2007), Gamba and Triantis (2008), Riddick and Whited (2009), Bazdresch (2013), and Nikolov and Whited (2014), among others. Models in this tradition have been used to reproduce salient features of the cross-sectional distribution and dynamic evolution of firms' financial ratios. Relative to the existing contributions, my analysis shows that the savings motive generated by time-varying credit spreads can help to match the high cash ratios observed in the data and their heterogeneous distributions across firm size buckets, an objective that calibrations of existing models that allow for cash holdings struggle with (Riddick and Whited, 2009).

The rising importance of corporate cash holdings among US firms has attracted the attention of numerous, mainly empirical papers, in recent years.[2] Generally, the empirical literature attributes the growth in corporate cash holdings to the rise in the cash flow risks faced by firms (Comin and Philippon, 2005; Bates, Kahle and Stulz, 2009; Boileau and Moyen, 2016). Bates, Kahle and Stulz (2009) additionally highlight that, since the 1980s, firms tend to go public with higher cash ratios, although this feature is not sufficient to explain the overall rise in cash holdings. They also emphasize the pronounced rise in cash holdings among smaller firms. Begenau and Palazzo (2017) and Falato, Kadyrzhanova and Sim (2018) argue that this is concentrated among firms that heavily invest in research and development (R&D) and intangible assets, and Denis and McKeon (2018) show that the increase in average cash ratios is concentrated among firms reporting negative operating cash flows.

My modeling of firms' precautionary cash holdings is consistent with recent work by Joseph et al. (2019), who document that firms benefit from a liquid balance sheet, especially when aggregate credit conditions worsen. They show that cash holdings allow firms to expand investment and increase market share over cash-poor competitors who become more financially constrained, both upon impact of the credit shock and in the subsequent recovery.

Eisfeldt and Muir (2016), Jeenas (2018), and Nikolov, Schmid and Steri (2019) develop

[2] See Denis (2011) for a review of the literature of corporate liquidity management and Acharya, Almeida and Campello (2007) for a seminal treatment on why cash is not negative debt in a simple three date setup.

dynamic quantitative models focused on corporate cash holdings. Jeenas (2018) analyzes the effect of monetary policy shocks on corporate investment, aiming to reproduce the empirically documented fact that firms with higher cash holdings are less responsive to such shocks. He extends a model à la Khan and Thomas (2013) to introduce long-term debt whose issuance involves a fixed cost. The model rationalizes cash holdings as a means to avoid having to adjust the level of long-term debt too frequently and successfully reproduces the lower responsiveness to monetary policy shocks of firms caught with higher cash holdings. My alternative approach shows that it is possible to rationalize cash holdings without resorting to fixed cost whose empirical counterpart is controversial (as leading issuance costs such as investment banking fees or underpricing due to adverse selection seem closer in nature to a variable or even proportional cost than to a fixed cost).

Nikolov, Schmid and Steri (2019) focus on understanding the role of credit lines as an alternative to cash holdings. The rationale for liquidity management arises due to an exogenous cost for obtaining external financing, but the authors do not check the capacity of their model to reproduce the distribution of cash holdings, leverage ratios and investment ratios across firms (for which, as my analysis reveals, taking account of firms' entry and exit turns out to be key), or the implications of shocks to the cost of external financing.

Eisfeldt and Muir (2016) combine their model with data on the coincidence of firms raising external funds and increasing cash to infer the aggregate cost of external finance. They illustrate that, compared to a model with a constant cost of raising external funding, introducing a stochastic cost component helps to match aggregate financing and saving patterns. Contrary to their approach, I focus on the distribution of investment, cash, and leverage across the firm size distribution, and the impact of shocks to financing cost on aggregate investment.

Structure of the paper. The rest of the paper is organized as follows. Section 2 presents the dynamic model of firm investment and financing decisions subject to real and financial frictions. Section 3 describes the calibration approach and discusses the fit of the calibrated model to the empirical target moments. Section 4 presents the numerical results of the model, starting with an illustration of firms' decision rules followed by an analysis of the model's steady state. Counterfactual exercises highlight the interaction between financial frictions and liquidity management. Section 4 ends by simulating the economy's response to an aggregate shock to corporate borrowing cost. Section 5 provides concluding remarks. Appendix A presents additional details on the model, Appendix B elaborates on the data set, Appendix C explains the numerical approach, and Appendix D discusses additional evidence on the variation in corporate credit spreads.

2 Model

This section describes a model of firm investment and financing decisions subject to real and financial frictions. Time is infinite, discrete, and indexed by t. A continuum of risk-averse firms i invest in physical capital, hold cash and borrow to maximize the discounted value of dividend streams in a perfectly competitive environment. Due to the time-varying cost of debt finance, firms benefit from the availability of cash to fund investment opportunities and dividend payments. Firms are born identical in size but face different idiosyncratic shocks throughout their lives, thereby becoming heterogeneous. At the beginning of each period, a constant fraction of firms is forced to exit the economy and replaced by an equal mass of entrants. In order to describe firms' optimization problem, I focus on a single firm and omit indexing variables with the firm identifier i.

2.1 Individual firm's problem

The firm is run by risk-averse owners who aim to maximize the discounted lifetime utility from dividends d_t. The preferences of the firm's owners over dividend payments are described by:

$$u(d_t) = \frac{d_t^{1-\sigma}}{1-\sigma}, \tag{1}$$

where σ is a parameter governing the owners' risk aversion and intertemporal elasticity of substitution. The utility of future dividend streams is discounted with the factor $\beta \in (0,1)$.

Technology and investment. The firm produces a final consumption good using capital as its only input. The production technology is described by $y_t = z_t k_t^{\alpha}$, where

$\alpha \in (0,1)$ controls the degree of returns to scale and k_t denotes the firm's capital stock at the time of production. The variable z_t reflects shocks to demand, input prices or productivity faced by the firm and follows an AR(1) process in logs:

$$log\left(z_t\right) = \mu + \rho_z \log\left(z_{t-1}\right) + \epsilon_t, \quad \epsilon_t \sim N\left(0, \sigma_z^2\right). \tag{2}$$

The parameter ρ_z governs the persistence of the process and satisfies $\rho_z \in (0,1)$.

The firm's capital stock evolves over time as a consequence of investment and disinvestment decisions. The law of motion is given by:

$$k_{t+1} = i_t + (1-\delta)\, k_t, \tag{3}$$

where i_t denotes investment and $\delta \in (0,1)$ is the depreciation rate.

The firm purchases and sells capital at a price of one but is subject to a convex capital adjustment cost as in the neoclassical literature (Abel et al., 1996; Hayashi, 1982):

$$\Psi\left(k_{t+1}, k_t\right) = \frac{\psi}{2}\left(\frac{i_t}{k_t}\right)^2 k_t = \frac{\psi}{2}\left(\frac{k_{t+1} - (1-\delta)\, k_t}{k_t}\right)^2 k_t, \tag{4}$$

where ψ is a parameter governing the severity of the adjustment cost.

Financing and liquidity. The firm uses internally generated cash flows, undepreciated capital, available cash and debt to finance physical capital, cash holdings and dividend payouts. The financial frictions laid out below imply that the ideal conditions of the Modigliani-Miller theorem, under which capital structure decisions are irrelevant, do not hold.

Cash consists of liquid, one-period zero-coupon bonds that trade at a price of $1/R$, where R is the safe interest rate. The face value of the liquid bonds the firm acquires at time t is denoted c_{t+1}. Firms cannot borrow using cash, effectively facing the constraint $c_{t+1} \geq 0$.

All external finance takes the form of safe, one-period zero-coupon corporate bonds. External financing is subject to two financial frictions. The first financial friction is a debt limit that ties the firm's borrowing to its physical capital; based on the idea of limited enforceability of financial contracts I assume that the face value of the firm's repayment obligations at $t+1$ must be less than or equal to a fraction θ of the physical capital with which the firm operates in that period, k_{t+1}:

$$b_{t+1} \leq \theta k_{t+1}, \tag{5}$$

where θ captures financial frictions that affect all firms equally. The constraint is an occasionally binding one in this environment. The specification of the collateral constraint is forward-looking in the spirit of Kiyotaki and Moore (1997), but abstracts from the asset price channel (since the price of capital is assumed to be one at all dates). In the calibrations considered below, the loan-to-value (LTV) parameter θ is low enough to guarantee that the firm can always repay all of its debt by liquidating its undepreciated capital. Firms cannot save through corporate bonds, i.e. they face the constraint $b_{t+1} \geq 0$.

The second financial friction affects the cost of corporate debt. The borrowing rate paid by the firm is $\eta_t R$ with $\eta_t \geq 1$. I specify η_t as a two-state Markov chain with realizations $\eta^L = 1$ and $\eta^H > 1$ and a time-invariant transition probability matrix $Q = \{q^{ij}\}_{i=L,H}^{j=L,H}$ where $q^{ij} = Pr\left(\eta_{t+1} = \eta^j | \eta_t = \eta^i\right)$. The shock η_t captures the idea that firms can have varying degrees of access to debt markets. In particular, if the firm does not face a credit shock ($\eta_t = 1$), it can raise debt at the risk-free rate. Instead, if the firm experiences an adverse credit shock ($\eta_t = \eta^H$), it pays lenders a premium over the risk-free rate.[3] In the transition matrix, q^{LL} is the probability of continuing to borrow at the risk-free rate, while $1-q^{HH}$ is the probability of escaping from the costly borrowing state.

In every period the firm uses its realized profits $z_t k_t^{\alpha}$, undepreciated physical capital $(1-\delta)k_t$ and current cash holdings c_t net of loan repayments b_t along with borrowed funds b_{t+1} to finance dividend payouts d_t, capital k_{t+1} along with the associated adjustment cost

[3] The corresponding credit spread can be written as $R\left(\eta_t - 1\right)$, which is positive if $\eta_t = \eta^H$.

$\Psi(k_{t+1}, k_t)$ and cash holdings c_{t+1}. The firm's budget constraint therefore reads:

$$z_t k_t^\alpha + (1-\delta)k_t + c_t - b_t + \frac{b_{t+1}}{\eta_t R} = d_t + k_{t+1} + \Psi(k_{t+1}, k_t) + \frac{c_{t+1}}{R}. \tag{6}$$

Firm exit. Each firm entering period t faces a constant probability $\gamma \in (0,1)$ of being forced to exit the economy before production takes place. Exiting firms liquidate their capital stock, repay lenders and pay out all remaining funds to their owners.[4] I denote the terminal dividend paid by exiting firms as:

$$e_t = (1-\delta)k_t + c_t - b_t. \tag{7}$$

Firm's net worth. A surviving firm takes a series of actions to maximize the expected discounted value of dividends returned to its owners, accounting for their possible exit in future periods. The firm undertakes intertemporal decisions on its capital stock for the next period, k_{t+1}, the level of cash and debt with which it will enter into the next period, c_{t+1} and b_{t+1}, respectively, and current dividends d. However, current levels of cash and debt do not separately affect the firm's choices of $(k_{t+1}, c_{t+1}, b_{t+1}, d_t)$ due to the absence of any financial adjustment costs in the model. Therefore I can collapse the two continuous individual state variables for debt and cash into a newly defined variable called net worth, m_t.[5] A surviving firm's net worth at the beginning of period t is the available resources after the realization of the productivity shock z_t and subsequent production:

$$m_t = z_t k_t^\alpha + (1-\delta)k_t + c_t - b_t. \tag{8}$$

In other words, current resources available to the firm are realized output, undepreciated physical capital and current cash holdings net of loan repayments. Notice that the decisions of k_{t+1}, b_{t+1} and c_{t+1}, along with the realization of z_{t+1}, determine the level of net worth in the next period $m_{t+1}(k_{t+1}, c_{t+1}, b_{t+1}, z_{t+1})$.

[4] Firms exiting the economy before production is consistent with the exit shock representing a zero-productivity state that is equally likely for all firms, regardless of their previous productivity. Allowing firms to consume their production upon exit does not affect the model's results significantly.

[5] We could simply collapse cash holdings and debt into the commonly used "net debt" variable. However, as highlighted by Nikolov, Schmid and Steri (2019), having capital and net worth as separate state variables proves useful for empirical work.

