

# Short-Term Debt and Incentives for Risk-Taking\*

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## Abstract

We challenge the view that short-term debt curbs moral hazard and analytically show how, in a world with financing frictions and fair debt pricing, short-term debt can increase incentives for risk-taking. To do so, we develop a model in which firms are financed with equity and short-term debt and cannot freely optimize their default decision because of financing frictions. Using this model, we show that short-term debt can give rise to a “rollover trap,” a scenario in which firms burn revenues and cash reserves to absorb severe rollover losses. In the rollover trap, shareholders find it optimal to increase asset risk in an attempt to improve interim debt repricing and prevent inefficient liquidation. These risk-taking incentives do not arise when debt maturity is sufficiently long.

Keywords: Short-term debt financing; rollover risk; risk-taking.

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# 1 Introduction

A central result in corporate finance is that equity holders in levered firms have incentives to increase asset risk, as they benefit from successful outcomes of high-risk activities while the losses from unsuccessful outcomes are borne by debtholders (see Jensen and Meckling (1976)).<sup>1</sup> As argued in the corporate finance literature, this “potential agency cost can be substantially reduced or eliminated by using shorter-term debt” (Leland and Toft (1996)).<sup>2</sup> Similarly, following Calomiris and Kahn (1991), much of the banking literature argues that short-term debt disciplines management, because the fragility induced by short-term debt prevents managerial moral hazard.

The view that short-term debt disciplines management and curbs moral hazard does not accord well, however, with the available evidence. In their survey of corporate managers, Graham and Harvey (2001) find little evidence that short-term debt reduces the chance that shareholders take on risky projects. Admati and Hellwig (2013), Admati, DeMarzo, Hellwig, and Pfleiderer (2013), and Eisenbach (2017) also question this theory by observing that the increasing reliance on short-term debt in the years before the financial crisis of 2007-2009 went hand in hand with exceedingly risky activities. Admati, DeMarzo, Hellwig, and Pfleiderer (2013) further note that “in addition to recent history, there are conceptual reasons to doubt the effectiveness of “debt renewal” as an optimal disciplining mechanism. Absent insolvency or market failure, debt can always be renewed at a sufficient yield.”

In this paper, we develop a model that can rationalize this evidence using two important features of real world environments: Financing frictions and fair debt pricing. Notably, we show that, in a world with financing frictions and fair debt pricing, short-term debt does not decrease but, instead, increases incentives for risk-taking. To demonstrate this result and examine its implications for corporate policies, we formulate a dynamic

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<sup>1</sup>See Eisdorfer (2008) and Favara, Morellec, Schroth, and Valta (2017) for empirical evidence on this “asset substitution” or “risk-shifting” problem.

<sup>2</sup>This view was first expressed in Barnea, Haugen and Senbet (1980). Important contributions to this literature also include Leland (1998), Cheng and Milbradt (2012), or Huberman and Repullo (2015).

model in which firms are financed with equity and short-term debt and cannot freely optimize their default decisions because of financing frictions. In this model, debt is repriced continuously to reflect changes in firm performance. Firms operate risky assets and have the option to invest in risk-free, liquid assets such as cash reserves. Firms maximize shareholder value by choosing their precautionary buffers of liquid assets as well as their payout, financing, risk management, and (constrained) default policies.

As in Leland and Toft (1996), Leland (1998), He and Xiong (2012a), and much of the literature on short-term debt and rollover risk, we consider that when a short-term bond matures, the firm rolls it over at market price. When the market price of the new bond is lower than the principal of the maturing bond, the firm bears rollover losses. To avoid default and liquidation, shareholders need to absorb these losses. A fundamental difference between our work and prior contributions is that we do *not* assume that outside equity can be issued instantly and at no cost to absorb rollover losses. Rather, firms face financing frictions, which may lead to forced, inefficient liquidations. This in turn provides shareholders with incentives to build up liquidity buffers that can be used to absorb operating or rollover losses and reduce expected refinancing costs and the risk of inefficient liquidation.

A first result of the paper is to show that combining fairly-priced short-term debt with financing frictions provides incentives for shareholders to increase asset risk, thereby rationalizing the evidence discussed above. Consider first the effects of financing frictions on shareholders' risk taking incentives. As shown by previous corporate finance models (e.g., Décamps, Mariotti, Rochet, and Villeneuve (2011) or Bolton, Chen, and Wang (2011)), shareholders in a solvent firm facing financing frictions behave in a risk-averse fashion to avoid inefficient liquidation. In a different setup, Leland (1994a) and Toft and Prucyk (1997) similarly show that shareholders become effectively risk-averse when default is exogenously triggered, e.g., by debt covenants or by liquidity or capital requirements. In all these models, shareholders cannot freely optimize the timing of default. If the firm is liquidity constrained but fundamentally profitable, default is sub-

optimal to shareholders. In such instances, the equity value function becomes concave, and shareholders effectively behave as if they were risk-averse.<sup>3</sup>

In all these models, debt is either absent or has infinite maturity. Our main contribution is to show that introducing fairly-priced short-term debt in these models yields radically different implications. Notably, when a firm experiences negative operating shocks, default risk increases: This leads to a drop in the price of newly issued debt and to an increase in rollover losses. Rollover losses therefore compound operating losses, increasing further default risk. Because firms issuing debt with shorter maturity need to roll over a larger fraction of their debt, this amplification mechanism is more important for firms financed with shorter-term debt. When firms are close to distress and debt maturity is short enough, rollover losses can become larger than net income. We call this scenario, in which the firm “burns” cash reserves and expected net cash flows are negative because of severe rollover losses, the “rollover trap.” In the rollover trap, the concavity generated by the threat of forced liquidation is more than offset by the convexity generated by rollover losses. That is, shareholders have incentives to increase asset volatility in an attempt to improve firm performance and interim debt repricing and thereby reduce the risk of inefficient liquidation.

Our result that short-term debt generates risk-taking incentives when debt is fairly priced is fundamentally driven by the presence of financing frictions and the ensuing inability of shareholders to freely optimize their default decision. As we show in the paper, this result also obtains in Leland-type models if default decisions are constrained, for instance by debt covenants or liquidity or capital requirements.<sup>4</sup> These risk-taking

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<sup>3</sup>This is also the case in the Black and Scholes (1973) model, in which maximum leverage ratio or minimum interest coverage ratio requirements imply that equity is akin to a down-and-out call option on the firm’s assets (see e.g. Black and Cox (1976)). In this case, shareholders do not have incentives to shift risk when firms fundamental worsen and asset value approaches the “knock-out” barrier corresponding to the protective covenant or regulatory requirement (see Derman and Kani (1996)).

<sup>4</sup>In this paper, we follow prior models on financing frictions (e.g. Décamps et al. (2011) or Bolton et al. (2011)) by assuming that the firm cash flows are governed by an arithmetic Brownian motion. This differs from Leland-type models in which cash flows are governed by a geometric Brownian motion. As

incentives in the presence of financing frictions decrease as debt maturity increases and do not arise when debt maturity is sufficiently long (or when firms are all-equity financed). In such cases, debt needs to be rolled over less often (or never), rollover losses are small (or absent), and expected net cash flows are always positive, implying that the main effect of financing frictions is to expose shareholders to the risk of an inefficient liquidation, so that shareholders do not want to increase asset risk.

An important question is whether risk-taking gives rise to an agency conflict between debtholders and shareholders. We show that agency conflicts arise *if* debt maturity is sufficiently short and the firm bears rollover losses. When rollover losses are moderate, only shareholders have risk-taking incentives close to distress. In this case, debtholders want to preserve their coupon and principal payments and have no incentives to increase asset risk. By contrast, when rollover losses are substantial, debtholders also have risk-taking incentives at the brink of distress, when their promised payments are at stake. Yet, a conflict of interest between shareholders and debtholders still arises. Indeed, because shareholders capture all the returns above those required to service debt and are protected by limited liability, they may have incentives to increase asset risk far from distress, when suboptimal for debtholders. We also find that firms financed with short-term debt are more likely to face such agency problems when they have higher leverage, lower profitability, and more volatile cash flows (i.e. a lower credit rating).

We additionally investigate how capital structure and cash hoarding decisions are affected by our economic mechanism. First, short-term debt maturity imposes rollover losses, which decrease the firm's debt capacity and increase the firm's incentives to keep large cash reserves. Second, short-term debt is cheaper when the firm is far from distress, an effect that increases the firm's debt capacity and decreases its optimal level of cash reserves. We show that firms at the shorter end of the maturity spectrum optimally choose lower leverage and larger cash holdings, which is consistent with the evidence in Harford, Klasa, and Maxwell (2014). In addition, we find that optimal debt maturity

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shown in the paper, our result that short-term debt increases risk-taking incentives does not rest on specific assumptions about the stochastic process governing the firm's cash flows (see Section 4.3).

may be finite, trading off the threat of large rollover losses (when the firm is close to distress) against cheaper cost of debt (when the firm is far from distress).

We show the robustness of our results to a number of alternative setups. First, we consider the possibility for the firm to acquire additional debt via a credit line. We show that when credit lines are senior to market debt (as is typically the case), rollover losses are larger when the firm approaches distress, which magnifies shareholders' incentives for risk-taking (this applies more generally when short-term debt is subordinated to other claims). Second, we demonstrate that our results are not driven by the specific way in which financing frictions are modeled. In fact, our results hold in the extreme case in which the firm does not have access to the equity market (and, thus, financing frictions are the largest) as well as when assuming that the cost of raising equity is time-varying. In this environment, we additionally show that shareholders may want to expose the firm to rollover risk when equity is cheaper and, thus, set countercyclical liquidity buffers, in line with the evidence in Acharya, Shin, and Yorulmazer (2010). Third, we show that our results are not driven by the specific assumption about the stochastic process governing firm cash flows, but rather by the shareholders' inability to freely optimize their default timing. To do so, we relax the assumption that shareholders have deep pockets in a setup à la Leland (1994b, 1998) and confirm in this setup our result that short-term debt generates risk-taking incentives.

Our work is related to the recent papers that incorporate financing frictions into dynamic models of corporate financial decisions. These include Asvanunt, Broadie, and Sundaresan (2011), Décamps, Mariotti, Rochet, and Villeneuve (2011), Bolton, Chen, and Wang (2011, 2013), Hugonnier, Malamud and Morellec (2015), or Décamps, Gryglewicz, Morellec, and Villeneuve (2017). In this literature, it is generally assumed that firms are all-equity financed. Notable exceptions are Gryglewicz (2011), Bolton, Chen, and Wang (2015), and Hugonnier and Morellec (2017), in which firms and/or financial institutions are financed with equity and long-term (infinite maturity) debt. In these models, firms are fundamentally solvent and because financing frictions introduce

the risk of forced liquidations, shareholders behave as if they were risk-averse. That is, convexity in equity value and risk-taking incentives do not arise in these models.<sup>5</sup> Our paper advances this literature by characterizing the interaction between debt maturity and corporate policies and by showing that short-term debt and rollover losses can encourage risk taking when firms are close to financial distress.

Our paper also relates to the literature that examines the relation between short-term debt financing and credit risk by using dynamic models with rollover debt structure. Starting with Leland (1994b, 1998) and Leland and Toft (1996), these models show that short-term debt generally leads to an increase in default risk via rollover losses. Important contributions in this literature include Hilberink and Rogers (2002), Ericsson and Renault (2006), Hackbarth, Miao, and Morellec (2006), He and Xiong (2012a), He and Milbradt (2014), Dangl and Zechner (2016), DeMarzo and He (2016), or Chen, Cui, He, and Milbradt (2018). All of these models assume that shareholders have deep pockets and can inject funds in the firm at no cost (i.e. there are no financing frictions) or just do not allow firms to hoard precautionary cash reserves. In our model, firms face financing frictions and optimally retain part of their earnings in cash reserves to absorb potential rollover losses. Consistent with this modeling, Harford, Klasa, and Maxwell (2014) document that refinancing risk due to short-term debt financing represents a key motivation for cash hoarding in non-financial firms.

Our paper is also related to the early studies of Diamond (1991) and Flannery (1986, 1994), in which short-term debt can be repriced given interim news. Debt repricing implies that the yield on corporate debt changes over time to reflect the firm's operating performance. A central difference with these papers is that, in our dynamic model, there are always creditors who are willing to buy debt at a sufficient yield and debt repricing does not lead short-term debt to discipline shareholders.

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<sup>5</sup>Notable exceptions are Hugonnier, Malamud and Morellec (2015) and Babenko and Tserlukevich (2017), in which equity value can be locally convex *away* from distress due to lumpy investment. In Bolton, Chen, and Wang (2013), convexity arises if shareholders want to time the equity market and issue equity before their cash reserves are depleted. In these models, firms are all-equity financed.

Lastly, our paper also relates to the banking literature on the disciplining role of short-term debt; see e.g. Calomiris and Kahn (1991), Diamond and Rajan (2001), Diamond (2004), or Eisenbach (2017).<sup>6</sup> In this literature, the fragility induced by short-term debt financing prevents moral hazard problems. The experience leading up to the 2007-2009 crisis calls into question the effectiveness of short-term debt as a disciplining device. Admati and Hellwig (2013) note, for example, that “in light of this experience, the claim that reliance on short-term debt keeps bank managers “disciplined” sounds hollow,” as the heavy reliance on short-term debt was accompanied by overly risky activities. Our paper shows that short-term debt financing exacerbates incentives for risk-taking when debt is fairly priced and shareholders’ cannot freely optimize their default decision because of financing frictions, regulatory constraints, or debt covenants.

The paper is organized as follows. Section 2 presents the model. Section 3 demonstrates the effects of short-term debt on risk-taking and discusses the key implications of the model. Section 4 shows the robustness of our results to alternative model specifications. Section 5 concludes. Technical developments are gathered in the Appendix.

## 2 Model and assumptions

Throughout the paper, time is continuous and all agents are risk neutral and discount cash flows at a constant rate  $r > 0$ . The subject of study is a firm held by shareholders that have limited liability. As in He and Xiong (2012a), one may interpret this firm as any firm, either financial or non-financial. However, our model is perhaps more appealing for financial firms because of their heavy reliance on short-term debt financing.<sup>7</sup>

Specifically, we consider a firm that owns a portfolio (or operates a set) of risky,

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<sup>6</sup>In Eisenbach (2017), short-term debt is effective as a disciplining device only if firms face purely idiosyncratic shocks. Otherwise, good aggregate states lead to excessive risk-taking while bad aggregate states suffer costly fire-sales.

<sup>7</sup>A number of intermediaries, such as insurance companies, hedge funds, brokers/dealers, special purpose vehicles, and government-sponsored enterprises, do not take deposits directly from households, but in many ways behave like banks in debt markets (see Krishnamurthy (2010)).

illiquid assets as well as cash reserves and is financed with equity and short-term debt. Risky assets generate after-tax cash flows given by  $dY_t$  and governed by the process:

$$dY_t = (1 - \theta) (\mu dt + \sigma dZ_t), \quad (1)$$

where  $\mu$  and  $\sigma$  are positive constants representing respectively the mean and the volatility of pre-tax cash flows from risky assets,  $(Z_t)_{t \geq 0}$  is a standard Brownian motion representing random shocks to cash flows, and  $\theta \in (0, 1)$  is the corporate tax rate. Equation (1) implies that over any time interval  $(t, t + dt)$ , the after-tax cash flows from risky assets are normally distributed with mean  $(1 - \theta)\mu dt$  and volatility  $(1 - \theta)\sigma\sqrt{dt}$ . This in turn implies that the firm can make profits as well as losses. This cash flow specification is similar to that used, for example, in DeMarzo and Sannikov (2006), Décamps, Mariotti, Rochet, and Villeneuve (2011), DeMarzo, Fishman, He, and Wang (2012), or Hugonnier, Malamud, and Morellec (2015).

Because it pays corporate income tax and interest payments are tax deductible, the firm has an incentive to issue debt. To make our results comparable with prior contributions in the literature, we consider finite-maturity debt structures in a stationary environment as in Leland (1998), Hackbarth, Miao, and Morellec (2006), He and Xiong (2012b), or Cheng and Milbradt (2012). Notably, we assume that the firm has issued debt with constant principal  $S$  and paying a constant total coupon  $C < \mu$ . At each moment in time, the firm rolls over a fraction  $m$  of its total debt. That is, the firm continuously retires outstanding debt principal at a rate  $mS$  and replaces it with new debt vintages of identical coupon, principal, and seniority. In the absence of default, average debt maturity equals  $M \equiv 1/m$ .

Management acts in the best interest of shareholders and chooses not only the firm's financing policy but also its payout and default policies. Notably, we allow management to retain earnings inside the firm and denote by  $W_t$  the firm's cash/liquid reserves at time  $t \geq 0$ . Cash reserves earn a rate of interest  $r - \lambda$  and can be used to cover operating and rollover losses if other sources of funds are costly or unavailable. The wedge  $\lambda > 0$

represents a carry cost of liquidity.<sup>8</sup> When choosing its target level of cash reserves, the firm balances this carry cost with the benefits of liquidity.

The firm can increase its cash reserves either by retaining earnings or by raising funds in the capital markets. As in Bolton, Chen, and Wang (2013), the firm operates in an environment characterized by time-varying financing opportunities. Specifically, the firm can be in one of two observable states of the world, that we denote by  $i = G, B$ . In the good state  $G$ , the firm can raise funds at any time by incurring a fixed cost  $\phi > 0$ . In the bad state  $B$ , the firm has no access to outside funds or, equivalently, funding costs are too high. The state switches from  $G$  to  $B$  (resp. from  $B$  to  $G$ ) with probability  $\pi_G dt$  (resp.  $\pi_B dt$ ) on any time interval  $(t, t + dt)$ . As we show below, financing frictions provide incentives for the firm to retain earnings and build up cash reserves.

We denote by  $D_i(w)$  the market value of short-term debt in state  $i = G, B$  for a level of cash reserves  $w$ . Debt rollover implies that short-term debt of a new vintage is issued at market price and has principal value and coupon payment given by  $mS$  and  $mC$ , respectively. The market value of newly issued debt—which represents a firm inflow—may differ from the principal repayment  $mS$  of maturing debt—which represents an outflow to the firm. When the market value of newly issued debt is lower than the principal, the firm bears rollover losses. Otherwise, it enjoys rollover gains. Over any time interval  $(t, t + dt)$ , the rollover imbalance is given by  $m(D_i(w) - S)dt$ , and the dynamics of cash reserves satisfy

$$dW_t = (1 - \theta)[(r - \lambda)W_t dt + (\mu - C)dt + \sigma dZ_t] \tag{2}$$

$$+ \underbrace{m(D_i(W_t) - S) dt}_{\text{Rollover gains/losses}} - dP_t + dH_t - dX_t,$$

where  $P_t$ ,  $H_t$ , and  $X_t$  are non-decreasing, adapted processes representing respectively

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<sup>8</sup>The cost of holding cash includes the lower rate of return on these assets because of a liquidity premium and tax disadvantages (Graham (2000) finds that cash retentions are tax-disadvantaged because corporate tax rates generally exceed tax rates on interest income). This cost of carrying cash may also be related to a free cash flow problem within the firm, as in Décamps, Mariotti, Rochet, and Villeneuve (2011), Bolton, Chen, and Wang (2011), or Hugonnier, Malamud, and Morellec (2015).

the cumulative payouts to shareholders, the firm's cumulative external financing, and the firm's cumulative issuance costs until time  $t$ . Equation (2) shows that cash reserves grow with earnings net of taxes, with outside financing, with rollover gains, and with the interest earned on cash holdings. Cash reserves decrease with payouts to shareholders, with the coupon paid on outstanding debt, with the cost of outside funds, and with rollover losses.

The firm can be forced into default if its cash reserves reach zero following a series of negative shocks and it is not possible/optimal to raise outside funds. The liquidation value of risky assets represents a fraction of their first best value and is given by

$$\ell \equiv (1 - \varphi) \frac{(1 - \theta)\mu}{r},$$

where  $\varphi \in [0, 1]$  represents a haircut related to default costs. We denote by  $\tau$  the stochastic default time of the firm.

Management chooses the firm's payout ( $P$ ), financing ( $H$ ), and default ( $\tau$ ) policies to maximize the present value of future dividends to shareholders. That is, management solves:

$$E_i(w) \equiv \sup_{(P, H, \tau)} \mathbb{E}_{w, i} \left[ \int_0^\tau e^{-rt} (dP_t - dH_t) + e^{-r\tau} \max \{0; \ell + W_\tau - S\} \right]. \quad (3)$$

The first term on the right-hand side of equation (3) represents the flow of dividends accruing to incumbent shareholders, net of the claim of new shareholders on future cash flows. The second term represents the present value of the cash flow to shareholders in default. In the following, we focus on the case in which the liquidation value of assets is lower than the face value of outstanding short-term debt, i.e.  $\ell < S$ . Since  $W_\tau = 0$  in default, short-term debt is risky. Also, in most of our analysis we take the debt structure  $(C, m, S)$  as given. We discuss the initial debt structure choice (maturity and leverage) in Section 3.6.

## *Discussion of assumptions*

Firms in our model have the same debt structure as firms in Leland (1994b, 1998), Hackbarth, Miao, and Morellec (2006), or Chen, Cui, He, and Milbradt (2018). As in these models, firm cash flows are stochastic and debt is repriced continuously to reflect changes in firm fundamentals. As a result, debt is always fairly priced and debtholders have no incentives to run. A key difference with our setup is that firms in these models do not face financing frictions and/or regulatory constraints. As a result, there is no role for cash holdings, the timing of default maximizes shareholder value, and shortening debt maturity decreases shareholders' incentives to increase asset risk.

Introducing financial or regulatory constraints in a setup à la Leland (1994b, 1998) implies that the firm can be forced into liquidation at a time that does *not* maximize equity value. In such instances, shortening debt maturity does not decrease but, instead, increases shareholders' incentives for risk-taking (see Section 4.3). That is, our main result is robust to different assumptions regarding the stochastic process governing the firm cash flows. In the baseline version of our model, we focus on a setup featuring precautionary cash reserves and cash flows following an arithmetic Brownian motion as in Décamps, Mariotti, Rochet, and Villeneuve (2011) or Bolton, Chen, and Wang (2011, 2013), because financing frictions are a key ingredient of our model. Consistently, Harford, Klasa, and Maxwell (2014) document that firms facing refinancing risk due to short-term debt financing have larger cash holdings.

The models of He and Xiong (2012b) and Cheng and Milbradt (2012) also share the debt structure described above. However, these models assume that firms deliver a constant cash flow through time, which is all paid out to debtholders. Because the firm's assets may be terminated at a random time and their liquidation value is assumed to fluctuate over time (and may fall below the face value of debt), debtholders have incentives to run if the liquidation value of assets falls below some endogenous threshold. By contrast, our model allows periodic cash flows to vary randomly and debt is repriced on any time interval to reflect time-varying operating performance. Because debt is fairly

priced, debtholders have no incentives to run, which is consistent with the Admati's et al. (2013)'s intuition reported in the introduction. Under these assumptions, we show that short-term debt financing can generate risk-taking incentives.

### **3 The rollover trap: Short-term debt and risk-taking**

In the model, management chooses the firm's payout, financing, savings, and default policies to maximize shareholder value. Because creditors have rational expectations, the price at which maturing short-term debt is rolled over reflects these policy choices and feeds back into the value of equity by determining the magnitude of rollover imbalances.

To aid in the intuition of the model, we focus in this section on an environment in which the firm only raises new funds by rolling over short-term debt and does not have access to outside equity. This is the case when the cost of equity financing is too high (due to, e.g., a liquidity crisis). Because there is only one financing state, we omit the subscript  $i$ . In Section 4.1, we give the firm access to a credit line and show that this reinforces the economic mechanism underlying our results and therefore the model's empirical predictions. In Section 4.2, we analyze a model in which the firm can raise outside equity and faces time-varying financing conditions (as described above) and show that all of our results hold in this more general model.