Timing and dynamic firm problem. At the beginning of each period t, the state of the firm is defined by its predetermined stock of capital, $k_t \in \mathbb{K} \subset \mathbb{R}_+$, the level of cash holdings, $c_t \in \mathbb{C} \subset \mathbb{R}$, the amount of debt carried over from the previous period, $b_t \in \mathbb{B} \subset \mathbb{R}$, the current idiosyncratic productivity level, $z_t \in \mathbb{Z} \subset \mathbb{R}_+$ and the idiosyncratic borrowing state $\eta_t \in \{1, \eta^H\}$. With probability γ, the firm is forced to exit the economy before production takes place, at which point the problem of the firm terminates. If, instead, the firm is not forced to exit, it produces output according to its predetermined capital stock and the current productivity level. After production takes place, the net worth of the surviving firm is $m_t \in \mathbb{M} \subset \mathbb{R}_+$. The idiosyncratic state of the surviving firm can thus be described as $\mathbf{s_t} = (k_t, m_t, z_t, \eta_t)$.

Figure 2 summarizes the timing of the model in a given period. To enhance readability, throughout the rest of this paper I denote current period variables without a time subscript and future period variables with a prime.

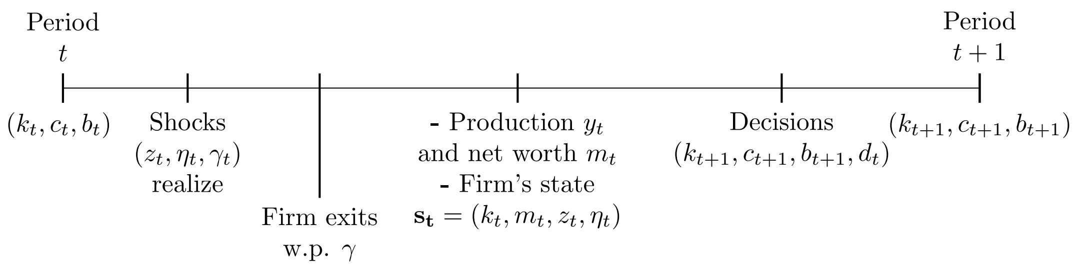

Figure 2: The sequence of events within a period

Given the firm's idiosyncratic state $\mathbf{s} = (k, m, z, \eta)$, denote the continuation value by $V(\mathbf{s})$. The real and financial decisions of a surviving firm, (k', c', b', d), aim to maximize the continuation value of the firm to its owners, which can be recursively written as:

$$
\begin{aligned}
V(\mathbf{s}) = \max_{k',c',b',d} \{u(d) + \beta\left((1-\gamma)\mathbb{E}\left[V(\mathbf{s}')\right] + \gamma\mathbb{E}\left[u(e')\right]\right)\} \\
m + \frac{b'}{\eta R} = d + k' + \Psi(k', k) + \frac{c'}{R} \\
e' = (1-\delta)k' + c' - b' \\
b' \leq \theta k' \\
c', b' \geq 0
\end{aligned}
\tag{9}
$$

The firm's optimization problem is subject to the capital accumulation constraint (3), the collateral constraint (5), the budget constraint (6) and the non-negativity constraints on new borrowing and cash holdings.

2.2 Aggregation and ergodic distribution

Because there is a continuum of firms that are subject to idiosyncratic shocks, there is a cross-sectional distribution Γ of firms over the state $\mathbf{s} = (k, m, z, \eta)$. The evolution of the distribution of firms over time is affected not only by shocks to firms' productivity and borrowing costs but also by entry and exit. At the beginning of each period, a share γ of firms is forced to exit the economy exogenously. An equal mass of new entrants replaces exiting firms, keeping the mass of active firms in the economy constant over time. The entrants replacing the exiting mass γ of incumbents at time t enter the period with an initial capital stock k_0, a calibrated parameter, and neither debt nor cash. Their initial levels of persistent productivity and borrowing condition are drawn from the respective ergodic distributions. When the distribution of firms remains constant over consecutive periods, $\Gamma' = \Gamma = \Gamma^*$, I call Γ^* the ergodic distribution.

2.3 Analyzing the firms' problem

In this section, I discuss how the shock to borrowing cost creates the demand for cash holdings at the firm level. To finance physical capital and dividend payouts in any period t, a firm has three options: it can sell part of its capital k brought into the period, draw on cash holdings built up in the previous period c, or issue debt b'. These three options are thus alternative sources of liquidity. Because selling capital is costly due to the capital adjustment cost, it is an inefficient source of liquidity. Therefore, the accumulation of cash and raising debt are the two main alternatives in providing liquid funds.

If the model featured no shock to the cost of borrowing, meaning $\eta^H = 1$, cash would be indistinguishable from "negative debt". In this version of the model equivalent borrowing and saving positions offset each other, meaning that firms have no incentive to borrow and save simultaneously. This is the assumption underlying traditional models of corporate finance and firm dynamics (see e.g. Khan and Thomas (2013)). In this setting firms rely on new debt issuances to raise liquidity when it is needed.

In the model presented in Section 2, however, the presence of financial frictions distinguishes cash from negative debt and gives cash buffers an important role in firms' liquidity management. The shock to external funding cost drives a wedge between firms' borrowing rate and the return on their savings. Consequently, when firms have to pay a positive credit spread, raising debt to provide liquidity is dominated by the alternative of drawing on outstanding cash balances. The prospect of such future states, characterized by high liquidity needs and insufficient collateral or costly access to external funds, gives value to holding cash. By anticipating borrowing when it is cheap and saving some of the proceeds in cash, firms can effectively self-insure against these states. Corporate liquidity management decisions are thus inherently dynamic and intimately related to capital structure decisions.

Since a significant share of firms' available funds is used to finance physical capital, this precautionary motive for cash holdings is especially strong in anticipation of future investment spending. The presence of capital adjustment cost and the persistence of productivity both amplify the precautionary demand for cash. A firm with ample current investment opportunities has to grow slowly towards its optimal scale of operations due to the real friction. In addition, the firm is likely to stay profitable in the future due to the persistent productivity shocks. Both of these effects make cash especially valuable for growing firms.

Keeping this trade-off between cash and debt as sources of liquidity in mind, I continue with a discussion of the firms' optimality conditions for capital accumulation, cash holdings and borrowing. Combining the first order conditions with the envelope conditions enhances the understanding of firms' behavior, as long as their optimal decisions are interior solutions to the dynamic problem presented in (9). To enhance readability I abstract from the non-negativity constraints on borrowing and savings and focus on the special case in which γ is set to zero. The formal derivation of the full set of optimality conditions is relegated to Appendix A.1. Denoting the Lagrange multiplier on the borrowing constraint by μ, the optimality conditions with respect to k', b' and c' are:

$$\mathbb{E}\left[\Lambda\left(f_k' + (1-\delta) + \frac{\psi I'}{k'}\left[\frac{I'}{2k'} - \frac{k''}{k'}\right]\right)\right] + \frac{\mu\theta}{d^{-\sigma}} = 1 + \psi\frac{I}{k} \tag{10}$$

$$E\left[\Lambda\right] + \frac{\mu}{d^{-\sigma}} = (\eta R)^{-1} \tag{11}$$

$$E\left[\Lambda\right] = R^{-1} \tag{12}$$

where $\Lambda \equiv \beta(d'/d)^{-\sigma}$ denotes the firm's stochastic discount factor and f_k is the marginal product of capital.

Equation (10) states that the firm equates the marginal benefit of installing an additional unit of capital (LHS) to its marginal cost (RHS). The payoff to increasing capital is: a marginal increase in output, some depreciated capital, and an adjustment cost to investment consideration (which says if you expect investment to be high tomorrow, there is a benefit to increasing capital today since you avoid large convex cost of investment tomorrow). The marginal cost of increasing investment is given by the unit cost of capital plus the associated adjustment cost. The presence of the Lagrange multiplier μ indicates that capital derives additional value because it relaxes the borrowing constraint.

Equation (11) states that the marginal benefit of raising an additional unit of debt today (RHS) equals its expected cost (LHS). Raising an additional unit of debt generates $(\eta R)^{-1}$ units of funds today, an amount that is increasing in the borrowing shock η. The marginal cost associated with raising debt today comes in the form of reducing available funds in the future by one, the repayment burden associated with the zero-coupon bond. Additionally, the presence of the Lagrange multiplier μ indicates that the marginal cost is higher when the firm bumps up against its collateral constraint, that is, exhaust its debt capacity.

Lastly, equation (12) shows that the marginal benefit of saving an extra unit of cash today is simply the discounted expected value of having an additional unit of funds tomorrow.

2.4 Discussion of key assumptions

This section discusses the implications of and rationale behind some of the key modeling assumptions made.

Exogenous exit of firms. The introduction of an exogenous exit rate serves two purposes. First, it allows the model to match several features of the cross-sectional distribution of firms by replacing old, mature firms with new incumbents. Second, it effectively makes firms more impatient than lenders and implies that firms keep rolling over debt as they accumulate internal funds in order to finance dividend payouts. This mechanism plays the same role as introducing a tax advantage of debt (e.g. Gomes (2001), Hennessy and Whited (2005)).

Time-varying cost of debt. The introduction of time variation in the cost of raising debt allows the model to generate features of firm-level debt and cash management behavior observed empirically, absent from an analogous model otherwise. The financial shock raises borrowing rates above the interest rate on savings, thus generating a positive credit spread per unit of borrowing. By hampering firms' ability to raise debt, the financial shock introduces a motive to accumulate savings when borrowing is cheap.

The stochastic nature of borrowing cost captures the idea that otherwise similar firms can have varying access to debt at any given point in time due to unmodeled differences in characteristics and the circumstances faced in financial management. The idea of idiosyncratic fluctuations in borrowing rates in the absence of default risk is in line with the "credit spread puzzle" in the corporate finance literature, which shows that less than one-half of the variation in corporate bond credit spreads can be attributed to the financial health of the issuer (Elton et al., 2001). Microfoundations of a time-varying marginal cost include agency frictions that vary over time, along the lines of Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997), and endogenously time-varying adverse selection problems as in Eisfeldt (2004), Kurlat (2013), and Bigio (2015). Other approaches capturing time variation in the cost of debt funding include variation in fixed cost of issuance (Jeenas, 2018), shocks to lenders' recovery rates in default affecting endogenous debt prices (Jermann and Quadrini, 2012) and an adjustment cost to the level of outstanding debt (Gamba and Triantis, 2008).

Utility specification. For the entrepreneurs' utility function I assume a standard CRRA utility function with risk aversion parameter σ. The utility specification implies an intertemporal elasticity of substitution of σ^{-1}, which governs the strength of the intertemporal dividend smoothing motive. Lintner (1956) showed that managers are concerned about smoothing dividends over time, a fact further confirmed by subsequent studies. Importantly, the utility specification also implies that firms are very averse towards small dividend payments. The dividend smoothing motive and aversion to small dividend payments play the same role as dividend adjustment cost combined with a target level of dividends as in e.g. Jermann and Quadrini (2012).

Non-negative dividends. The utility specification implies that firms never choose to raise equity, a common assumption in the macrofinance literature. The assumption captures two key facts about external equity documented in the corporate finance literature. First, firms face significant costs of issuing new equity, both direct flotation costs (Smith Jr et al., 1977) and indirect costs (Asquith and Mullins Jr, 1986). Combined, the costs related to equity issuances are significantly larger than those for debt issuance (Altınkılıç and Hansen, 2000). Second, equity issuance is more infrequent and lumpier than debt issuance for Compustat firms (Bazdresch, 2013; DeAngelo, DeAngelo and Stulz, 2010). Other potential assumptions include proportional costs of equity issuances (Jermann and Quadrini, 2012; Gomes, 2001; Cooley and Quadrini, 2001; Hennessy and Whited, 2005; Gilchrist, Sim and Zakrajšek, 2014) and quadratic costs (Hennessy and Whited, 2007).

Firm-level capital adjustment costs. To generate slow convergence to the optimal firm size implied by the decreasing returns to scale assumption and idiosyncratic productivity, I introduce adjustment costs for capital at the firm level. In the absence of adjustment costs and financial frictions, the firm size distribution would be only determined by firms' idiosyncratic shocks. In other words, adjustment costs, together with financing frictions, generate a more realistic firm size distribution.

The quadratic adjustment cost specification is standard in the literature on investment (Abel et al., 1996) and important for the quantitative implications of the model. The convex nature of the adjustment cost implies that firms smooth out their investment over time. Due to the uncertainty about future borrowing cost, the desire to preserve future investment capacity induces firms to build up cash buffers.