#### *3.1 Valuing corporate securities*

We start our analysis by deriving the value of equity. In our model, financing frictions lead the firm to value inside equity and, therefore, to retain earnings. Keeping cash inside the firm, however, entails an opportunity cost  $\lambda$  on any dollar saved. For sufficiently large cash reserves, the benefit of an additional dollar retained in the firm is decreasing. Since the marginal cost of holding cash is constant, we conjecture that there exists some target level  $W^*$  for cash reserves where the marginal cost and benefit of cash reserves are equal and it is optimal to start paying dividends.

To solve for equity value, we first consider the region in  $(0, \infty)$  over which it is optimal for shareholders to retain earnings. In this region, the firm does not deliver any cash flow to shareholders and equity value satisfies:

$$rE(w) = \left[ (1-\theta)((r-\lambda)w + \mu - C) + \underbrace{m(D(w) - S)}_{\text{Rollover gains/losses}} \right] E'(w) + \frac{1}{2} ((1-\theta)\sigma)^2 E''(w). \quad (4)$$

The left-hand side of this equation represents the required rate of return for investing in the firm's equity. The right-hand side is the expected change in equity value in the earnings retention region. The first term on this right-hand side captures the effects of cash savings and reflects debt rollover. That is, one important aspect of this equation is that the value of short-term debt feeds back into the value of equity via rollover imbalances. The second term captures the effects of cash flow volatility.

Equation (4) is solved subject to the following boundary conditions. First, when cash reserves exceed the target level  $W^*$ , the firm places no premium on internal funds and it is optimal to make a lump sum payment  $w - W^*$  to shareholders. We thus have

$$E(w) = E(W^*) + w - W^*$$

for all  $w \geq W^*$ . Subtracting  $E(W^*)$  from both sides of this equation, dividing by  $w - W^*$ , and taking the limit as  $w$  tends to  $W^*$  yields the condition:

$$E'(W^*) = 1.$$

The equity-value-maximizing payout threshold  $W^*$  is then the solution to the high-contact condition (see Dumas (1991)):

$$E''(W^*) = 0.$$

When the firm makes losses, its cash buffer decreases. If its cash buffer decreases sufficiently, the firm may be forced to raise new equity or to default. When the firm has no access to outside equity, it defaults as soon as its cash reserves are depleted. As a result, the condition

$$E(0) = \max\{\ell - S; 0\} = 0$$

holds at zero, and the liquidation proceeds are used to partially repay debtholders.

Consider next the value of short-term debt. Denote by  $D^0(w, t)$  the date- $t$  value of short-term debt issued at time 0. Since a fraction  $m$  of this original debt is retired continuously, these original debtholders receive a payment rate  $e^{-mt}(C + mS)$  at any time  $t \geq 0$  as long as the firm is solvent. Now define the value of total outstanding short-term debt by  $D(w) \equiv e^{mt}D^0(w, t)$ . Because  $D(w)$  receives a constant payment rate  $C + mS$ , it is independent of  $t$ . In the following, we only derive the function  $D(w)$ , i.e. the value of total short-term debt. From this value, we can also derive the value of newly issued short-term debt, denoted by  $d(w, 0)$ . In the Appendix, we show that it satisfies:  $d(w, 0) = mD(w)$ .

To solve for the value of total short-term debt  $D(w)$ , we first consider the region in  $(0, \infty)$  over which the firm retains earnings. In this region, the value of total short-term debt satisfies:

$$(r + m)D(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]D'(w) + \frac{((1 - \theta)\sigma)^2}{2}D''(w) + C + mS. \quad (5)$$

The left-hand side of equation (5) is the return required by short-term debtholders. The right-hand side represents the expected change in the value of total short-term debt on any time interval. The first and second terms capture the effects of a change in cash reserves and in cash flow volatility on debt value. The third and fourth terms are the coupon and principal payments to short-term debtholders.

This equation is solved subject to the following boundary conditions. First, the firm defaults the first time that its cash buffer is depleted. The value of short-term debt at this point is equal to the liquidation value of assets:

$$D(0) = \min\{\ell, S\} = \ell.$$

Second, the value of short-term debt does not change when dividends are paid out, because dividend payments accrue exclusively to shareholders. We thus have:

$$D'(W^*) = 0.$$

### 3.2 *The economic mechanism*

Before proceeding with the model analysis, we provide some intuition on the economic mechanism underlying our results—in particular, how short-term debt can generate risk-taking incentives. Our model incorporates two important features of real world environments: Financing frictions and fair debt pricing. Consider first the effects of financing frictions on shareholders’ risk taking incentives. As shown by previous dynamic models, shareholders in a profitable firm facing financing frictions behave in a risk-averse fashion to preserve equity value and prevent inefficient liquidations (see, e.g., Décamps et al. (2011) or Bolton et al. (2011)). Similarly, Leland (1994a) and Toft and Prucyk (1997) show that equity value can become a concave function of asset value in Leland-type models when the possibility of inefficient liquidation is introduced, e.g., via protective debt covenants or liquidity constraints (see Section 4.3). In these environments, shareholders cannot freely optimize the timing of default and, if the firm is fundamentally solvent (implying that the default option has a negative payoff), the equity value function is concave and shareholders are effectively risk-averse.

In all of these models, debt is either absent or has infinite maturity. The main contribution of our paper is to show that allowing for fairly-priced short-term debt financing in the presence of financing frictions yields radically different implications. Notably, when debt has finite maturity, it needs to be rolled over. If the firm cash flows deteriorate, the market value of newly-issued debt drops, leading to rollover losses. If rollover losses become sufficiently large, expected net cash flows may turn negative. When this is the case, shareholders have incentives to increase asset risk and “gamble for resurrection” to improve firm performance and avoid inefficient closure.

To single out this economic mechanism, consider a counterfactual firm financed with equity and infinite maturity debt (as in Leland (1994a), Bolton, Chen, and Wang (2015), or Hugonnier and Morellec (2017)). Since this firm does not need to roll over debt, its equity value  $E_\infty(w)$  satisfies the following equation

$$rE_\infty(w) = (1 - \theta) [(r - \lambda)w + \mu - C] E'_\infty(w) + \frac{1}{2} ((1 - \theta)\sigma)^2 E''_\infty(w)$$

in the earnings retention region. This equation is solved subject to the following boundary conditions:  $E_\infty(0) = E'_\infty(W_\infty^*) - 1 = E''_\infty(W_\infty^*) = 0$ , where  $W_\infty^*$  is the optimal payout trigger for shareholders. The value of risky, infinite-maturity debt satisfies:

$$rD_\infty(w) = (1 - \theta) [(r - \lambda)w + \mu - C] D'_\infty(w) + \frac{1}{2} ((1 - \theta)\sigma)^2 D''_\infty(w) + C,$$

in the earnings retention region, which is solved subject to  $D_\infty(0) - \ell = D'_\infty(W_\infty^*) = 0$ .

Three important features differentiate a firm financed with infinite-maturity debt from a firm financed with finite-maturity debt. First, while the value of debt reflects the equity value-maximizing payout/saving policy ( $W_\infty^*$  enters the debt's boundary conditions), the market value of infinite-maturity debt *does not* directly affect the market value of equity, because debt does not need to be rolled over. By contrast, when maturity is finite, the repricing of debt affects the market value of equity via debt rollover.

Second, expected net cash flows are given by  $(1 - \theta)(\mu - C)dt > 0$  in the infinite-maturity case, i.e. they are time-invariant and positive. As a result, the expected change in cash reserves on each interval of length  $dt$  is given by

$$(1 - \theta)[(r - \lambda)w + \mu - C]dt > 0,$$

and is always positive because  $\mu > C$  and  $w \geq 0$ . By contrast, expected net cash flows are given by  $[(1 - \theta)(\mu - C) + m(D(w) - S)]dt$  in the finite-maturity case and can become negative if rollover losses are sufficiently large. As a result, the expected change in cash reserves on each interval of length  $dt$  is given by

$$[(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]dt, \tag{6}$$

and can become negative if rollover losses are sufficiently large.

Third, because the firm is solvent and its expected net cash flows are positive in the infinite maturity case, shareholders behave in a risk-averse fashion. The reason is that shareholders want to avoid inefficient liquidation (or save on refinancing costs in the model with time-varying costs analyzed in Section 4.2) and have no incentives to

increase asset risk, even when the firm is levered. By contrast, expected net cash flows as well as the expected change in cash reserves can become negative in the finite debt maturity case because of rollover losses. In these instances, the firm is temporarily unprofitable and shareholders are not afraid of liquidation. The value of equity becomes convex (because of shareholders' limited liability), and shareholders have incentives to increase the riskiness of assets in order to improve firm fundamentals and debt repricing close to distress, as we show next.

### 3.3 *Risk-taking generated by short-term debt financing*

When a firm is financed with short-term debt (i.e.  $m > 0$ ), it needs to roll over maturing debt. Fair debt pricing implies that the value of newly-issued debt may differ from the principal repayment on maturing debt, leading to rollover imbalances. Over each time interval of length  $dt$ , rollover imbalances are given by the difference between the market value of newly-issued debt and the repayment on maturing debt:

$$R(w)dt \equiv m(D(w) - S)dt.$$

Because the probability of liquidation decreases with cash reserves  $w$ , the value of debt is monotonically increasing in  $w$  in the earnings retention region. Thus, there exists at most one threshold  $\bar{W}$  at which the rollover imbalance is zero, i.e. such that:  $D(\bar{W}) = S$ . The firm bears rollover losses for any  $w < \bar{W}$ , as the market value of debt  $D(w)$  is smaller than the principal repayment  $S$ . That is, lower cash reserves are associated with higher default risk, which reduces the value of newly-issued debt. Conversely, for any  $w \in (\bar{W}, W^*]$ , the firm is financially strong and default risk is low. The proceeds from newly issued debt exceed the principal repayment of maturing debt.

Insert Figure 1 Here

Figure 1 plots the firm's rollover imbalances as a function of cash reserves. The baseline values of the model parameters are reported in Table 1. We set the risk-free

rate of return to  $r = 0.035$ , the corporate tax rate to  $\theta = 0.3$ , and the mean cash flow rate to  $\mu = 0.09$ . We base the volatility of cash flows on the estimates reported by Sundaresan and Wang (2017) and set  $\sigma = 0.08$ . We base the value of liquidation costs on the estimates of Glover (2016) and set  $\varphi = 0.45$ . The carry cost of cash is set to  $\lambda = 0.01$ , as in Décamps et al. (2011) and Bolton et al. (2011). Given these input parameter values, the liquidation value of assets is equal to  $\ell = 0.99$ . The coupon rate  $C$  is set to 0.052. The face value  $S = 1.27$  is uniquely determined by requiring that debt is issued at par when at  $W^*/2$  for  $M = 1$ . This face value implies a recovery rate of 78% in default (i.e.  $\frac{\ell}{S} = 0.78$ ).

Insert Table 1 Here
---------------------

Figure 1 shows that rollover imbalances are markedly asymmetric, as rollover losses are larger in absolute value than rollover gains. The reason is that at the target cash level, positive operating shocks are paid out to shareholders, and debt value is insensitive to these shocks (i.e.,  $D'(W^*) = 0$ ). This in turn implies that debt value is almost insensitive to changes in cash if cash reserves are sufficiently large. The left panel of the figure also shows that rollover losses are more severe when debt maturity is shorter, because the fraction of debt that needs to be rolled over on each time interval is larger. The right panel shows that rollover losses are increasingly larger as the firm's profitability declines (i.e.,  $\mu$  decreases). If profitability deteriorates, the market value of debt decreases and rollover imbalances become more negative, all else equal.

As we show next, severe rollover losses due to short-term debt financing lead to convexity in equity value and, thus, to risk-taking incentives when firms face financing frictions. The reason is that as the firm approaches financial distress, the market value of debt decreases, and rollover losses increase. As a result, when the firm is sufficiently close to default, the expected change in cash reserves (i.e., expression (6)) can be negative and the firm can become temporarily unprofitable. This leads to the following proposition (see Appendix A.2).

**Proposition 1 (Short-term debt and incentives for risk-taking)** *When a firm is financed with short-term debt, equity value is locally convex when rollover losses are sufficiently large so that the inequality*

$$M [(1 - \theta)((r - \lambda)w + \mu - C)] + D(w) \leq S \quad (7)$$

*holds, where  $M = \frac{1}{m}$  is the average maturity of outstanding debt. In such instances, short-term debt financing provides shareholders with risk-taking incentives.*

A direct implication of Proposition 1 is that, in the presence of financing frictions and short-term debt financing, fair debt pricing implies that shareholders have risk-taking incentives if expected net cash flows are negative so that condition (7) is satisfied. The reason is the following. As long as (7) is satisfied, the sum of the expected net cash flows, the interest earned on cash holdings, and the proceeds from newly issued debt (i.e., the left-hand side of (7)) is lower than the repayment of maturing debt (the right-hand side of (7)). In other words, rollover losses are larger than net income. As a result, the value of an additional unit of cash to shareholders is low because it plays a minor role in helping the firm escape financial distress. (That is, consistently with Faulkender and Wang (2006), shareholders place a relatively low value on cash when they are burdened by sizable debt obligations.) Indeed, that unit of cash will be used to repay maturing debt and not to rebuild cash reserves. In expectation, the firm makes rollover losses, further reducing its cash reserves and increasing the risk of inefficient liquidation. In such instances, shareholders want to improve firm fundamentals and interim debt repricing to turn cash flows from negative to positive, which provides them with incentives to increase risk. As shown by condition (7), risk-taking incentives decrease as debt maturity  $M$  increases (because the fraction of debt that needs to be rolled over on each time interval is smaller, and so are rollover losses) and do not arise with infinite maturity debt.

We call this scenario, in which the firm “burns” cash and expected net cash flows are negative because of severe rollover losses, “the rollover trap.” When a firm is in the rollover trap, the marginal value of cash progressively increases as the firm approaches the break-even point at which (6) becomes positive. The marginal value of

cash to shareholders only starts decreasing with cash reserves—and equity value becomes concave—when expected cash flows become sufficiently large to guarantee that an additional unit of cash helps increase cash reserves rather than cover rollover losses.

Figure 2 plots the value of equity  $E(w)$  and the marginal value of cash to shareholders  $E'(w)$  as functions of cash reserves for  $w \in [0, W^*]$ . Figure 2 shows that the value of equity is increasing in cash reserves. However, the top panel of the figure also shows that the relation between value of equity, debt maturity, and cash reserves is non-trivial and reflects the potential losses generated by debt rollover. A shorter debt maturity decreases (respectively, increases) the value of equity when cash reserves are small (large) due to rollover losses (gains). Equity value is concave and shareholders are quasi risk-averse for any  $w$  for long debt maturities. Equity value can be locally convex close to liquidity distress if debt maturity  $M$  is sufficiently short.

Insert Figure 2 Here

To understand when short-term debt is more likely to generate incentives for risk-taking, Figure 2 also plots the value of equity  $E(w)$  and the marginal value of equity  $E'(w)$  as functions of cash reserves for varying levels of asset profitability  $\mu$  and liquidation costs  $\varphi$  when  $M = 5$ . The figure shows that larger liquidation costs are associated with a larger region of convexity for equity value. A lower recovery rate makes debt more risky and rollover losses more severe in distress, which in turn fuels risk-taking incentives. A decrease in asset profitability increases the region of convexity for equity value. That is, less profitable firms face larger costs of debt, implying that both rollover losses and shareholders' risk-taking incentives are larger.

Our result that short-term debt is associated with larger risk-taking incentives contrasts with previous models of rollover risk in which shareholders have deep pockets and can optimally choose the timing of default, such as Leland and Toft (1996) or Leland (1998). Section 4.3 shows that relaxing the assumption that shareholders can freely default at the time that maximizes equity value—for instance, because they face regulation, debt covenants, or financing frictions—implies that short-term debt *increases*

risk-taking incentives in these models as well, thereby demonstrating the robustness of our result. Also, it is worth noting that the principal and the coupon payment on outstanding aggregate debt are fixed in our model, as in Leland and Toft (1996), Leland (1998), or He and Xiong (2012a), among many others. This assumption does not trim the generality of our results. Suppose that shareholders are allowed to take on more debt when close to distress, to cover operating losses. As the face value of debt increased, rollover losses would widen with respect to the case in which shareholders keep leverage constant. All else equal, our results would be magnified. Section 4.1 illustrates this point by allowing the firm to take on more debt via credit line drawdowns.

### *3.4 Incentive compatibility problems*

An important question is whether risk-taking incentives generated by short-term debt financing are a source of agency conflicts. Agency conflicts arise if shareholders have risk-taking incentives (i.e., the value of equity is convex) whereas debtholders do not (i.e., the value of debt is concave). In this section, we seek to answer this question.

The dynamics of the value of short-term debt in the earnings retention region are given by equation (5). Now, consider a firm with a negative expected growth in cash reserves (i.e. (6) is negative or, equivalently, (7) is satisfied). Condition (7) is necessary but not sufficient for convexity in debt value to arise. Indeed, a key difference between debt and equity is that debtholders receive the periodic payments  $C + mS > 0$  (coupon plus principal payments) in the earnings retention region. Because debtholders want to preserve these periodic payments, they only have incentives to increase asset risk at the very brink of distress, when these payments are at stake. As a result, the region of convexity for the value of risky debt is always smaller than the region of convexity for equity value, or may not exist. An incentive compatibility problem therefore exists for the range of cash reserves for which the value of equity is convex and the value of debt is concave. This leads to the following proposition (see Appendix A.3).

**Proposition 2 (Agency conflicts and risk-taking)** *Whenever rollover losses are sufficiently large, the value of debt can be locally convex. The region of convexity in debt value is smaller than the region of convexity in equity value, giving rise to agency conflicts between shareholders and debtholders.*

Figure 3 illustrates the results in Proposition 2. When debt maturity is sufficiently long, both shareholders and debtholders are effectively risk averse and there are no agency conflicts (top panel). When debt maturity is sufficiently short so as to generate convexity in equity value, two scenarios are possible. First, only shareholders have incentives to increase asset risk, and an agency conflict arises when cash reserves are close to zero (middle panel). Second, both shareholders and debtholders have incentives to increase asset risk at the very brink of distress. In this case, an agency problem still arises for intermediate levels of cash reserves (bottom panel).

Insert Figure 3 Here

To better understand when incentive compatibility problems are likely to arise, Table 2 reports the inflection points for debt ( $W_D$ ) and equity ( $W_E$ ), the size of the region over which equity value is convex and debt value is concave (the agency region  $AR$ ), as well as the target cash level ( $W^*$ ) for different debt maturities ( $M$ ), cash flow drift ( $\mu$ ), cash flow volatility ( $\sigma$ ), liquidation costs ( $\varphi$ ), and debt principal ( $S$ ).

Insert Table 2 Here

Table 2 shows that risk-taking incentives are more likely to arise if debt maturity is short, in that both  $W_D$  and  $W_E$  decrease with  $M$ . When debt maturity is sufficiently long, equity and debt values are concave for any level of cash reserves, and both classes of claimholders behave as if they were risk-averse (this case is depicted in the top panel of Figure 3). In this case,  $W_D \notin (0, W^*]$  and  $W_E \notin (0, W^*]$ . In Table 2, we indicate these cases using “n.a.” for the values of  $W_D$  and  $W_E$ . The last column of this panel also shows that shorter debt maturity is associated with larger cash holdings, which is

consistent with the evidence reported by Harford, Klasa, and Maxwell (2014).<sup>9</sup>

We further investigate how risk-taking incentives vary as a function of other firm characteristics, when fixing debt maturity at  $M = 1$ . The second panel of Table 2 shows that both risk-taking incentives (i.e.,  $W_D$  and  $W_E$ ) and agency problems (i.e., the agency region  $AR$ ) decrease with profitability  $\mu$ . Indeed, a decrease in profitability exacerbates rollover losses and makes it more likely that the inequality (7) is satisfied. The third panel shows that increasing volatility results in a decrease (respectively, increase) in debtholders' (shareholders') risk-taking incentives. As a result, agency problems are more likely to arise if  $\sigma$  is large, all else equal. The fourth panel shows that liquidation costs increase the risk-taking incentives of both shareholders and debtholders. Liquidation costs decrease the market value of debt when close to distress, magnifying rollover losses and fueling risk-taking incentives for both shareholders and debtholders. Overall, our results show that firms financed with short-term debt are more likely to face such agency problems when they have higher leverage, lower profitability, and more volatile cash flows (i.e. lower credit rating). It is worth emphasizing that if we set  $M = \infty$ , agency conflicts do not arise when varying  $\mu$ ,  $\sigma$ ,  $\varphi$ , and  $S$  and all claimholders are effectively risk-averse for any  $w \in [0, W^*]$ . Finally, the last panel of Table 2 shows that, all else equal, the region of agency conflicts is larger when the firm is more levered. If the face value of debt  $S$  is small enough, debtholders have no incentives for risk-taking. As  $S$  increases,  $W_D$  becomes positive, and the agency region widens.

Figure 4 plots the value of debt  $D(w)$  and the marginal value of cash to debtholders  $D'(w)$  as functions of cash reserves, for different debt maturities.  $D(w)$  increases with maturity, as a shortening of maturity implies an increase in rollover losses and, thus, in liquidation risk. In addition, while debtholders suffer from the risk implied by a shorter

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<sup>9</sup>In unreported results, we find that the target cash level *can* be locally increasing in debt maturity at the higher end of the maturity spectrum (especially if leverage is relatively low). The reason is that when debt maturity is sufficiently long, rollover losses are minimal. Thus, the main effect of shortening debt maturity is a decrease in the cost of debt, which leads to a decrease in the precautionary need of cash and, thus, in the target cash level.

debt maturity due to larger rollover losses, they do not capture the upside potential due to any rollover gains. Figure 4 also shows that the convexity is less pronounced for debtholders than for equityholders.

Insert Figure 4 Here

It is worth noting that our predictions are different from the standard Jensen and Meckling (1976) result that risk-shifting incentives are larger when firms are close to default. In our model, maturity plays a key role in determining risk-taking incentives—i.e., shareholders have no incentives to increase asset risk if the firm is financed with debt with sufficiently long maturity. In addition, risk-taking incentives lead to agency conflicts for intermediate levels of cash reserves (i.e., in the cash interval  $(W_D, W_E)$ ), but may be optimal at the very brink of distress for both shareholders and debtholders.

### 3.5 *Assessing the effect of risk-taking strategies*

We have just shown that, in a world with financing frictions and fair debt pricing, short-term debt financing generates a local convexity in the value of equity and, to a lower extent, in the value of debt. In this section, we analyze the effects of risk-taking strategies on the value of corporate securities. To do so, we follow Bolton, Chen, and Wang (2011), Hugonnier, Malamud, and Morellec (2015), and Décamps, Gryglewicz, Morellec, and Villeneuve (2017) and assume that the firm has access to a futures contract whose price is a Brownian motion  $B_t$ , uncorrelated with the Brownian motion  $Z_t$  driving the firm cash flows. A position  $\gamma_t$  in the futures contract thus changes the dynamics of firm cash flows from  $dY_t$  to  $dY_t + (1 - \theta)\gamma_t dB_t$ , i.e., it only changes the riskiness of cash flows. Futures positions are generally constrained by margin requirements. To capture these requirements, we consider that the futures position  $\gamma_t$  cannot exceed some fixed size  $\Gamma$ .