No default. The calibrated collateral constraint parameter θ implies that firms always have sufficient collateral, in the form of physical capital, to repay lenders. Since I abstract from the possibility of strategic default, there is no endogenous link between firms' cost of external funds and their balance sheet position. This assumption removes a key incentive for firms to hold cash: to build resilience against adverse shocks that diminish profits or limit access to external funding and threaten to put the firm in financial distress.

3 Calibration

Because this model does not permit a closed-form solution to the firms' decision problem, I resort to numerical methods. Appendix C provides details on the numerical solution method. To solve the model, I need to assign parameter values. I assume that a time period in the model corresponds to one year. In the calibration of most model parameters, I follow prior work and use parameter values which are commonly used in the literature. For the remaining parameters, central to the mechanisms of interest I employ internal calibration matching moments of the model's stationary equilibrium to empirical targets based on non-financial, non-utility US firms in the Compustat database. Whenever possible, I compute empirical moments based on the period 1980-2015. This sample period is characterized by substantial levels of corporate cash holdings. I provide more details about the sample selection process and the matching between variables in the model to Compustat items in Appendix B.

Externally calibrated parameters. I set the annual risk-free interest rate $R-1$ to 4%, a standard parameter in the literature. Firm owners' discount factor is consequently set to R^{-1}. The parameter determining the firm's risk aversion, σ, is set to 2.[6] For the parameters that govern the AR(1) process for idiosyncratic productivity (TFP), I assume a persistence and volatility level of $\rho_z = 0.70$ and $\sigma_z = 0.23$, as employed by Gourio and Miao (2010). These estimates are based on sales data of Compustat firms.

The next set of parameters governs the life cycle of firms: the annual exit rate γ and k_0, the initial capital stock of new entrants. Following Xiao (2018) I set γ to 0.08, which corresponds to the observed exit rate in the Business Dynamics Statistics (BDS), the public-release sample of statistics aggregated from the Census Longitudinal Business Database (LBD). The parameter implies an expected lifetime of 12.5 years and produces an age distribution that resembles the one in Compustat as reported by Begenau and Palazzo (2017), who proxy firm age by their years since going public. Lastly, I follow Khan and Thomas (2013) and set the size of new entrants k_0 equal to 10% of the average firm's size in the economy.

Internally calibrated parameters. Among the remaining parameters of the model, I choose those governing the borrowing cost shock to directly match key features of (average) US corporate credit spreads as reported by Gilchrist and Zakrajšek (2012). I set the level of the borrowing shock, η^H, so that firms facing the adverse borrowing state pay a credit spread of 7.65%. This corresponds to the average credit spread at the peak of the Global Financial Crisis in Q4-2008 estimated by Gilchrist and Zakrajšek (2012). While this high *average* credit spread was a feature of the financial crisis, Appendix D provides empirical evidence showing that during the last three decades it has not been uncommon for at least a share of US firms to pay such high spreads. Next, I choose the transition probabilities of the borrowing shock, $\left(q^{HH}, q^{LL}\right)$, to match the unconditional mean and volatility of the (average) corporate credit spread over the years 1973-2010.[7]

The remaining parameters of the model are jointly calibrated to match the investment

[6] The assumption of risk-averse firms should not be taken literally given that the model is calibrated to Compustat firms, which are typically large and owned by well diversified shareholders. Instead, as described in Section 2.4, the assumption serves as a convenient modeling shortcut to replicate corporate dividend payout patterns.

[7] Denoting the stationary probability of state η^H by $q_{SS}^{HH} = (1 - q^{LL})/[2 - (q^{LL} + q^{HH})]$, the unconditional mean (average) credit spread in the economy is given by $\overline{CS} = q_{SS}^{HH} R(\eta^H - 1)$. The volatility of the (average) spread can be computed in a similar fashion.

and financing behavior of US non-financial, non-utility Compustat firms. The calibration procedure begins by solving the heterogeneous firm dynamics model globally under a specific set of parameters. That is, given a parametrization, I find the policies and the value functions by modified policy function iteration.[8] The idiosyncratic productivity process is discretized using the method proposed by Rouwenhorst (1995).[9] Then, I compute relevant moments from the simulated data derived from the current parametrization and compare them to the equivalent target moments in the data. The procedure is repeated until the difference between the data and the model implied targeted moments has been minimized.

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. The first of the remaining parameters, θ, governs the tightness of the collateral constraint and naturally drives the median leverage ratio in the economy. While the depreciation rate δ drives the median investment rate, I choose the capital adjustment cost parameter ψ to match the median cash to asset ratio.

Table 1 illustrates the parametrization underlying the quantitative results presented in the following section. In addition, Panel B illustrates the fit of the model to the empirical moments targeted in the calibration. The model matches the empirical patterns of investment, leverage and cash holdings well.

The calibrated persistence parameters of the borrowing shock imply average durations of 12.4 and 4.4 years of the good and bad borrowing state, respectively. The debt capacity parameter, θ, implies that firms can pledge close to a third of their assets as collateral when raising debt finance. This estimate is consistent with the results obtained in Li, Whited and Wu (2016) and Nikolov, Schmid and Steri (2019). Lastly, the adjustment cost parameter ψ implies that adjustment costs at the firm level are on average 21% of the firms' output, well within the range of 16.5 to 35.4% reported in other studies of firms' investment behavior (Caballero and Engel, 1999; Cooper and Haltiwanger, 2006;

[8]I provide further details on the numerical solution method in Appendix C.

[9]I normalize the unconditional mean of z to 1 by setting the mean of the log-productivity process to $\bar{\mu} = -0.5\sigma^2/(1+\rho)$.

A. Externally calibrated					
Description	**Parameter**	**Value**	**Target/Source**		
Discount factor	β	0.96	Standard		
Risk-free rate	R	β^{-1}	Annual safe rate 4%		
Risk aversion	σ	2.0	Standard		
Returns to scale	α	0.65	Hennessy and Whited (2007)		
TFP persistence	ρ_z	0.767	Gourio and Miao (2010)		
Std. dev. TFP innovations	σ_z	0.211	Gourio and Miao (2010)		
Entrants initial size	k_0	$0.1k^{SS}$	Khan and Thomas (2013)		
Exit rate	γ	8.0%	Xiao (2018)		
B. Internally calibrated					
Description	**Parameter**	**Value**	**Target**	**Data**	**Model**
Borrowing shock	η^H	1.073	Avg GZ spread Q4-2008 (bps)	765	765
Persistence of $\eta = 1$	q_{LL}	0.919	Avg. credit spread '73-2010 (bps)	204	202
Persistence of $\eta = \eta^H$	q_{LL}	0.775	SD of credit spreads '73-2010 (bps)	281	290
Collateral constraint	θ	0.32	Med. debt to assets (%)	21.1	18.2
Convex adj. cost	ψ	4.5	Med. cash to assets (%)	7.9	8.8
Depreciation	δ	0.12	Med. investment rate (%)	22.1	22.2

Table 1: Parametrization of the model

Age bins	1-5	6-10	11-15	16-20	>20
Model	34.0	22.4	14.8	9.9	18.9
Data	29.6	20.6	15.9	11.9	22.1

Table 2: Age distribution in steady state

This table presents the age distribution generated by the model and compares it to the distribution among Compustat firms reported by Begenau and Palazzo (2017). In the data, "age" refers to years since going public.

Bloom, 2009).

Table 2 illustrates that the exogenous exit shock γ generates an age distribution that fits the empirical counterpart in Compustat over the period 1979-2013 reported by Begenau and Palazzo (2017). In the model (as in the data), the years since entry ("age") distribution matters because young firms tend to be smaller and have larger cash-to-assets ratios. For this reason, it is crucial to replicate the empirical age distribution well.

4 Quantitative results

In this section, I analyze the dynamic model of firm investment, cash and debt management presented in Section 2. Section 4.1 analyzes the decision problem of a single firm by inspection of the policy functions that solve the problem of the firm numerically.

Section 4.2 studies the results from aggregating individual firms' behavior by inspecting the model in steady state. The steady state analysis is based on a simulation of a large number of firms that are born ex-ante identical but subject to different realizations of the idiosyncratic productivity, borrowing cost and exit shocks. Section 4.3 explores the impact of financial frictions on macroeconomic outcomes. Finally, Section 4.4 illustrates the economy's response to an aggregate shock to corporate borrowing cost.

4.1 Analysis of a single firm's decision problem

To provide intuition for the results on firms' decisions, Figure 3 illustrates the policy rules as functions of the firm's current net worth (left column) and capital (right column). The four rows of the figure correspond to (in descending order) the firm's investment rate, i/k, cash holdings, c', borrowing, b', and dividend payments d. The policies illustrate the decision rules of a firm that can borrow at the risk-free rate ($\eta = 1$) and contrast the choices of a firm with low (solid line) and high (dashed line) current productivity.

The left column illustrates the choices of a firm with an intermediate level of capital and low net worth. The firm's outstanding capital consumes net worth due to the presence of adjustment costs. As the firm has very limited internal funds, its decisions are driven by the desire to pay positive dividends. Therefore, it is forced to sell a fraction of its capital and raise external funds. Holding cash has no value to the firm as all available funds are paid out to the firms' owners. As the firm's net worth grows it can increasingly finance physical capital and dividend payments. The dividend smoothing motive combined with the adjustment cost of capital implies that the firm also builds up substantial cash buffers. In addition, less productive firms lack profitable investment opportunities and therefore channel more of their funds into cash.

The right column illustrates that firms with an intermediate amount of net worth and varying levels of capital operate differently. Firms with a low capital stock are small both in absolute terms and relative to their optimal scale implied by their productivity level. Consequently, these firms invest at high rates, despite the capital adjustment cost slowing their expansion down compared to a benchmark without real frictions. Importantly, however, these firms also build up cash buffers. Large firms instead may already

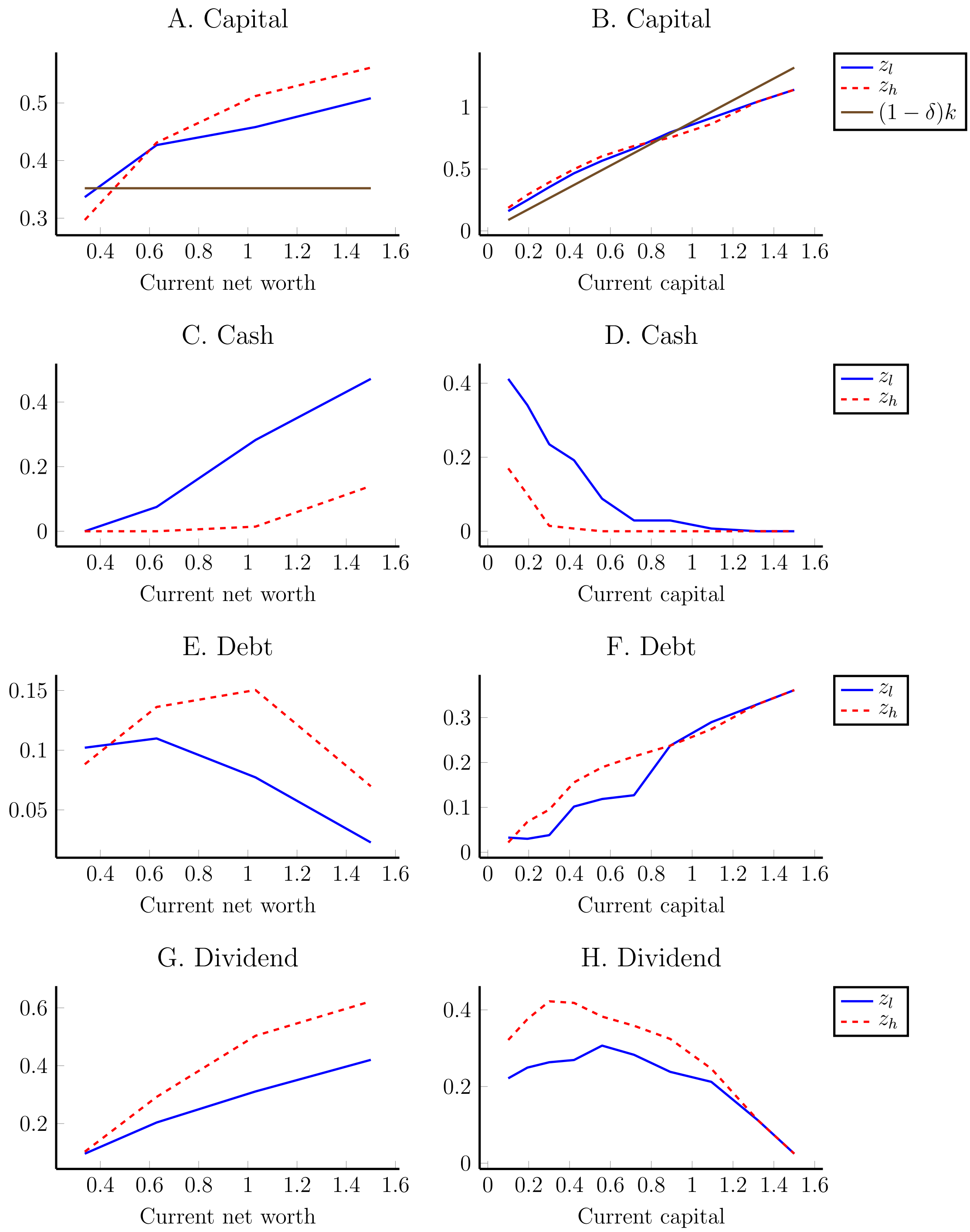

Figure 3: Optimal policies: capital, cash, borrowing and payouts

The figure illustrates firms' optimal policies as a function of current net worth m (left column) and current capital stock k (right column) for a firm with low (solid) and high (dashed) productivity. Capital and net worth are kept at intermediate levels unless explicitly indicated otherwise and the firm borrows at the risk-free rate.

possess excess capital that consumes net worth due the presence of capital adjustment costs. This drives the negative relation between capital and dividend payouts for these firms. As net worth is fixed, an exogenous increase in the firm's capital stock implies increasing costs associated with downsizing the firm, requiring the firm to lever up.