Assuming frictionless trading in the futures contract, standard arguments show that

in the region over which the firm retains earnings, equity value satisfies:

$$rE(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]E'(w) + \max_{0 \leq \gamma \leq \Gamma} \left\{ \frac{1}{2}(1 - \theta)^2 (\sigma^2 + \gamma^2) E''(w) \right\}, \quad (8)$$

where the last term on the right-hand side captures the effects of risk-taking on equity value. By differentiating with respect to  $\gamma$ , we can determine the optimal risk-taking strategy. This leads to the following Proposition (see Appendix A.4).

**Proposition 3 (Optimal risk-taking strategy)** *For all  $w$  such that  $E''(w) > 0$ , shareholders find it optimal to increase the volatility of assets by taking the maximum position in future contracts ( $\gamma = \Gamma$ ). For all  $w$  such that  $E''(w) < 0$ , shareholders behave as if they were risk-averse and take no positions in future contracts ( $\gamma = 0$ ).*

Proposition 3 reveals that the optimal risk-taking policy is of bang-bang type: If risk-taking is optimal for shareholders because equity value is convex, shareholders choose the riskiest strategy (Appendix A.4 solves for the values of equity and debt). Our result can therefore rationalize the evidence reported by Gan (2004), who finds that if (financial) firms are hit by a shock that wipes out their profits, they tend to choose either the minimal or the maximal feasible risk. Our model illustrates that firms take the minimal or the maximal risk depending on debt maturity: If maturity is sufficiently short (respectively, long), firms will take on the maximal (minimal) risk.

Insert Figure 5 Here

The top panel of Figure 5 shows the effect of different risk-taking strategies on the value of equity, when debt maturity  $M$  is one year (left panel) and three years (right panel). The figure shows that risk-taking increases the value of equity when it is convex—that is, when debt maturity is short and cash reserves are low. The figure also shows that the increase in equity value due to risk-taking is greater when debt maturity is shorter, because the region of convexity is larger. Moreover, when equity value is convex, the

strategy associated with the largest increase in cash flow volatility (i.e., the largest  $\Gamma$ ) is the one that increases equity value the most.

Proposition 2 and Proposition 3 together lead to the following result.

**Corollary 4 (Risk-taking and debt value)** *Risk-taking leads to: (1) an increase in the value of debt in the region over which debt value is convex, (2) a decrease in the value of debt in the region over which equity value is convex but debt value is concave.*

To illustrate the results in Corollary 4, recall the scenarios represented in the middle and bottom panels of Figure 3. In the middle panel, debt value is concave for any level of cash reserves. In this case, risk-taking strategies lead to a decrease in the value of debt. This result is in line with previous models following Jensen and Meckling (1976). Shareholders have incentives to increase asset risk in distress, and this is detrimental to debtholders. As a result, risk-taking increases credit risk.

The bottom panel of Figure 3 illustrates a different scenario, in which debt value can be locally convex. As shown in Section 3.4, the value of debt is locally convex when rollover imbalances are large and the firm is sufficiently close to distress. In such instances, risk-taking strategies increase the values of equity *and* debt. This result is illustrated in the bottom panel of Figure 5, which shows that increasing asset volatility leads to a modest decrease in yield spreads (i.e., a modest increase in debt value) at the very brink of distress. However, because the size of the region of convexity in equity value is larger than the region of convexity in debt value (by Proposition 2), shareholders have incentives to increase asset risk even when this is suboptimal for debtholders. Consistently, Figure 5 shows that increasing asset volatility leads to an increase in yield spreads for intermediate levels of cash reserves—i.e. when the value of debt is concave. The increase in yields is greater when debt maturity is shorter (because, as shown in Table 2, the agency region is larger) and amplified for larger values of  $\Gamma$ . It is also worth noting that the increase in yield spreads for intermediate levels of cash reserves (i.e., outside distress) is greater in absolute value than the decrease in spreads for small levels of cash reserves (i.e., close to distress). That is, risk-taking strategies

lead to a sharp increase in the cost of debt when the firm is far from distress, which raises the likelihood of entering the rollover trap.

Cheng and Milbradt (2012) also show that risk-taking incentives can increase both equity and debt values close to distress. Our result differs from theirs in two important dimensions. First, in Cheng and Milbradt (2012), increasing asset risk enhances creditors' confidence that future creditors will not run. Instead, in our model, increasing asset risk has a positive impact on the price of newly-issued debt in distress, effectively reducing yield spreads on debt and decreasing the magnitude of rollover losses. Second, in Cheng and Milbradt (2012), risk-shifting incentives are minimized for an intermediate debt maturity, as long debt maturities lead to an increase in risk-taking in good times (i.e., when the firm is sufficiently far from default). In our model, agency problems decrease with debt maturity and do not arise if debt maturity is sufficiently long.

### *3.6 Implications for capital structure*

We next investigate the capital structure implications of our economic mechanism. To do so, we allow the debt principal to be a function of the coupon  $C$  and impose that debt is issued at par at a given level of cash reserves. We use different initial levels of cash reserves to account for varying degrees of financial constraints at the time the firm is set up. As in Leland (1994), the coupon is chosen at the initial date to maximize the sum of equity and debt values (as calculated in Section 3.1), under the constraint that debt is issued at par. That is, we look for

$$V(w_0; C, m, S) \equiv \sup_{C \in \mathbb{R}_+} [E(w_0; C, m, S) + D(w_0; C, m, S)],$$

under the budget constraint

$$w_0 = W_{0-} + S - I,$$

where  $I$  is the initial investment cost and  $W_{0-}$  is the initial cash endowment before financing and the constraint that short-term debt is initially issued at par

$$D(w_0; C, m, S) = S.$$

Table 3 shows the capital structure that maximizes firm value as a function of debt maturity. When debt maturity is infinite, there are no rollover imbalances. In this case, the optimal debt level balances the tax benefits of debt with bankruptcy costs. When debt maturity is finite, two additional factors shape capital structure choices. First, a short debt maturity imposes larger rollover losses when cash reserves are low, which increases the cost of debt and, thus, decreases the firm’s debt capacity. Second, a short debt maturity increases the proceeds from debt rollover when cash reserves are large (and default risk is low), which decreases the cost of debt and increases the firm’s debt capacity. When debt maturity is relatively short, the first effect dominates and the threat of large rollover losses makes the coupon that maximizes firm value smaller compared to the infinite maturity case. That is, by generating substantial rollover losses, a shorter maturity decreases the firm’s debt capacity and optimal leverage.

Insert Table 3 Here
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Table 3 also shows that our model can deliver a *finite* optimal debt maturity. In our model, a decrease in average debt maturity decreases the value of risky debt by increasing rollover losses and default risk. As mentioned earlier, debtholders suffer from the downside risk and do not capture any upside from issuing short-term. Therefore, the value of debt is the largest when maturity is infinite. This is what we call the *debt effect*. For shareholders, however, a shortening of average debt maturity has contrasting effects depending on the firm’s cash reserves (see Figure 2). When cash reserves are low, a shorter debt maturity leads to larger rollover losses, which decrease the value of equity. When cash reserves are large, a shorter maturity leads to larger net proceeds from rolling over maturing debt, which increase the value of equity. This is what we call the *equity effect*. Table 3 shows that the maturity that maximizes initial firm value is finite if the initial level of cash reserves is sufficiently large— $W^*/2$  in our numerical example. The underlying motive for choosing short-term debt maturities in our model is thus very different from previous contributions, in which short-term debt maturity allows firms to *reduce* the agency costs of risk-shifting (Leland and Toft (1996) or Cheng

and Milbradt (2012)) or to reduce the cost of bond illiquidity (Ericsson and Renault (2006), He and Xiong (2012a) or He and Milbradt (2014)). In our model, short-term debt maturity decreases the cost of debt financing for solvent firms, but this benefit needs to be weighted against severe rollover losses when cash flows deteriorate.

## 4 Robustness to alternative model specifications

### 4.1 Increasing debt exposure via credit lines

In our benchmark analysis, the firm is forced into liquidation when cash reserves are depleted and access to the equity market is prohibitively expensive. We now assess the robustness of our main results by allowing the firm to take on additional debt via credit line drawdowns. In practice, credit lines provide firms with immediate liquidity that can be used in times of need (see Sufi (2009)). In our model, they allow the firm to acquire flexibility in their debt and liquidity policies, with a total amount of (net) debt varying between  $S - W^*$  and  $S + L$ , where  $L$  is the pre-established limit on the credit line.

Specifically, assume that the firm has access to a credit line with pre-determined limit  $L \geq 0$ . For the amount of credit that the firm uses, the interest spread over the risk-free rate is  $\beta > 0$ . Because of this spread, the firm will optimally avoid using its credit line before exhausting internal funds. That is, the firm uses cash as the marginal source of financing if  $w \in [0, W^*(L)]$  (the cash region), where  $W^*(L)$  denotes the target cash level when the firm has access to a credit line. Conversely, the firm draws funds from the credit line when  $w \in [-L, 0]$  (the credit line region). In the following, we assume that the credit line has priority over short-term debt and that  $L < \ell$ , implying that the credit line is fully collateralized. We report the system of equations satisfied by equity and debt values when the firm has access to a credit line in Appendix A.5.

Insert Figure 6 Here

Figure 6 describes the effects of credit lines on the values of corporate securities and rollover imbalances. Because a credit line serves as an additional source of liquidity,

the figure shows that credit lines reduce the need for large cash balances in that the target cash level is smaller when  $L > 0$  (see also Bolton, Chen, and Wang (2011) or Décamps, Gryglewicz, Morellec, and Villeneuve (2017)). By reducing the expected cost of financing frictions, credit lines increase the values of debt and equity in the cash region. Nonetheless, credit lines reduce the value of short-term debt in the credit line region. The reason is that the credit line has to be paid in full before debtholders can collect any liquidation proceeds. The resulting lower payoff to short-term debt in liquidation leads to larger rollover losses when the firm is close to exhausting the credit line (see the bottom right panel). This implies that *senior* credit lines strengthen the amplification mechanism highlighted in Section 3.3 and, therefore, shareholders' incentives for risk-taking. This analysis therefore not only confirms our results on the effects of short-term debt on risk-taking incentives, but also shows that these effects can be magnified by the presence of a secured credit line.

## 4.2 Time-varying financing conditions

Having explained the effects of short-term debt on corporate policies and incentives for risk-taking in a model in which firms do not have access to outside equity, we now analyze a more general environment in which funding conditions are time-varying, as described in Section 2.

In such an environment, the firm still finds it optimal to hold cash reserves, but the target level of cash reserves is state-dependent, denoted by  $W_i^*$ . Notably, because financial frictions are more severe in state  $B$  than in state  $G$ , we expect the target level of cash reserves to be larger in state  $B$ . That is, we expect  $W_B^* > W_G^*$ . Another key difference with the model presented in Section 3 is that the firm can raise equity at a cost when in state  $G$ . As in Bolton, Chen, Wang (2013), the firm may choose to raise funds before its cash buffer gets completely depleted, to avoid that financing conditions worsen when cash reserves are close to zero. We denote the issuance boundary in state  $G$  by  $\underline{W} \in [0, W_G^*)$ . We report in Appendix A.6 the system of equations satisfied by the

values of equity  $E_i(w)$  and short-term debt  $D_i(w)$  in each state  $i$ .

We first analyze how time-varying financing conditions affect the price at which short-term debt is rolled over and the magnitude and sign of rollover imbalances. Consider first the bad state. In that state, the firm may be forced into default after a series of negative shocks because it is unable to raise new equity if it runs out of funds. Thus, the bad state displays a pattern that is analogous to the case analyzed in Section 3. Specifically, there exists a level of cash reserves  $\bar{W}_B$  such that  $D_B(\bar{W}_B) = S$ , i.e. such that new debt is issued at par. Rollover imbalances are negative (respectively positive) below (above) the threshold  $\bar{W}_B$ . Moreover, as in the case analyzed in Section 3, rollover imbalances decrease as debt maturity increases.