Next, I illustrate how the firm's policy functions map into the investment and financing ratios targeted in the calibration exercise. This allows us to get a better understanding of the cross-sectional implications of the model. In addition, it demonstrates which types of firms are most affected by the borrowing constraint. To this extent, Figure 4 illustrates the optimal investment rate (top row), cash to asset (middle row) and leverage ratios (bottom row). Again, figures in the left column correspond to a firm with an intermediate capital stock and varying degrees of net worth, while the right column depicts a firm with intermediate net worth and a varying capital stock. The benchmark case of a firm with intermediate productivity borrowing at the risk-free rate (solid line) is contrasted with a firm paying a positive credit spread (dashed line) and a low productivity firm (dotted line).

First, firms with an intermediate capital stock and low net worth are forced to sell some of their capital and borrow up to their leverage constraint in order to finance dividend payments. As the firm's net worth grows, the firm starts investing in capital and cash and decreases its reliance on leverage.

The right column of Figure 4 illustrates that firms with intermediate net worth and low current capital have high investment rates due to their ample investment opportunities. In order to preserve future investment capacity, they also build up substantial cash buffers. As the firm's capital stock grows, both investment rates and cash ratios decline. Since the increased capital stock consumes net worth, the firm has to increasingly rely on debt to finance dividends and outstanding capital.

Less productive firms have fewer investment opportunities and consequently invest less. Instead of using available funds to expand their physical capital stock, they build up cash buffers in anticipation of future, higher productivity states. As unproductive firms do not grow as quickly, they raise less debt compared to more productive firms.

In comparison, the effect of the borrowing cost shock has barely any effect on the investment behavior of a firm with average productivity. It does, however, alter its financing decisions: a firm paying a premium on its debt is substantially less levered and importantly does not raise debt and accumulate cash simultaneously.

4.2 Aggregate financing and investment behavior

Building on the intuition on individual firms' behavior, I analyze the life cycle and macroeconomic implications of the model. The previous section illustrated firms' policy functions, which formally map the firms' current state $\mathbf{s} = (k, c, b, z, \eta)$ into the optimal choice variables (k', c', b', d). Combining the policy functions, simulated series for productivity, funding cost and exit shocks, and initial levels of capital and net worth, I analyze a panel of firms as in Gomes (2001).

Figure 5 compares the relationships between firm size, investment, cash holdings and leverage generated by the model to their empirical counterparts, which were first depicted in Figure 1.[10] Note that the calibration strategy has not targeted these moments, which allows us to use these moments to get a good sense of the model fit.

The model generates investment rates and cash holdings that decline with firm size, as in the data. In particular, the model does not only fit the general trend but replicates the intricate patterns of corporate investment and cash holdings: while investment rates do not differ too strongly across small and large firms, the median cash ratio of the smallest 25% of firms is almost three times as high as the cash holdings of the largest 25% of firms. Lastly, leverage is overall positively related to firm size although the smallest firms borrow slightly more compared to firms in the second quantile of the size distribution. Again, the model matches this pattern almost perfectly.

The life cycle aspects of the model may be seen from Figure 6, which displays the

[10] Table B.1 in the Appendix presents the underlying moments. Moreover, Figure B.1 in the Appendix highlights that the relationship between firm size and investment and financing behavior is consistent across three subsamples of the period from 1980-2015.

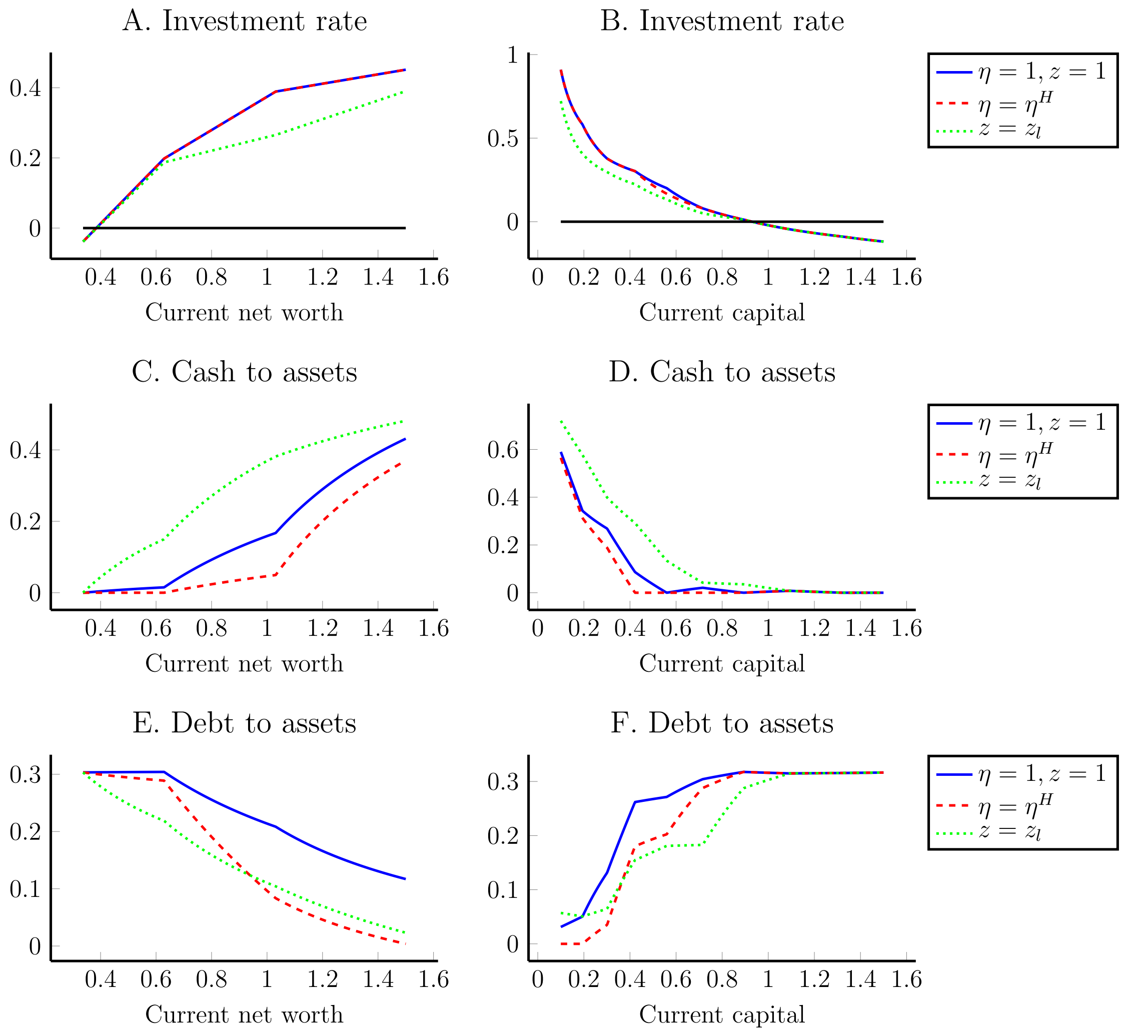

Figure 4: Optimal investment and financing ratios

This figure illustrates how the firm's policy functions map into investment rates (top row), cash to asset (middle row) and leverage ratios (bottom row). Investment and financing ratios are depicted as functions of current net worth m (left column) and current capital stock k (right column). The benchmark case of a firm with intermediate productivity borrowing at the risk-free rate (solid line) is contrasted with a firm paying a positive credit spread (dashed line) and a low productivity firm (dotted line). Capital and net worth are kept at intermediate levels unless explicitly stated otherwise.

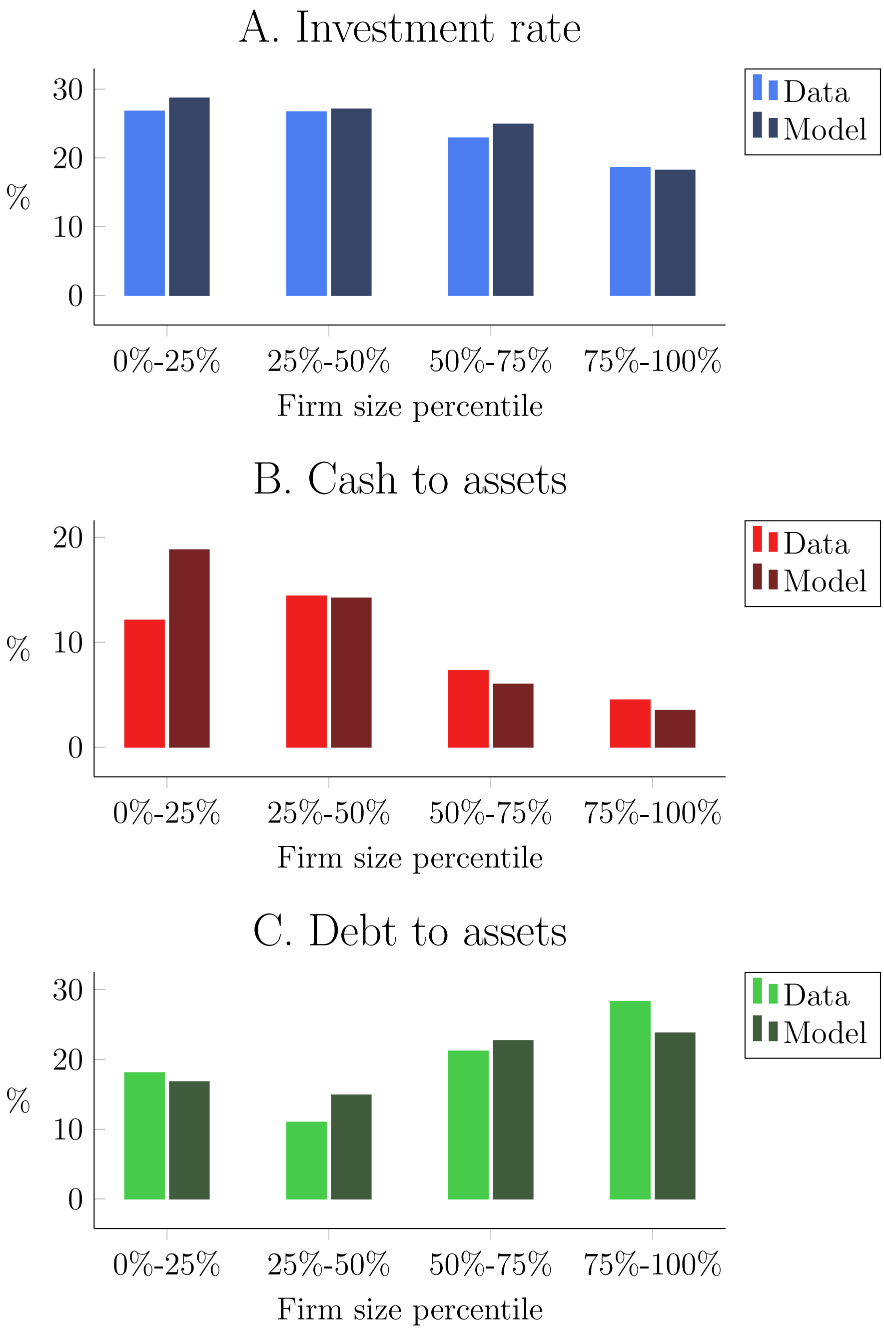

Figure 5: Cross-sectional investment and financing patterns

This figure presents the cross-sectional, untargeted fit of the model (dark bars, right) to the empirical moments (light bars, left) that were first presented in Figure 1.