Insert Figure 7 Here

Consider next the good state. In this state, default never occurs because the firm can always raise capital by paying the cost  $\phi$ . The value of newly-issued debt is greater than in the bad state, and even more so if debt maturity is shorter. As noted by Acharya, Krishnamurthy, and Perotti (2011): “Creating exposure to liquidity risk is profitable in good times, but creates vulnerability to massive losses when the risk perception changes.” In line with this intuition, Figure 7 (top panel) shows that short-term debt financing may be attractive to shareholders in the good state, because the market value of debt is relatively larger and so are the proceeds from debt rollover, which increases equity value (middle panel). However, short-term debt leads to rollover losses in the bad state, which increases default risk and decreases the value of equity.

The analysis in Section 3 has shown that the value of equity can be locally convex when rollover losses are large. When financing conditions are time-varying, this pattern is preserved in the bad state. The value of equity can also be locally convex in the good state, but for a different reason (Figure 7, bottom panel). In the good state, this convexity is related to the possibility to time the market by issuing securities when the cost of external finance is low, as in Bolton, Chen, and Wang (2013). Overall, Figure 7 demonstrates that short-term debt generates incentives for risk-taking in this alternative

financing environment too. That is, our main result is not specific to the way financing frictions are modeled.

To better understand the relation between debt maturity, time-varying financing frictions, and cash holdings policies, Table 4 reports the target level of cash reserves in the bad and good states for different debt maturities.

Insert Table 4 Here
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The table reveals that by imposing larger rollover losses in bad times, a shorter maturity pushes the firm to increase its target cash reserves, in line with Harford, Klasa, and Maxwell (2014). Table 4 also shows that the bad state commands a larger target cash level ( $W_B^* > W_G^*$ ), consistent with the evidence reported by Acharya, Shin, Yorulmazer (2010) that bank liquidity buffers are counter-cyclical. Lastly, consistent with the fact that the timing option in the good state is more valuable when the firm has issued shorter-term debt, Table 4 shows that the refinancing threshold  $\underline{W}$  (i.e. the exercise threshold for the timing option) decreases as debt maturity increases.

### 4.3 *Introducing financing frictions in a Leland-type setup*

Our result that short-term debt generates risk-taking incentives goes against the long-standing idea that short-term debt reduces the agency cost of asset substitution, as discussed for example in Leland and Toft (1996) or Leland (1994b, 1998). In this section, we show that this result is not driven by the assumption about the stochastic process governing the firm’s cash flows but rather by the fact that financing frictions constrain shareholders’ default decision.<sup>10</sup> To do so, we consider in this section a setup à la Leland (1994b, 1998) in which we relax the assumption that shareholders have deep pockets and can choose the timing of default that maximizes equity value. The results derived

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<sup>10</sup>In line with previous dynamic models with financing frictions such as Décamps, Mariotti, Rochet, and Villeneuve (2011), Bolton, Chen, and Wang (2011, 2013), or Hugonnier, Malamud and Morellec (2015), cash flows are governed by an arithmetic Brownian motion in our model. In Leland-type models, total cash flows and asset values are governed by a geometric Brownian motion.

in this section also hold in a Leland and Toft (1996) setup, in which bond expirations are uniformly spread out over time.

Consider a firm whose unlevered asset value  $V = (V_t)_{t \geq 0}$  follows a geometric Brownian motion:

$$dV_t = (\mu - \delta)V_t dt + \sigma V_t dZ_t, \quad (9)$$

where  $\mu$  is the total expected rate of return,  $\delta$  is the constant payout rate, and  $dZ_t$  is the increment of a standard Brownian motion. The firm is financed with equity and short-term debt, as described in Section 2. In Leland (1994b, 1998) or Leland and Toft (1996), the process in (9) continues without time limit unless  $V$  falls to a default-triggering value  $V_B$ , which is endogenously determined to maximize equity value. In these models, shareholders can inject funds in the firm instantaneously and at no cost, and equity value is a convex function of asset value when debt maturity is infinite or sufficiently long. Shareholders thus have incentives to increase asset risk, which is detrimental to debtholders. Conversely, if maturity is sufficiently short, increasing risk does not benefit shareholders, except when default is imminent. In this setting, short-term debt acts as a disciplining device by decreasing shareholders' risk-taking incentives.

Suppose now that shareholders *cannot* optimize the timing of default because of financing frictions, debt covenants, or regulatory constraints, and denote by  $V_b$  the exogenous threshold (for asset value) triggering default. To consider relevant cases, we assume that  $V_b$  is greater than  $V_B$ , so that shareholders are forced to liquidate the firm's assets early, when suboptimal for them. Default can be interpreted in this context as being triggered by the breach of a net-worth covenant. Alternatively, it can be interpreted as a liquidity default caused by financing frictions. As shown by Leland (1994a) and Toft and Prucyk (1997), when the default boundary is exogenous and sufficiently large, equity value becomes a concave function of asset value. In this case, shareholders are effectively risk-averse and have no risk-taking incentives.<sup>11</sup>

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<sup>11</sup>A similar result obtains in the models of cash management with financing frictions and infinite maturity debt developed by Bolton, Chen, and Wang (2015) or Hugonnier and Morellec (2017).

We now show that short-term debt can restore the convexity of equity value when the default boundary is exogenous. The mechanism is similar to that analyzed in Section 3. To see this, consider the expected net cash flow to shareholders when varying debt maturity  $M$ . When  $M = \infty$ , this expected net cash flow is given by

$$[\delta V_t - (1 - \theta)C]dt, \tag{10}$$

on any interval of length  $dt$ , which is the total firm payout minus the after-tax coupon payment. When  $M$  is finite, the net cash flow to equityholders is given by

$$[\delta V_t - (1 - \theta)C + \underbrace{m(D(V_t; m) - S)}_{\text{Rollover imbalance}}]dt \tag{11}$$

where the last term in the square bracket represents the firm's rollover imbalance. When asset value is low so that  $D(V_t; m) < S$ , the firm faces rollover losses. When average debt maturity is shorter, the fraction  $m$  of debt that needs to be rolled over each time interval is larger, which magnifies rollover losses as fundamentals deteriorate. For sufficiently short debt maturity, expression (11) can be negative even for values of  $V_t$  that make expression (10) positive. That is, if rollover losses are sufficiently large, expected net cash flows to shareholders turn negative. In this case, shareholders hold an out-of-the-money option and have incentives to increase asset risk.

Insert Figure 8 Here

Figure 8 provides an illustration of this result by plotting the value of equity and the marginal value of equity as functions of the value of the firm's assets, for different debt maturities. In this figure, we base our parametrization on Leland (1994b) and set the risk-free rate to 7.5%, the cash flow volatility to 0.20, bankruptcy costs to 0.5, the tax rate to 0.35, and the payout rate to 0.07. Additionally, we set the value of debt principal and coupon to 65 and 6, respectively. In the top panel, we impose an exogenous default boundary equal to  $V_b = 90$ , which is larger than the endogenous default boundaries. The top panels of the figure demonstrate that incentives for risk taking are less pronounced for long-term debt than for short-term debt *if* shareholders

are constrained in their default decisions. If debt maturity is sufficiently long, equity value is concave for all asset values and equityholders have no risk-taking incentives. If debt maturity is short, equity value becomes convex when asset value is sufficiently close to the default threshold. As shown in the bottom panels, this is not the case when shareholders are unconstrained in their default decisions. In this case, long-term debt is associated with risk-taking incentives for any  $V$ .

It is worth noting that risk-taking incentives in this context arise in fundamentally solvent firms, i.e. firms for which expression (10) is positive. They are driven by liquidity problems rather than by solvency problems. Because financing frictions are key to this mechanism and because they lead shareholders to value retained earnings, our baseline model is one in which we allow firms to keep cash reserves, as in Décamps, Mariotti, Rochet, and Villeneuve (2011) or Bolton, Chen, and Wang (2011).

## 5 Conclusion

A commonly-accepted view in corporate finance and banking is that short-term debt can discipline management and curb moral hazard, thereby improving firm value. This view does not seem to be supported, however, by the available evidence. This paper shows that, for firms facing financing frictions or regulatory constraints, short-term debt does not decrease but, instead, increases incentives for risk-taking. To demonstrate this result and examine its implications for corporate policies, we develop a model in which firms are financed with equity and risky short-term debt and face taxation, financing frictions, and default costs. In this model, firms own a portfolio/operate a set of risky assets and have the option to invest in risk-free, liquid assets such as cash reserves. Firms maximize shareholder value by choosing their buffers of liquid assets as well as their financing, risk management, and default policies. A key difference with prior work is that financing frictions and/or regulatory constraints affect the firm's default decision, so that the timing of default may be suboptimal for shareholders.

With this model, we show that when a firm has short-term debt outstanding and debt

is fairly priced, negative operating shocks lead to a drop in cash reserves and cause the firm to suffer losses when rolling over short term debt, due to weaker fundamentals. This amplification mechanism leads to an increase in default risk, that gets more pronounced for firms financed with shorter-term debt. When firms are close to distress and debt maturity is short enough, rollover losses can be larger than expected operating profits, dragging the firm closer to default. In contrast with extant models with long-term debt financing and financing frictions or with short-term debt but without financing frictions or regulatory constraints, our model demonstrates that in such instances short-term debt provides shareholders with incentives for risk-taking. That is, we show that financing frictions or regulatory constraints combined with fair debt pricing imply behavior that is in sharp contrast with the long-standing idea that short-term debt has a disciplinary role and reduces agency costs.

## Appendix

### A.1 Deriving the value of short-term debt

We start by deriving the value of total short-term debt, denoted by  $D(w)$ . Since the firm keeps a stationary debt structure,  $D(w)$  receives a constant payment rate  $C + mS$  that is independent of  $t$ . Following standard arguments, the function  $D(w)$  satisfies the following ordinary differential equation (ODE):

$$(r + m)D(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + d(w) - mS]D'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 D''(w) + C + mS$$

where  $d(w)$  is the value of currently-issued short-term debt. For any given time  $t$ , we denote by  $d(w, \tau)$  the value of the outstanding debt of generation  $\tau \leq t$ , with  $\tau \in [-\infty, 0]$ . Therefore,  $d(w, 0) = d(w)$  represents the value of currently-issued short-term debt (i.e.,  $\tau = 0$  at the current time), and we have the following relation

$$d(w, \tau) = e^{m\tau} d(w).$$

All remaining units of short-term debt from prior issues have the same value per unit, as units of all vintages pay the same coupon, and the remaining units of all vintages will be retired at the same fractional rate. However, there are fewer outstanding units of debt of older generations due to accumulated debt retirement. Integrating  $d(w, \tau)$  over  $\tau \in [-\infty, 0]$  gives the total value of short-term debt outstanding  $D_i(w)$ , and then the following important relation

$$D(w) = d(w) \int_{-\infty}^0 e^{\tau m} d\tau = \frac{d(w)}{m}$$

holds. Using this relation, together with the ODE describing the dynamics of  $D(w)$ , we finally get the ODE for currently issued short-term debt, given by

$$rd(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + d(w) - mS]d'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 d''(w) + mC + m[mS - d(w)].$$

The third term on the right-hand side implies that the short-term debt issued today promises a coupon payment  $mC$  on any time interval. Recall that exponential repayment of debt with average maturity  $1/m$  implies that debt matures randomly at the jump times of a Poisson process with intensity  $m$ . The fourth term on the right-hand side then represents the payoff obtained by the debtholders when the debt randomly matures times the probability of this occurrence.

### A.2 Proof of Proposition 1

Condition (7) in Proposition 1 can be rewritten as

$$(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S) \leq 0,$$

where  $m$  is the fraction of total debt that is rolled over. When shareholders have limited liability, equity value satisfies  $E(w) \geq 0$ . In addition, equity value is increasing in cash reserves, in that  $E'(w) > 0$ . As a result, when the above condition is satisfied we have

$$\underbrace{rE(w)}_{\geq 0} = \underbrace{[(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)] E'(w)}_{\leq 0} + \frac{1}{2} ((1 - \theta)\sigma)^2 E''(w),$$

which implies that  $E''(w) \geq 0$ . That is, equity value is locally convex.