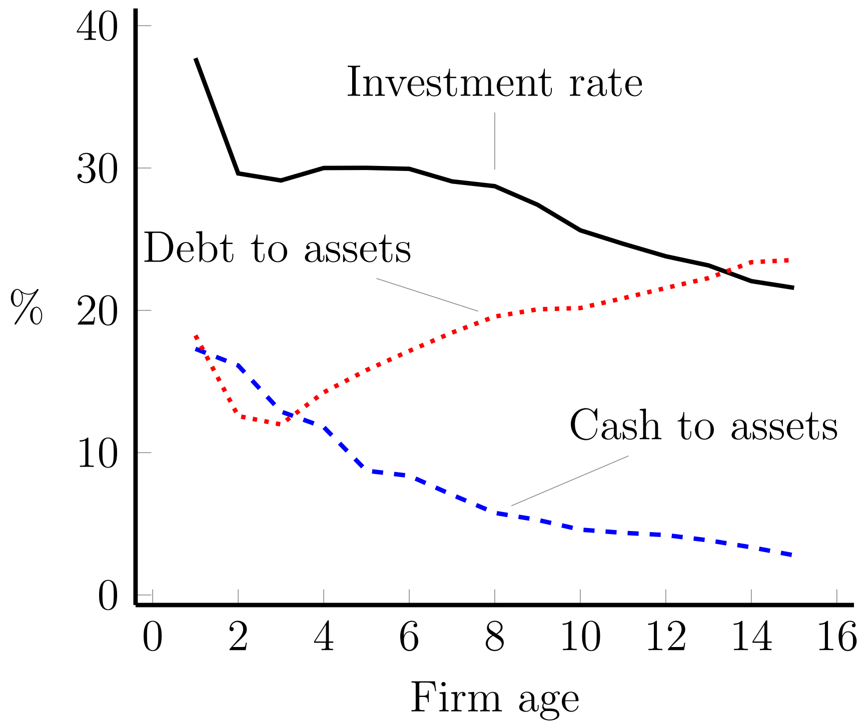

Figure 6: Life cycle aspects in steady state

This figure presents cohort medians from the steady state of the model based on an unbalanced panel of $100,000$ firms.

average cash, leverage and investment ratios in a panel of initially $100,000$ firms. Notice that this figure is not drawn from a balanced panel of firms; given the constant exit rate, there are fewer firms in the right half of the figure than there are on the left. Since entering firms (age 1) are small, their investment rates during early years remain high. Due to adjustment costs, young firms spread their investment over time and accumulate capital gradually as they grow to their optimal scale. In order to secure funding for the continual growth of young firms, they build up substantial cash buffers. As firms mature and accumulate net worth, their cash holdings continue to decline. Consequently, mature firms invest less and hold less cash compared to young firms.

Firms' reliance on debt over their life cycle exhibits an interesting non-linearity: while the youngest firms are highly levered, they first reduce their reliance on external financing in the early stages of their life before starting to continually increase their leverage ratios. This non-linearity can be explained as follows: Investment by entrants is extremely profitable, but they possess only the capital stock that they are born with. Taking on leverage allows financing these investment opportunities but is associated with rollover risk due to the shock to borrowing cost. A highly levered firm incurs the risk of not being able to refinance its outstanding debt when access to debt becomes costly in the future. Firms with little net worth, such as young firms, would then be forced to either decelerate their growth or reduce dividend payouts. Investment cuts are suboptimal due to the high marginal return of capital for small firms, while the aversion to dividend reductions arises from firms' dividend smoothing motive. As firms mature and accumulate net worth, the rollover risk decreases since firms can finance a larger share of their operations internally. Consequently leverage ratios among mature firms are substantially higher. Contrary to the canonical model of firm dynamics developed by Khan and Thomas (2013), my model is thus able to replicate the positive relationship between firm size and leverage observed in the data.[11]

Figure 7 compares the impact of financial and productivity shocks on investment and financing behavior across the firm size distribution in steady state. Light blue (left) bars in Panel A indicate the percentage change in median investment rates by firms that currently pay a premium on their borrowing relative to those that do not.[12] Light blue bars in Panel A indicate that the median investment rate of firms currently paying a premium on debt is about 70% lower than the investment rate of firms with cheap access to debt across the firm size distribution. Similarly, dark blue (right) bars indicate the percentage change in investment rates when comparing firms with below average productivity with those above average. While median investment rates of firms in the lower half of the firm size distribution barely differ among firms with above and below average productivity, large and productive firms' investment rates are ca. 15-20% higher than those by their less productive counterparts.

In contrast, the funding cost shock has a stronger impact on both cash and leverage ratios. Panels B and C repeat the same exercise as in Panel A for cash and debt to

[11]Figure A.2 in Appendix A.2 shows that these savings and borrowing patterns are robust to conditioning on firm size instead of age.

[12]For example, blue (left) bars in Figure 7.A depict

$$100 \times \left(\frac{median\left(\frac{I_i}{k_i}|\eta_i = \eta^H, (k_i + c_i) \in Q_j\right)}{median\left(\frac{I_i}{k_i}|\eta_i = 1, (k_i + c_i) \in Q_j\right)} - 1 \right), \; j = 1, .., 4$$

where Q_j refers to the j-th quantile of the firm size distribution.

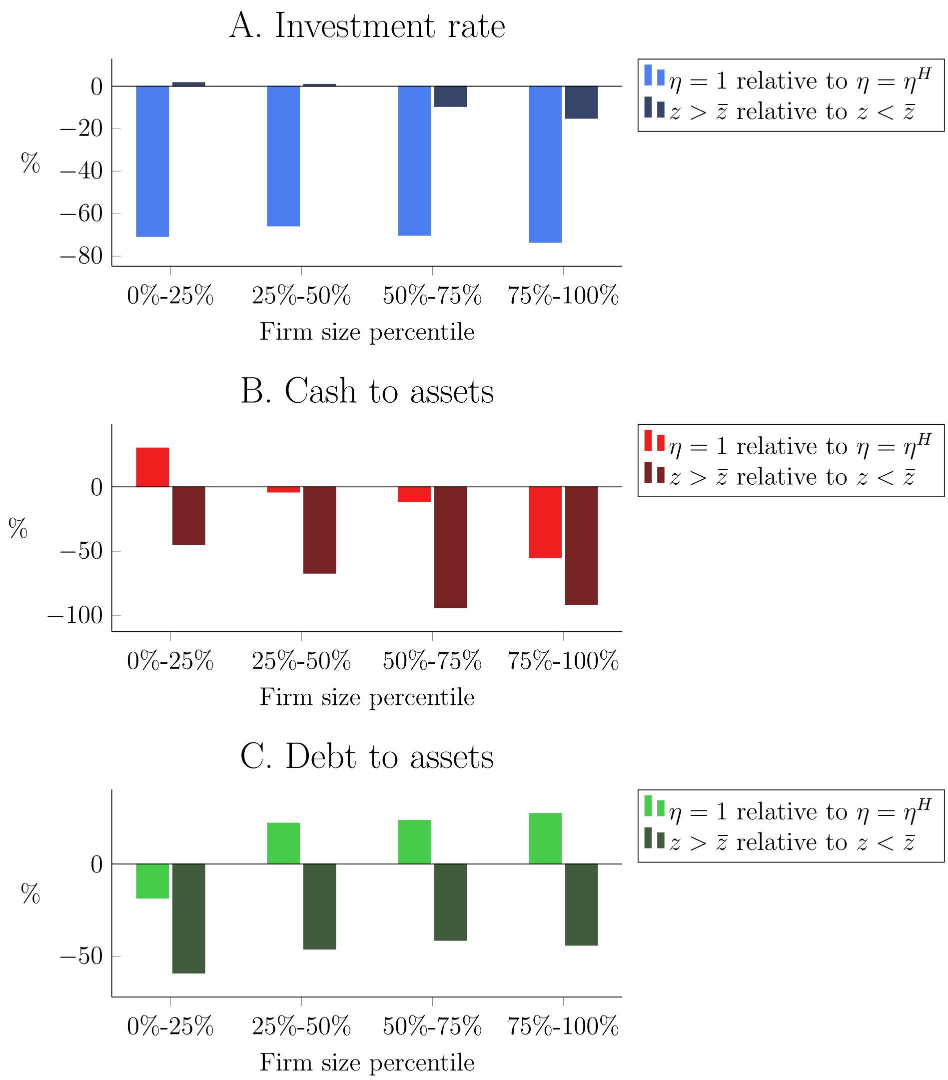

Figure 7: Productivity and financial shocks in the cross-section

This figure compares investment and financing behavior in steady state across firms of varying size for i) firms paying a credit spread with those that do not and ii) firms with productivity levels below and above average. Blue bars (left) depict the percentage change in conditional medians for firms paying no credit spread with those that do, while orange (right) bars depict the change going from firms with above average productivity to those below average.

asset ratios. Firms that are subject to the funding cost shock have substantially lower cash ratios compared to firms with costless access to debt. As external funds command a premium, it is cheaper for firms to draw on their outstanding cash balances to finance capital and dividend payments. Since firms in the top quantiles of the size distribution have large capital stocks that need refinancing, they exhibit the strongest declines in cash holdings. Firms paying positive credit spreads have substantially lower leverage ratios because levering up is more costly for them. Interestingly, the impact is most pronounced for the smallest firms, who are especially dependent on external finance to fund their high investment rates. However, these firms are also ones with very little net worth, which limits their ability to borrow at high cost.

When comparing leverage ratios across firms with varying productivity, it turns out that less productive firms are more levered and especially so for the largest firms in the economy. As less productive firms generate less revenue, they have to resort to external funding to finance their outstanding capital stock and dividend payments. Since the largest firms need to finance a large outstanding capital stock their demand for external funds is especially strong.

4.3 Aggregate implications of financial frictions

The above has shown that the introduction of time-varying borrowing cost allows an otherwise conventional framework of heterogeneous firms and borrowing constraints to rationalize the cross-sectional properties of firm financing and investment policies. In this section, I investigate the implications of the financial frictions for the macroeconomy, both regarding output losses and changes in the aggregate investment and financing behavior of the corporate sector in a stationary equilibrium. To assess the impact of financial frictions, I perform a counterfactual analysis in which I consider increases and decreases in the collateral constraint parameter, θ, and the parameter governing the size of the credit shock, η^H, while keeping the remaining parameters fixed at their baseline values.

Table 3 shows that relaxing the severity of financial frictions, either through a higher debt capacity, θ, or a softening in the borrowing cost shock, η^L, has positive effects on

Relative change to baseline (%)	5pp increase in θ	5pp decrease in θ	1pp decrease in η^H	1pp increase in η^H
Output	0.42	-0.19	0.09	-0.37
Investment	0.75	-0.28	0.21	-0.41
Dividend	1.31	-0.34	0.39	-0.67
Cash to assets	-2.82	7.04	1.91	5.45
Debt to assets	5.65	-3.4	3.4	-1.7

Table 3: Counterfactuals: the effects of financial frictions

This table displays the relative changes (in %) of aggregate outcomes with respect to the baseline steady state due to a 5% change of the collateral constraint parameter θ and a 1% change in the credit shock parameter η^H, respectively.

various aspects of the aggregate economy: dividends, output, investment and leverage ratios all increase as a result of easing friction. Relaxing the frictions affecting external financing clearly allows firms to better manage their liquidity needs over time and therefore enhances efficiency in the overall economy. By the same token, worsening financial frictions, either through lower debt capacity, θ, or a greater shock to credit spreads, η^H, have adverse consequences for the macroeconomy. Interestingly, however, the two frictions have differential impacts on aggregate cash holdings: increasing the collateral constraint parameter θ allows firms to borrow more, thereby decreasing their reliance on cash as an alternative source of funds. Consequently, cash holdings decline with respect to the baseline calibration. In contrast, cash holdings *increase* when the shock to external funding costs is less severe. This highlights the intricate non-linearities embedded in the model.