### A.3 Proof of Proposition 2

Debt value is non-negative ( $D(w) \geq 0$ ) and non-decreasing in cash reserves ( $D'(w) \geq 0$ ). Moreover, the periodic payment to debtholders  $C + mS \geq 0$  is non-negative. When condition (7) in Proposition 1 is satisfied, we have

$$\underbrace{(r + m)D(w)}_{\geq 0} = \underbrace{[(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)] D'(w)}_{\leq 0} + \frac{1}{2} ((1 - \theta)\sigma)^2 D''(w) + \underbrace{C + mS}_{\geq 0}$$

which implies that  $D''(w)$  can be positive (and, thus, the value of debt is convex) if condition (7) is sufficiently negative.

As in the main text, we denote by  $W_D$  the level of cash reserves that separates the region of concavity and of convexity in debt value (i.e., such that  $D''(W_D) = 0$ ). We also denote by  $W_E$  the level of cash reserves that separates the region of concavity and of convexity in equity value (i.e., such that  $E''(W_E) = 0$ ). Because debtholders receive the periodic payment  $C + mS$  (which increases the right-hand side of the above ODE), the inequality  $W_D \leq W_E$  holds. As a result, the region of convexity in debt value is smaller than the region of convexity in equity value.

#### *A.4 Proof of Proposition 3*

We derive the optimal risk-taking policy and the value of the firm's securities under the assumptions in Section 3.5. Assuming frictionless trading in futures contracts, standard arguments imply that, in the earnings retention region, the value of equity satisfies the Hamilton-Jacobi-Bellman equation reported in Section 3.5, equation (8). By simply differentiating this equation with respect to the control, it follows that management takes on the maximum position  $\Gamma$  in the future contract if  $E''(w) > 0$ , i.e. if the value of equity is convex. Conversely, management takes no position in the contract if  $E''(w) < 0$ , i.e. if the value of equity is concave. We denote by  $W_\Gamma$  the cash level that separates the convex and the concave region, i.e. such that

$$E''(W_\Gamma) = 0.$$

The optimal risk-taking policy is thus of a bang-bang type:

$$\gamma = \begin{cases} \Gamma & \text{if } 0 \leq w < W_\Gamma, \\ 0 & \text{if } W_\Gamma \leq w < W^*(\Gamma). \end{cases}$$

That is, if risk-taking is optimal, it happens at the maximal rate. Note that the target level of cash holdings is denoted by  $W^*(\Gamma)$  in this environment.

In analogy to Section 3, management finds it optimal to pay out dividends to shareholders when the cash reserves exceed  $W^*(\Gamma)$ , and the value of equity is linear above this target level. Differently, the optimal risk-taking policy means that, when

$W_\Gamma \in (0, W^*(\Gamma))$ , the cash retention region  $[0, W^*(\Gamma))$  is characterized by a risk-taking region,  $[0, W_\Gamma)$ , and a no-risk-taking region,  $[W_\Gamma, W^*(\Gamma))$ . In the risk-taking region  $[0, W_\Gamma)$ , the value of equity satisfies the following differential equation

$$rE(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]E'(w) + \frac{1}{2}(1 - \theta)^2 (\sigma^2 + \Gamma^2) E''(w).$$

In the no-risk-taking region  $[W_\Gamma, W^*(\Gamma))$ , the value of equity satisfies

$$rE(w) = (1 - \theta)[(r - \lambda)w + \mu - C + m(D(w) - S)]E'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 E''(w).$$

The system of ODEs for the value of equity is solved subject to the following boundary condition at the default/liquidation threshold,  $E(0) = 0$ , and the boundary conditions at the target cash level,  $\lim_{w \uparrow W^*(\Gamma)} E'(w) = 1$  and  $\lim_{w \uparrow W^*(\Gamma)} E''(w) = 0$ . These boundary conditions are similar to those derived in Section 3 and admit an analogous interpretation. In addition, we now need to impose continuity and smoothness at  $W_\Gamma$ ,

$$\lim_{w \uparrow W_\Gamma} E(w) = \lim_{w \downarrow W_\Gamma} E(w) \quad \text{and} \quad \lim_{w \uparrow W_\Gamma} E'(w) = \lim_{w \downarrow W_\Gamma} E'(w),$$

to ensure that the risk-taking region and the no-risk-taking regions are smoothly pasted.

Since debtholders have rational expectations, the value of debt reflects this risk-taking policy. As this policy is chosen by management to maximize shareholders' value, this means that risk-taking may occur even when the value of debt is concave — then decreasing the value of debt. In the risk-taking region  $[0, W_\Gamma)$ , the value of short-term debt  $D(w)$  satisfies

$$(r + m)D(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]D'(w) + \frac{1}{2}(1 - \theta)^2 (\sigma^2 + \Gamma^2) D''(w) + C + mS.$$

In the no-risk-taking region  $[W_\Gamma, W^*(\Gamma))$ ,  $D(w)$  satisfies

$$(r + m)D(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]D'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 D''(w) + C + mS.$$

On top of the boundary conditions at 0 and  $W^*(\Gamma)$  as in Section 3, respectively  $D(0) = (\ell - \Delta)^+$  and  $D'(W^*(\Gamma)) = 0$ , we impose continuity and smoothness at  $W_\Gamma$ , i.e.

$$\lim_{w \uparrow W_\Gamma} D(w) = \lim_{w \downarrow W_\Gamma} D(w) \quad \text{and} \quad \lim_{w \uparrow W_\Gamma} D'(w) = \lim_{w \downarrow W_\Gamma} D'(w).$$

### A.5 Credit lines

We derive the system of equations for the values of equity and short-term debt in the presence of a credit line, as analyzed in Section 4.1. The firm uses cash as the marginal source of financing if  $w \in [0, W^*(L)]$  (the cash region), where  $W^*(L)$  denotes the target cash level as a function of  $L$ . Conversely, the firm draws funds from the credit line when  $w \in [-L, 0]$  (the credit line region). In the cash region, the value of equity satisfies the following ODE

$$rE(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]E'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 E''(w).$$

In the credit line region, the firm needs to pay interests on borrowed funds, and the value of equity satisfies

$$rE(w) = [(1 - \theta)((r + \beta)w + \mu - C) + m(D(w) - S)]E'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 E''(w).$$

Similarly, the value of short-term debt satisfies the following ODE

$$(r+m)D(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D(w) - S)]D'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 D''(w) + C + mS$$

in the cash region, whereas it satisfies the following ODE

$$(r+m)D(w) = [(1 - \theta)((r + \beta)w + \mu - C) + m(D(w) - S)]D'(w) + \frac{1}{2}((1 - \theta)\sigma)^2 D''(w) + C + mS$$

in the credit line region.

The system of equations is solved subject to the following boundary conditions at the liquidation boundary  $(-L)$  and at the payout boundary  $(W^*(L))$ :

$$E(-L) = E'(W^*(L)) - 1 = E''(W^*(L)) = 0,$$

and

$$D(-L) - (\ell - L) = D'(W^*(L)) = 0,$$

as well as the continuity and smoothness conditions where the credit line and cash regions are pieced together

$$\begin{aligned} \lim_{w \uparrow 0} E(w) &= \lim_{w \downarrow 0} E(w), \text{ and } \lim_{w \uparrow 0} E'(w) = \lim_{w \downarrow 0} E'(w) \\ \lim_{w \uparrow 0} D(w) &= \lim_{w \downarrow 0} D(w), \text{ and } \lim_{w \uparrow 0} D'(w) = \lim_{w \downarrow 0} D'(w). \end{aligned}$$

### *A.6 Time-varying financing conditions*

To solve for equity value, we first consider the region in  $(0, \infty)$  over which it is optimal for firm shareholders to retain earnings. In this region, the firm does not deliver any cash flow to shareholders and equity value satisfies for  $i = G, B, i \neq j$ :

$$\begin{aligned} rE_i(w) &= [(1 - \theta)((r - \lambda)w + \mu - C) + m(D_i(w) - S)]E_i'(w) \\ &\quad + \frac{1}{2} ((1 - \theta)\sigma)^2 E_i''(w) + \pi_i [E_j(w) - E_i(w)]. \end{aligned} \tag{A1}$$

Equation (A1) is solved subject to the following boundary conditions. First, when cash reserves exceed  $W_i^*$ , the firm places no premium on internal funds and it is optimal to make a lump sum payment  $w - W_i^*$  to shareholders. As a result, we have

$$E_i(w) = E_i(W_i^*) + w - W_i^*$$

for all  $w \geq W_i^*$ . Subtracting  $E_i(W_i^*)$  from both sides of this equation, dividing by  $w - W_i^*$ , and taking the limit as  $w$  tends to  $W_i^*$  yields the condition:

$$E_i'(W_i^*) = 1.$$

The equity-value-maximizing payout threshold  $W_i^*$  is then the solution to:

$$E_i''(W_i^*) = 0.$$

When the firm makes losses, its cash buffer decreases. If its cash buffer decreases sufficiently, the firm may be forced to raise new equity or to liquidate. Consider first state  $G$  in which refinancing is possible. In this state, the firm may raise funds before its cash buffer gets completely depleted to avoid that financing conditions worsen when cash reserves are close to zero (as in Bolton, Chen, Wang (2013)). We denote the issuance boundary in state  $G$  by  $\underline{W} \in [0, W_G^*)$ . For any  $w \leq \underline{W}$  in state  $G$ , the firm raises new equity and resets its cash buffer to  $W_G^*$  if optimal to do so. This implies that

$$E_G(w) = E_G(W_G^*) - (W_G^* - w) - \phi, \quad \forall w \leq \underline{W}.$$

If  $\underline{W}$  is strictly greater than zero, the firm effectively taps the equity markets before its cash reserves are depleted. In this case, it must be that the condition

$$E'_G(\underline{W}) = 1$$

holds. Indeed, management delays equity issues until the marginal value of cash to shareholders equals the marginal cost of refinancing, that is equal to one.

Consider next state  $B$ . In that state, the firm has no access to outside funding and defaults as soon as its cash reserves are depleted. As a result, the condition

$$E_B(0) = \max\{\ell - S; 0\} = 0$$

holds at zero and the liquidation proceeds are used to repay debtholders.

Note that the cash reserves process evolves in  $[0, W_B^*]$  in the bad state and in  $[\underline{W}, W_G^*]$  in the good state. This implies that if the financing state switches from bad to good while the firm's cash reserves are in  $(0, \underline{W}]$ , the firm immediately taps the equity market to raise its cash reserves to their optimal level  $W_G^*$ . In these instances, the value of equity jumps from  $E_B(w)$  to  $E_G(W_G^*) - (W_G^* - w) - \phi$  for any  $w \in [0, \underline{W}]$ . If, instead, the financing state switches from bad to good when  $w \in [W_G^*, W_B^*]$ , the firm makes a lump sum payment to shareholders and cash reserves go down to  $W_G^*$ .