4.4 A credit crisis

In this section, I consider an aggregate shock to firms' borrowing conditions and show that the model predicts aggregate changes resembling those from the GFC in several respects. Starting from the model's steady state at date zero, I explore the effects of a simultaneous increase in external funding costs to η^H for all firms at date one. From the first date of the credit cost shock onwards, firms return to normal borrowing conditions with probability $1 - q^{HH}$, consistent with the calibrated parameters. Thus, when the aggregate shock occurs at date one, firms expect it to last for 4.4 years. Figure 8 depicts the response of the aggregate economy to this credit crisis.

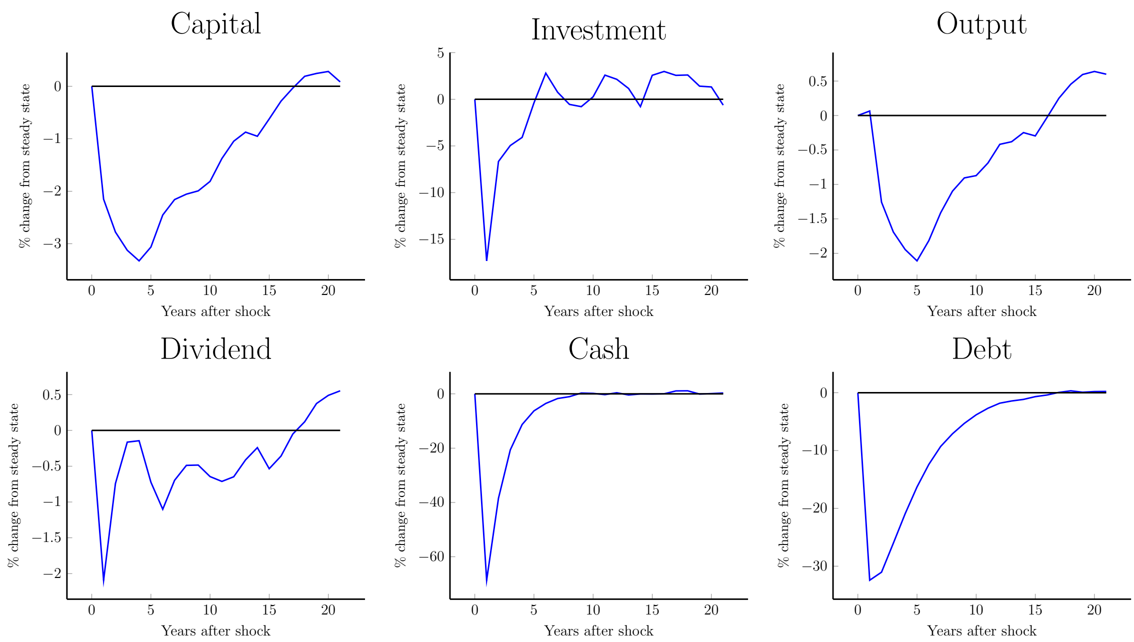

Figure 8: The effects of a credit crisis

Impulse response functions to an aggregate shock to borrowing cost in year one. From year two onwards, idiosyncratic borrowing conditions revert to $\eta = 1$ with probability $1 - q^{HH}$. Each panel highlights the percentage deviation from the respective aggregate moment in steady state.

The results in Figure 8 indicate that the aggregate credit shock implies a 30 percent reduction in aggregate leverage. This reduction is consistent with the actual declines in various series reflecting lending during the GFC; it matches the ultimate fall in US commercial and industrial loans reported by Khan and Thomas (2013), and it is smaller than the fall in syndicated investment loans reported by Ivashina and Scharfstein (2010). In addition, the model replicates the unusually steep fall in investment of 20 percent as well as a contraction of aggregate consumption (here proxied by dividends) of 2 percent. Both of these features are a direct result of firms' lacking funding to sustain their capital stock and dividend payouts. Importantly, this liquidity shortage occurs despite the fact that firms draw upon their cash buffers, leading to a 60 percent decline in aggregate cash. Albeit counterfactual with respect to the behavior of aggregate cash during the GFC, the sharp decline in cash holdings is a direct result of the modeling assumptions that rule out default and do not allow for equity issuance. The sharp decline of investment upon impact of the crisis, however, does not immediately translate into aggregate output. As production at the arrival of the crisis is predetermined by the capital investment made in year zero, there is no initial impact. In the following years, aggregate output continuously and gradually declines until reaching its minimum level four years after the aggregate cost to external funding cost struck the economy.

A key characteristic of the GFC was the slow recovery that followed in its wake. The credit crisis studied here has similar, long-lasting effects. Although the decline in aggregate output of two percent is muted compared to the drop of six percent induced by the GFC (Khan and Thomas, 2013), the effects of the credit crisis are not rapidly reversed. While borrowing conditions start to improve in year two, aggregate output is very slow to return to its pre-crisis level. The slow recovery of output arises because the credit crisis has a significant adverse impact on the aggregate capital stock. As firms' costs of external funds spike and their cash buffers are depleted, firms are forced to sell some of their capital stock to raise liquidity. Since the shock to funding cost is persistent at the firm level, investment remains heavily impaired in the years following the credit crisis. Consequently the economy's capital stock is slow to settle back to its pre-shock state.

Lastly, I assess the extent to which cash holdings help firms accommodate aggregate shocks to the cost of external financing and, as a result, reduce the implications of such shocks for aggregate investment. To this end, I decompose the investment crunch following the credit crisis depicted in Figure 8. Figure 9 depicts the change in aggregate investment within each of the four quantiles of the distribution of cash to total assets in the economy.

The contraction in investment is clearly concentrated among the firms with lower cash buffers. In particular, firms in the bottom quantile of the cash holdings distribution exhibit the sharpest decline in investment.[13] This is consistent with the idea that cash holdings help firms to accommodate shocks to their external funding. However, I have shown that current levels of corporate cash holdings are insufficient to insulate the macroeconomy from aggregate shocks to the cost of external funding. The results presented in this section are consistent with the empirical evidence on the role of rises in corporate credit spreads in causing or amplifying economic contractions (Gilchrist and Zakrajšek, 2012). Specifically, the analysis shows the capacity to generate such effects in

[13]The erratic behavior of aggregate investment by firms in the lowest cash holdings quantile long after the aggregate shock is largely driven by new entrants, whose initial investment is very sensitive to their initial draws of productivity and borrowing cost.

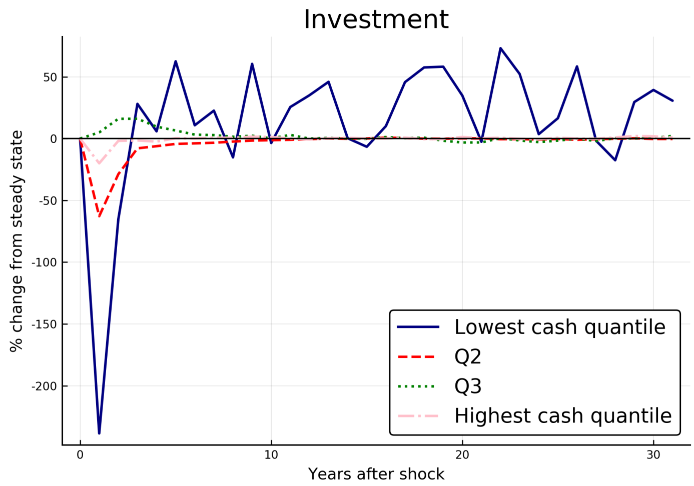

Figure 9: Decomposing the investment crunch by cash holdings

This figure shows the percentage changes in aggregate investment following an aggregate funding cost shock in year one split by quantiles of the cash holdings distribution. The credit crisis is the same as the one underlying Figure 8.

a context where firms can hold cash buffers with the purpose of self-insuring against the shocks causing them.

5 Conclusion

This paper studied the role of shocks to corporate borrowing cost in shaping firms' investment and financial decisions. A stochastic determinant of corporate credit spreads incentivizes firms to borrow and simultaneously build up cash buffers, consistent with the empirical data that is at odds with many traditional models of firm financing.

I highlighted the quantitative significance of exogenously driven variation in credit spreads through the lens of a dynamic model of firm financing and investment subject to capital adjustment cost and financial frictions affecting firms' access to debt. The quantitative model replicates key features of the empirical relationship between firm size and corporate investment and financing behavior: small firms concurrently have higher investment rates and larger cash buffers while being less levered than their large counterparts. In the model, firms accumulate savings both to smooth dividends over time and to preserve future investment capacity. The latter channel arises because shocks to borrowing cost imply that firms may not be able to raise sufficient external funds when profitable investment opportunities arise. Analyses of the dynamic model illustrate that the firms' incentives to save interact with the financial and real frictions: both capital adjustment cost and classic borrowing constraints tied to firms' physical collateral make corporate cash more valuable.

Finally, I explored how shocks to the cost of external funding and corporate cash holdings matter for macroeconomic outcomes. While the calibrated model suggests that equilibrium cash holdings provide some protection against such financing shocks, an aggregate financial shock can nevertheless cause significant aggregate effects. In particular, an aggregate shock to corporate borrowing cost in the model replicates key features of the GFC, including a long-lasting contraction of investment and output that is concentrated among firms with lower cash buffers.

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Appendix

A Model details

A.1 Optimality conditions

Using subscripts to denote partial derivatives of the value function, the firm's optimality conditions with respect to k', b' and c' are respectively given by:

$$d^{-\sigma}\left[1+\psi\frac{I}{k}\right]+\mu\theta+\beta\mathbb{E}\left[(1-\gamma)V_{k'}+\gamma\left(1-\delta\right)e^{-\sigma}\right]=0 \tag{A.1}$$

$$d^{-\sigma}(\eta R)^{-1}+\beta E\left[\left(1-\gamma\right)V_{b'}-\gamma e^{-\sigma}\right]-\mu+\chi_b=0 \tag{A.2}$$

$$-d^{-\sigma}R^{-1}+\beta E\left[\left(1-\gamma\right)V_{c'}+\gamma e^{-\sigma}\right]+\chi_c=0 \tag{A.3}$$

The associated envelope conditions are:

$$V_k=d^{-\sigma}\left[\alpha zk^{\alpha-1}+(1-\delta)+\frac{\psi}{k}\left[0.5\frac{I}{k}-\frac{k'}{k}\right]\right] \tag{A.4}$$

$$V_b=-d^{-\sigma} \tag{A.5}$$

$$V_c=d^{-\sigma} \tag{A.6}$$

Combining the first order conditions with the envelope conditions in the subsequent period yields the Euler equations:

$$d^{-\sigma}\left[-1-\psi\frac{I}{k}\right]+\mu\theta+\beta\mathbb{E}\left[\left(1-\gamma\right)\left(d'\right)^{-\sigma}\left[f_k'+\left(1-\delta\right)+\frac{\psi'}{k'}\left[0.5\frac{I'}{k'}-\frac{k''}{k'}\right]\right]+\gamma\left(1-\delta\right)e^{-\sigma}\right]=0 \tag{A.7}$$

$$d^{-\sigma}(\eta R)^{-1}-\beta E\left[\left(1-\gamma\right)\left(d'\right)^{-\sigma}+\gamma e^{-\sigma}\right]+\chi_b=0 \tag{A.8}$$

$$-d^{-\sigma}R^{-1}+\beta E\left[\left(1-\gamma\right)\left(d'\right)^{-\sigma}+\gamma e^{-\sigma}\right]+\chi_c=0 \tag{A.9}$$

where $f_k=\alpha zk^{\alpha-1}$ denotes the marginal return to capital.

Defining $\Lambda = (1-\gamma)\,\beta\,(d'/d)^{-\sigma}$ and $\Lambda_E = \gamma\beta\,(e/d)^{-\sigma}$ and subsequently rearranging yields

$$\mathbb{E}\left[(1-\gamma)\Lambda\left[f_k' + (1-\delta) + \frac{\psi'}{k'}\left[0.5\frac{I'}{k'} - \frac{k''}{k'}\right]\right] + \Lambda_E\,(1-\delta)\right] + \frac{\mu\theta}{d^{-\sigma}} = 1 + \psi\frac{I}{k} \tag{A.10}$$

$$E\left[\Lambda + \Lambda_E\right] = (\eta R)^{-1} - \frac{\mu - \chi_b}{d^{-\sigma}} \tag{A.11}$$

$$E\left[\Lambda + \Lambda_E\right] + \chi_c = R^{-1} \tag{A.12}$$

Focusing on the case with $\gamma = 0$ and ignoring the multipliers on non-negativity constraints yields the optimality conditions (10)-(12) discussed in the main body of the paper.

A.2 Additional numerical results

Life cycle aspects of the model.

Figure A.2 illustrates the cross-sectional patterns of borrowing and savings policies at a more granular level by depicting the average cash to asset and debt to asset ratios across firm size deciles, where size is measured as total assets. Consistent with the evidence presented in Table B.3 and Figure 6, small firms hold significantly higher cash ratios while being less levered compared to larger firms.

Figure A.3 illustrates what the life cycle of a firm in the steady state of the economy looks like. The figure plots the paths of the firm's capital stock, cash holdings and outstanding debt over time. I assume that in every year the firm draws the same average productivity and favorable borrowing shocks, except for years 5 and 10. In year 5, the firm faces an adverse credit shock and must consequently pay a positive credit spread per unit of borrowing. In year 10, instead, the firm realizes a low productivity draw.

B Data

Empirical moments describing the cross-sectional distribution of key investment and financing ratios are obtained from Compustat. Starting from the full annual sample of Compustat firms for the period 1980-2015 I exclude all firms that are not incorporated in the US. I remove all regulated (Standard industrial classification (SIC) 4900 to 4999)

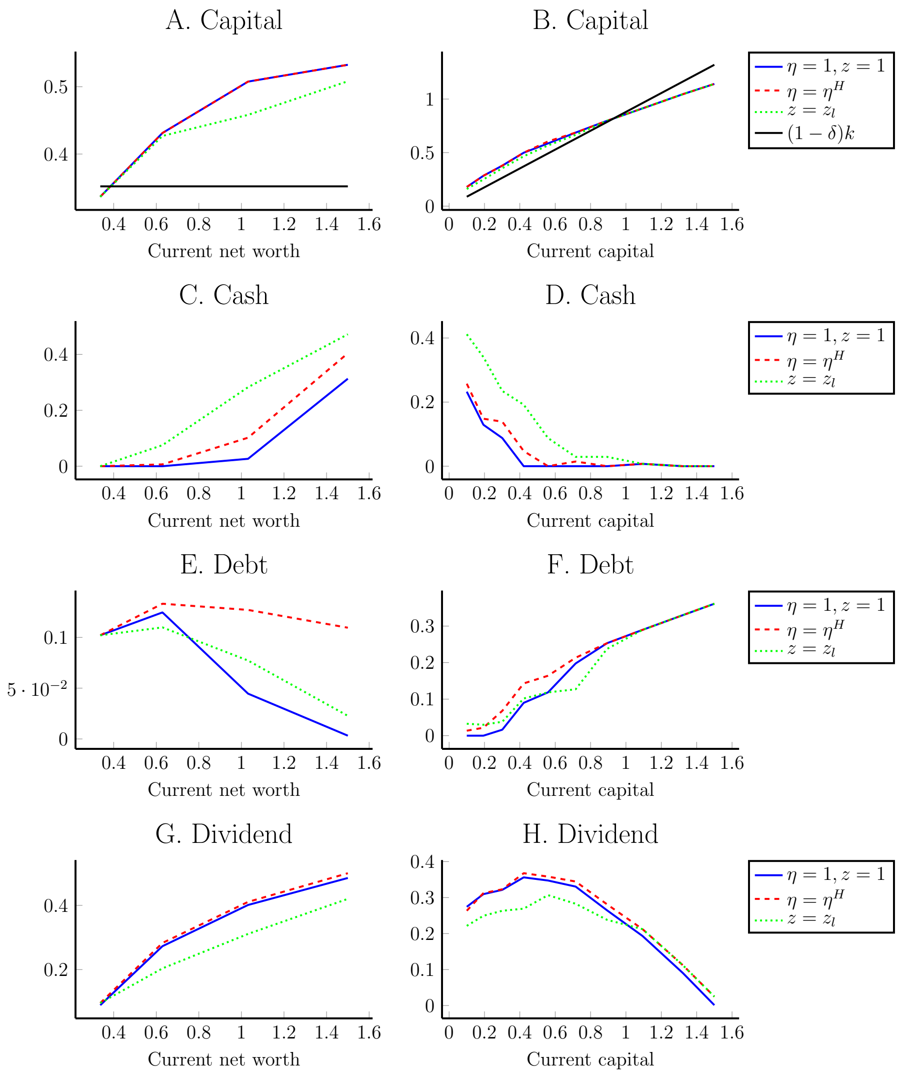


Figure A.1: Optimal policies: capital, liquidity, borrowing and payouts

The figure illustrates firms' optimal policies as a function of current net worth m (left column) and current capital stock k (right column). Capital and net worth are kept at intermediate levels unless explicitly indicated otherwise.

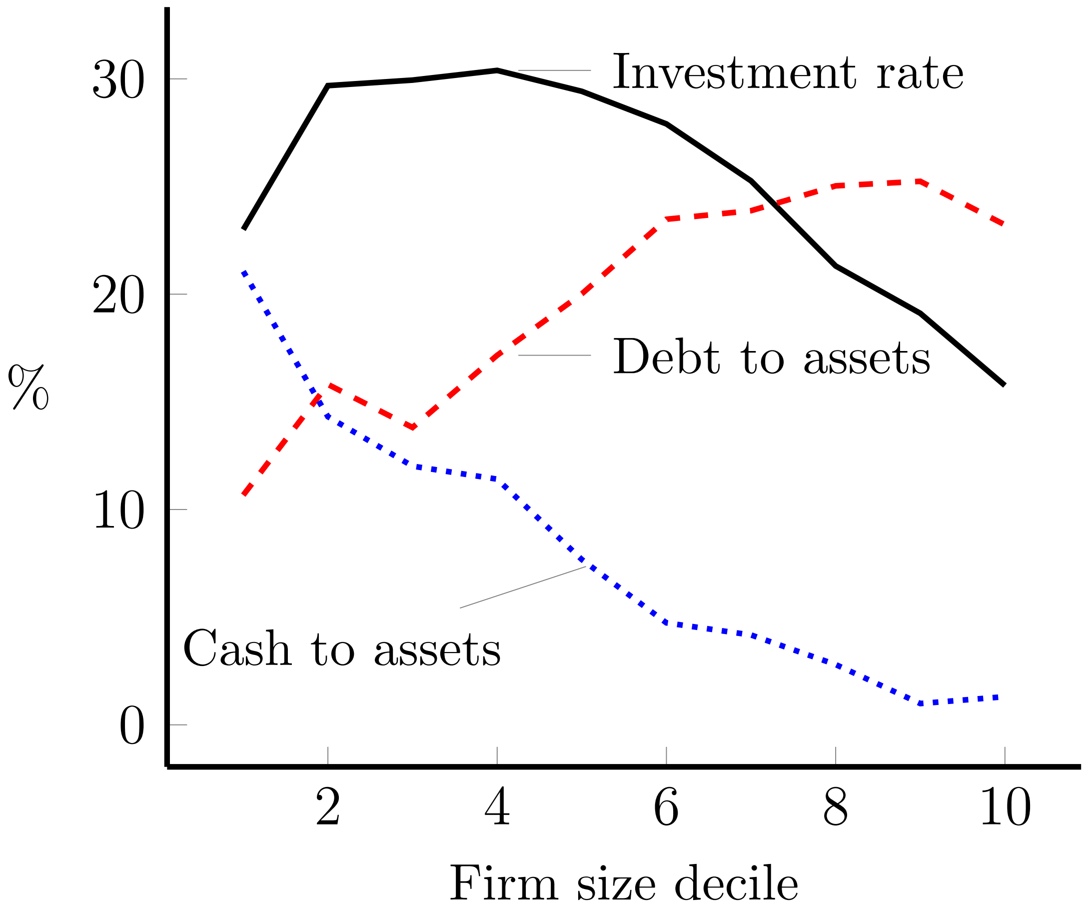


Figure A.2: Median cash and debt ratios by firm size decile

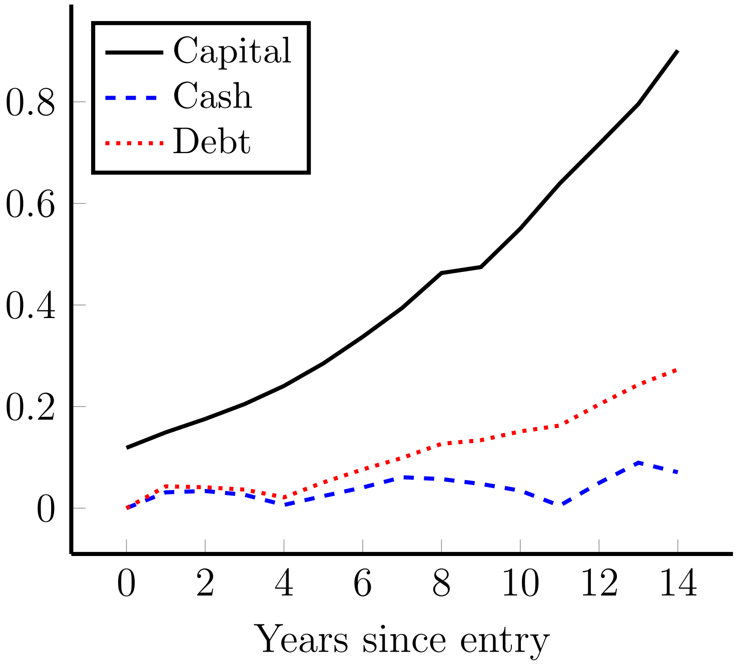


Figure A.3: Dynamic evolution of a firm

This figure illustrates the life cycle of a firm in the stationary equilibrium of the calibrated model. The firm pays no credit spread and receives average productivity draws ($z = \bar{z}, \eta = 1$) except for years 5 and 10, in which it receives a borrowing shock ($t = 5$) and a low productivity draw ($t = 10$), respectively.

and financial firms (SIC 6000 to 6999). Observations with missing total assets, market value, gross capital stock, cash, long-term debt, debt in current liabilities and SIC code are excluded from the final sample. I obtain a panel dataset of 18,892 firms with a total of 190,184 firm-year observations.

Table B.1 illustrates the matching between variables in the model to their empirical counterparts in Compustat. The matching is fairly standard and follows Nikolov, Schmid and Steri (2019).

In the main body of the paper I report empirical evidence on corporate investment and financing behavior: the time-medians of cross-sectional median investment, cash to asset, and debt to asset ratios for the period 1980-2015. These moments are drawn from an unbalanced sample of non-financial, non-regulated firms similar to those examined by Bates, Kahle and Stulz (2009) and Khan and Thomas (2013). Table B.2 reports moments from each year in my sample and illustrates the comparability of my data to that used

Model		Compustat	
Description	Variable	Description	Variable
Cash	c	Cash and Short-Term Investments	CHE
Debt	b	Long-Term Debt + Debt in Current Liabilities	DLTT + DLC
Investment	$k' - (1-\delta)k$	Capital Expenditures	CAPX
Capital stock	k	Property, Plant and Equipment - Total (Net)	PPENT
Net worth	m	Common/Ordinary Equity - Total	CEQ
Total assets	$c+k$	Assets - Total	AT

Table B.1: Variable definitions in the model and the data

The table summarizes variable definitions with reference to Compustat items and their model counterparts following Nikolov, Schmid and Steri (2019).

in the two aforementioned studies.

Figure B.1 reports the key investment and financing ratios across three subsamples: 1980-2008, 2009-2015 and 1995-2015. The figure highlights that the key relationships between firm size and corporate investment, cash holdings and leverage highlighted in the main body of the paper are robust across different subperiods of the sample. Consistent with Table B.2, the figure illustrates that cash holdings have been higher in the most recent decade.

Table B.3 displays the cross-sectional fit of the model to the data. It presents the data underlying both Figures 1 and 5. To compute the empirical moments, I first compute the cross-sectional median within each firm size bin for each year between 1980-2015. Then I compute the time-series median of each data series and report them in Table B.3.

C Numerical method

I solve the firm's optimization problem using discretized value function iteration (VFI) with Howard's improvement algorithm, allowing for a fully nonlinear global solution which accounts for the occasionally binding nature of the collateral constraint. To find a numerical solution, I need to specify a finite state space for the state variables, k, m, η, and z as well as for the choice variables c and b. The idiosyncratic productivity process for z is discretized using 5 grid points with the method proposed by Rouwenhorst (1995). I discretize the continuous variables k, m, c and b using non-uniformly spaced grids with

Year	N	Aggregate Cash to Assets	Median Cash to Assets	Median Debt to Assets	Median Investment Ratio
1980	4,682	5.6	5.2	25.9	24.0
1981	4,703	5.2	5.5	24.0	24.4
1982	4,945	5.4	6.0	24.8	22.1
1983	5,144	6.7	7.8	21.9	21.0
1984	5,122	6.1	6.4	23.4	25.0
1985	5,382	6.2	6.4	24.9	23.5
1986	5,507	6.9	7.3	25.9	22.5
1987	5,492	6.9	6.9	26.0	21.9
1988	5,322	5.6	6.1	26.2	20.2
1989	5,208	4.9	5.5	27.4	20.2
1990	5,214	4.7	5.3	26.6	19.5
1991	5,311	5.0	6.2	24.8	17.8
1992	5,644	5.1	6.6	22.6	19.8
1993	5,923	5.5	7.2	20.8	21.1
1994	6,196	5.4	6.8	20.5	24.0
1995	6,883	5.5	6.8	21.2	25.0
1996	7,026	6.1	7.9	19.3	26.5
1997	6,844	6.3	8.5	19.9	27.4
1998	6,963	6.1	7.9	21.3	27.9
1999	6,883	7.1	8.1	21.4	26.1
2000	6,521	6.8	7.4	21.1	26.2
2001	5,995	7.4	8.4	21.7	21.1
2002	5,702	8.5	9.5	20.4	17.6
2003	5,434	9.7	11.4	19.6	17.6
2004	5,247	10.6	13.0	17.3	22.0
2005	5,050	10.4	13.5	16.5	24.0
2006	4,818	10.2	12.8	16.5	25.5
2007	4,564	9.6	12.1	17.2	24.8
2008	4,332	9.8	11.2	19.7	23.7
2009	4,208	11.7	14.0	16.7	16.1
2010	4,090	12.0	14.7	15.8	18.8
2011	4,006	11.9	13.5	16.8	21.9
2012	4,076	11.7	12.9	18.9	22.0
2013	4,067	12.5	13.7	19.1	21.8
2014	3,942	12.0	13.4	20.7	22.9
2015	3,728	11.9	12.9	23.0	22.0

Table B.2: Corporate investment and financing behavior over 1980-2015

This table illustrates median investment ratios along with cash and debt to asset ratios (in percent) for each year in my sample. The aggregate cash to asset ratio is defined as the sum of cash dividend by the sum of (book) assets in the economy. All remaining variable definitions are provided in Table B.1.

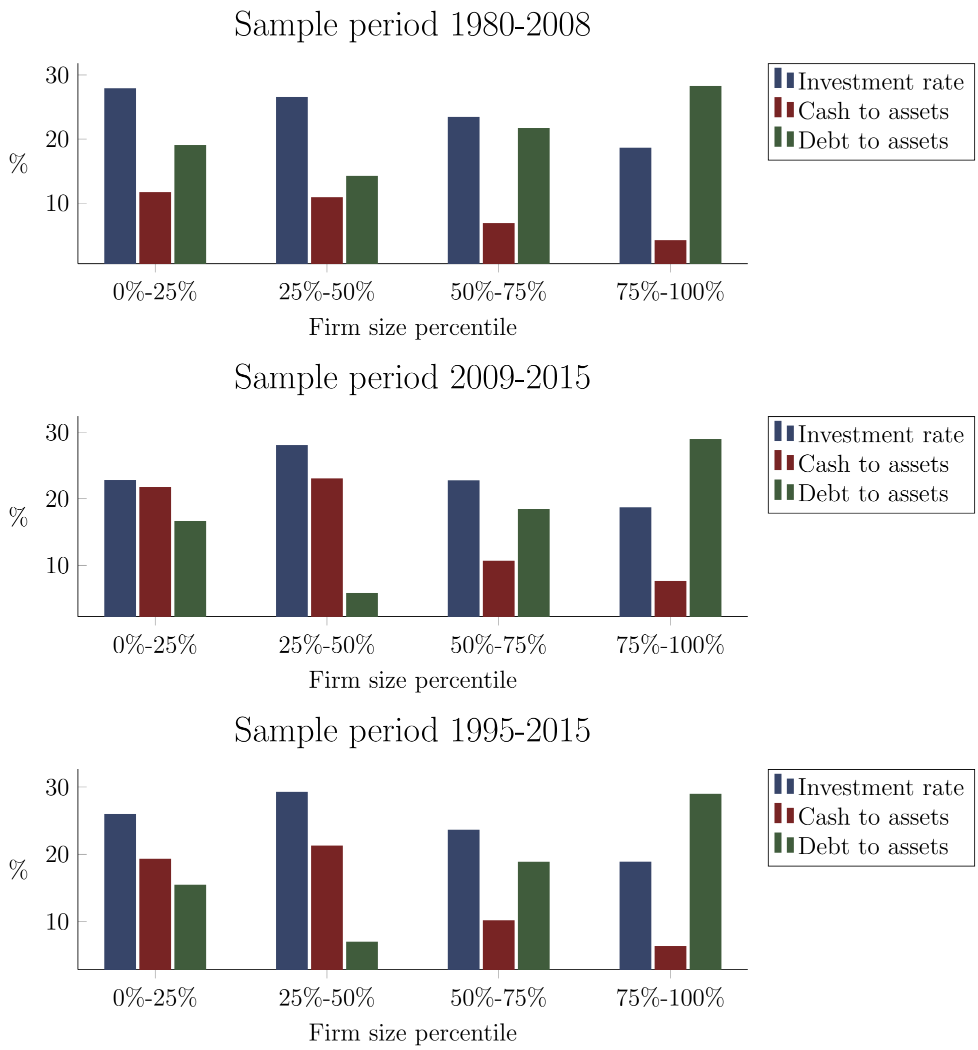


Figure B.1: Investment and financing patterns by firm size across subsamples

This figure presents median investment rates (left), cash ratios (middle) and leverage ratios (right) across four quantiles of the firm size distribution for three different subsamples.

	Cash to assets		Debt to assets		Investment rate	
Asset %-tile	Data	Model	Data	Model	Data	Model
0%-25%	12.1	14.1	18.1	12.7	26.8	22.5
25%-50%	14.4	17.1	11.0	13.9	26.7	26.8
50%-75%	7.3	6.7	21.2	22.6	22.9	23.0
75%-100%	4.5	3.5	28.3	23.9	18.6	17.1
Aggregate	6.8	6.2	30.7	19.4	17.5	11.6

Table B.3: Cross-sectional, untargeted fit of the model

This table showcases the cross-sectional investment and financing moments in the model and the data, which are illustrated in Figure 5.

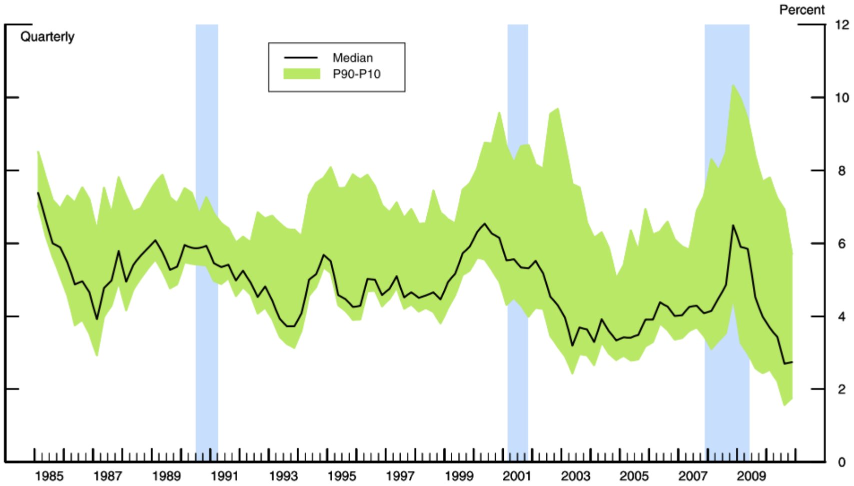
more points around areas in which the firm's value function exhibits more curvature. The upper bounds of the respective grids are chosen such that firms do not exceed or come close to them. I use 25 points along the k and m grids and 15 points along the c and b grids, respectively. Additionally, I allow the firm to choose policies in between these grid points, with 5 equally spaced choices between each grid point. I rely on multivariate linear interpolation to evaluate the value function outside of the grid points.

Howard's improvement algorithm can significantly increase the speed of convergence compared to standard VFI and proceeds as follows: At each iteration j of the VFI, given an initial value function guess $V^{j-1}(\mathbf{s})$, one computes an updated value function, $V^j(\mathbf{s})$, and corresponding policy functions, $A^j(\mathbf{s}) = (k'(\mathbf{s}), c'(\mathbf{s}), b'(\mathbf{s}), d(\mathbf{s}))$. In standard VFI, one would now proceed to the next iteration, $j + 1$, and repeat this procedure. However, with Howard's improvement algorithm, one now uses the policy functions $A^j(\mathbf{s})$ to update the value function a fixed number of times without recomputing the decision rules. This limits the number of times one has to update the policy functions, which is one of the most computationally demanding parts of VFI. The improvement over traditional VFI comes from the fact that one saves on computing decision rules that are immediately discarded because they are based upon wrong value functions.

D Empirical evidence: variation in credit spreads

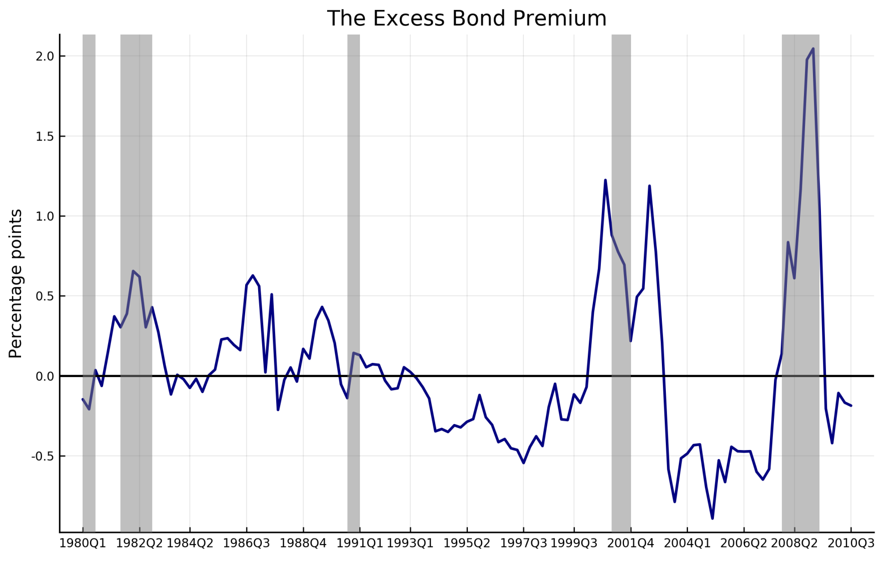
Figure D.1a depicts the time-series evolution of the cross-sectional distribution of real interest rates for a sample of manufacturing firms with access to the corporate bond market. The shaded band around the median real interest rate (the solid line) depicts the 90th (P90) and 10th (P10) percentiles of the distribution of borrowing costs at each point in time. Over the 1985-2010 period, the P90-P10 range has fluctuated in the range between 140 and 670 basis points, an indication of a significant time-series variation in the dispersion of firm-level borrowing costs.

However, default risk is a key determinant of corporate credit spreads. Since loans in the model are fully collateralized, default risk plays no role in determining borrowing cost in the model. Therefore, it is necessary to look at an empirical measure of corporate borrowing cost that is not influenced by variations in default risk. Figure D.1b depicts the excess bond premium developed by Gilchrist and Zakrajšek (2012), a measure of credit spreads purged of default premia.



(a) Dispersion of firm-level borrowing costs in US manufacturing

Sample period: 1985:Q12010:Q4. The solid line depicts the median of real interest rates for our sample of 496 manufacturing firms that have access to the corporate bond market; the shaded band depicts the corresponding P90-P10 range. The shaded vertical bars represent the NBER-dated recessions. Source: Gilchrist, Sim and Zakrajšek (2013)



(b) The Excess Bond Premium

The figure depicts the estimated excess bond premium, a measure of credit spreads purged of default premia. The shaded vertical bars represent the NBER-dated recessions.

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