To solve for the value of total short-term debt  $D_i(w)$  (where we again omit the arguments  $(C, m, S)$ ), we also first consider the region in  $(0, \infty)$  over which the firm

retains earnings. In this region,  $D_i(w)$  satisfies for  $i = G, B, i \neq j$ :

$$(r + m)D_i(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D_i(w) - S)]D'_i(w) + \frac{1}{2}((1 - \theta)\sigma)^2 D''_i(w) + C + mS + \pi_i [D_j(w) - D_i(w)].$$

This system of equations is solved subject to the following boundary conditions. First, the firm is liquidated the first time that the cash buffer is depleted in the bad state. The value of short-term debt at this point is equal to the liquidation value of assets:

$$D_B(0) = \min\{\ell, S\} = \ell.$$

In the good state, management raises new equity up to the target level  $W_G^*$  whenever cash reserves are below  $\underline{W}$ . Since the net proceeds from the issue are stored in the cash reserve, the value of short-term debt satisfies:

$$D_G(w) = D_G(W_G^*), \quad \text{for } w \leq \underline{W}.$$

Lastly, the value of short-term debt does not change when dividends are paid out, because dividend payments accrue to shareholders. We thus have:

$$D'_i(W_i^*) = 0, \quad \text{for } i = G, B.$$

To fully characterize the value of short-term debt, note that if the state switches from bad to good when  $w \in (0, \underline{W}]$ , shareholders raise new funds to reset cash reserves to  $W_G^*$  and the value of short-term debt jumps from  $D_B(w)$  to  $D_G(W_G^*)$ . In addition, if the state switches from bad to good when  $w \in (W_G^*, W_B^*]$ , the firm makes a payment  $w - W_G^*$  to shareholders, leading to a jump in the value of debt from  $D_B(w)$  to  $D_G(W_G^*)$ . Therefore, in the region  $(0, \underline{W}] \cup [W_G^*, W_B^*]$ ,  $D_B(w)$  satisfies

$$(r + m)D_B(w) = [(1 - \theta)((r - \lambda)w + \mu - C) + m(D_B(w) - S)]D'_B(w) + \frac{1}{2}((1 - \theta)\sigma)^2 D''_B(w) + C + mS + \pi_B [D_G(W_G^*) - D_B(w)].$$

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Table 1: BASELINE PARAMETRIZATION.

A. Parameter values		
Parameter	Symbol	Value
Mean cash flow rate	$\mu$	0.09
Cash flow volatility	$\sigma$	0.08
Risk-free rate	$r$	0.035
Carry cost of cash	$\lambda$	0.01
Liquidation cost	$\varphi$	0.45
Tax rate	$\theta$	0.30
Coupon on debt	$C$	0.052
Principal on debt	$S$	1.27
Average debt maturity	$M$	1
Fixed financing cost	$\phi$	0.012
Switching intensity (good to bad state)	$\pi_G$	0.20
Switching intensity (bad to good state)	$\pi_B$	0.60
B. Implied variables in one-state model		
Variable	Symbol	Value
Target level of cash reserves	$W^*$	0.456
Equity value at $W^*$	$E(W^*)$	1.196

Table 2: RISK-TAKING THRESHOLDS.

The table reports the inflection points for debt ( $W_D$ ) and equity ( $W_E$ ), the size of the agency region ( $AR$ ), and the target cash level ( $W^*$ ) for different debt maturities ( $M$ ). Fixing  $M = 1$ , we also investigate the effects of the cash flow drift ( $\mu$ ), cash flow volatility ( $\sigma$ ), liquidation costs ( $\varphi$ ), and aggregate debt principal ( $S$ ).

	$W_D$	$W_E$	$AR$	$W^*$
$M = 1$	0.144	0.183	0.039	0.456
$M = 3$	0.052	0.085	0.033	0.368
$M = 5$	0.017	0.046	0.029	0.341
$M = 10$	n.a.	0.003	0.003	0.322
$M = \infty$	n.a.	n.a.	0.000	0.312
$\mu = 0.07$	0.358	0.414	0.056	0.709
$\mu = 0.08$	0.248	0.295	0.047	0.579
$\mu = 0.09$	0.144	0.183	0.039	0.456
$\mu = 0.10$	0.050	0.083	0.033	0.343
$\mu = 0.11$	n.a.	0.011	0.011	0.270
$\sigma = 0.06$	0.154	0.173	0.019	0.357
$\sigma = 0.08$	0.144	0.183	0.039	0.456
$\sigma = 0.10$	0.130	0.194	0.064	0.556
$\sigma = 0.12$	0.115	0.208	0.093	0.655
$\sigma = 0.14$	0.097	0.222	0.125	0.752
$\varphi = 0.30$	n.a.	n.a.	0.000	0.296
$\varphi = 0.35$	0.008	0.051	0.043	0.331
$\varphi = 0.40$	0.071	0.112	0.041	0.388
$\varphi = 0.45$	0.144	0.183	0.039	0.456
$\varphi = 0.50$	0.220	0.257	0.037	0.526
$S = 1.05$	n.a.	0.021	0.021	0.292
$S = 1.15$	0.048	0.085	0.037	0.352
$S = 1.25$	0.127	0.166	0.039	0.437
$S = 1.35$	0.212	0.254	0.042	0.530
$S = 1.45$	0.302	0.346	0.044	0.627

Table 3: OPTIMAL CAPITAL STRUCTURE.

The table reports the value-maximizing capital structure (coupon, principal, leverage ratio) as well as firm value at debt issuance, under the baseline parametrization and varying the average maturity of corporate debt.

Maturity ( $M$ )	Coupon ( $C$ )	Principal ( $S$ )	Leverage ratio	Firm Value
AT PAR AT $W^*/4$				
1	0.036	1.003	53.4%	1.879
3	0.044	1.091	57.7%	1.890
5	0.049	1.161	61.1%	1.900
10	0.054	1.263	66.1%	1.913
Inf	0.052	1.362	70.9 %	1.920
AT PAR AT $W^*/3$				
1	0.036	1.012	51.2%	1.976
3	0.044	1.138	57.0%	1.996
5	0.050	1.239	61.6%	2.012
10	0.056	1.371	67.4%	2.036
Inf	0.056	1.488	72.6%	2.049
AT PAR AT $W^*/2$				
1	0.040	1.123	53.5%	2.100
3	0.048	1.292	60.3%	2.142
5	0.054	1.418	65.3%	2.172
10	0.063	1.619	73.0%	2.219
Inf	0.062	1.673	75.6%	2.215

Table 4: FINANCING DECISIONS.

The table reports the target level of cash reserves in good ( $W_G^*$ ) and in bad times ( $W_B^*$ ), the issue threshold ( $\underline{W}$ ), and the issue size ( $W_G^* - \underline{W}$ ) when varying the average debt maturity  $M$ .

	$M = 1$	$M = 5$	$M = 10$	$M = \infty$
$W_G^*$	0.320	0.245	0.237	0.234
$W_B^*$	0.344	0.269	0.261	0.258
$\underline{W}$	0.150	0.071	0.063	0.054
$W_G^* - \underline{W}$	0.170	0.174	0.174	0.180

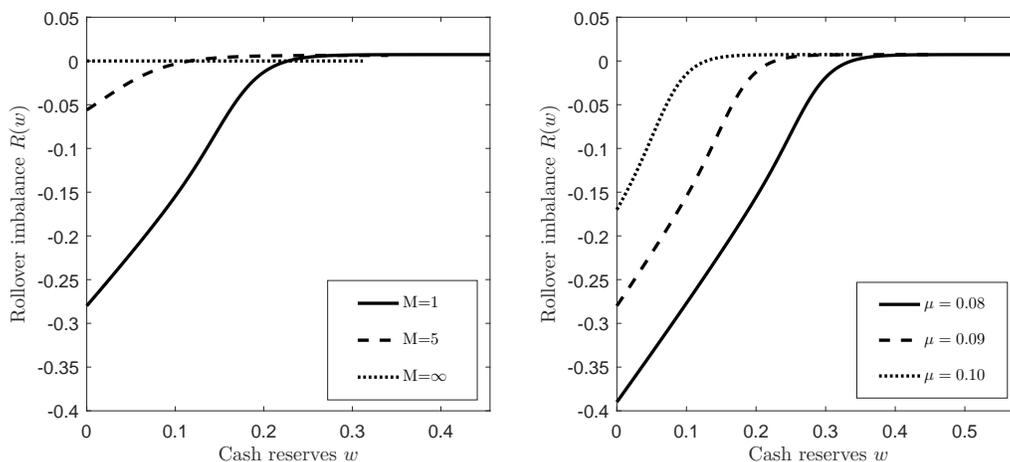


Figure 1: ROLLOVER IMBALANCES.

The figure plots the rollover imbalance  $R(w) \equiv m(D(w) - S)$  as a function of cash reserves  $w \in [0, W^*]$  for different values of average debt maturity  $M$  and for different values of asset profitability  $\mu$ .

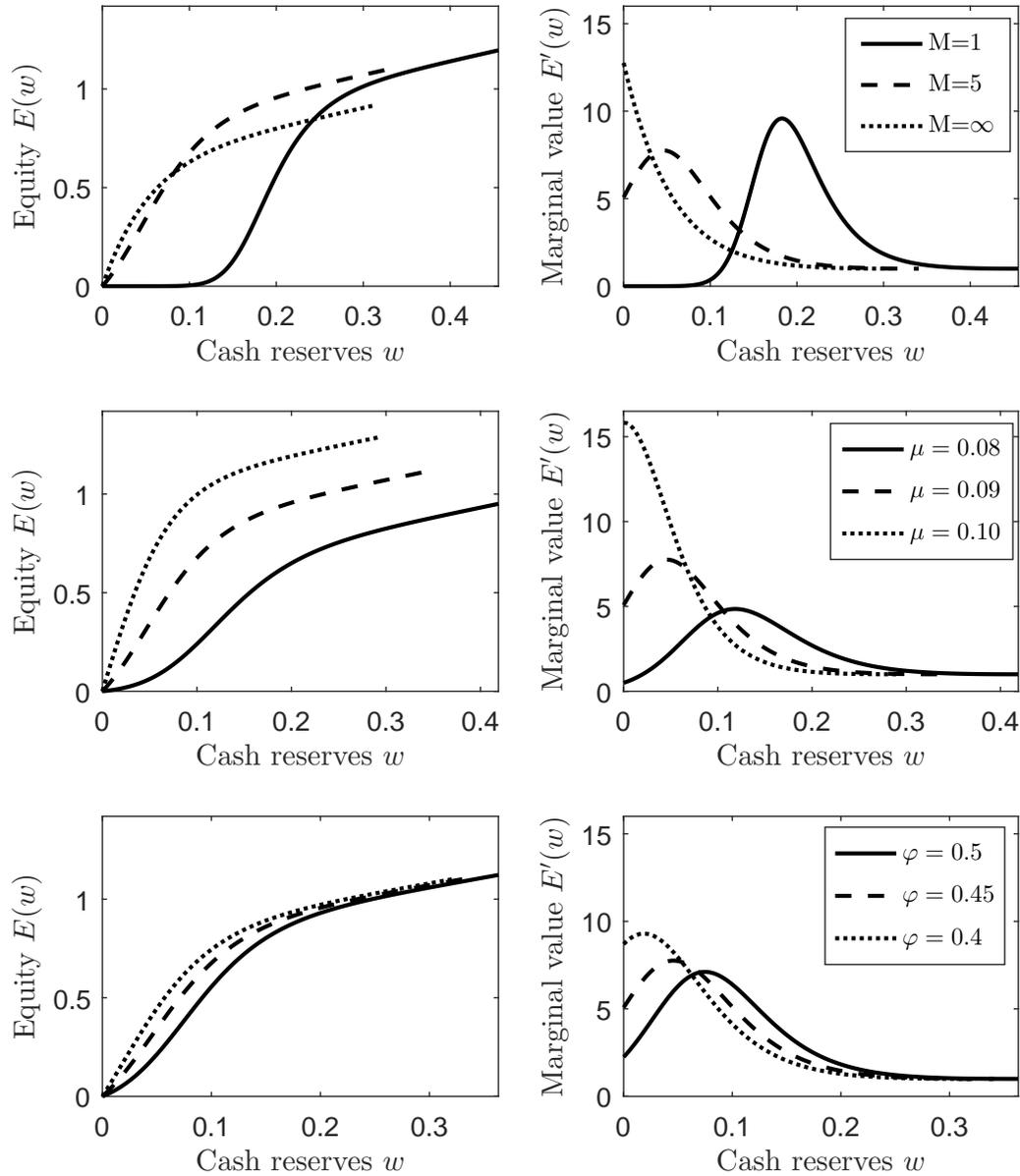


Figure 2: VALUE OF EQUITY AND THE ROLLOVER TRAP.

The figure plots the value of equity (left panel) and the marginal value of cash for shareholders (right panel) as functions of cash reserves  $w \in [0, W^*]$ , for different debt maturities  $M$  (top panel), asset profitability  $\mu$  (middle panel), and liquidation costs  $\varphi$  (bottom panel).

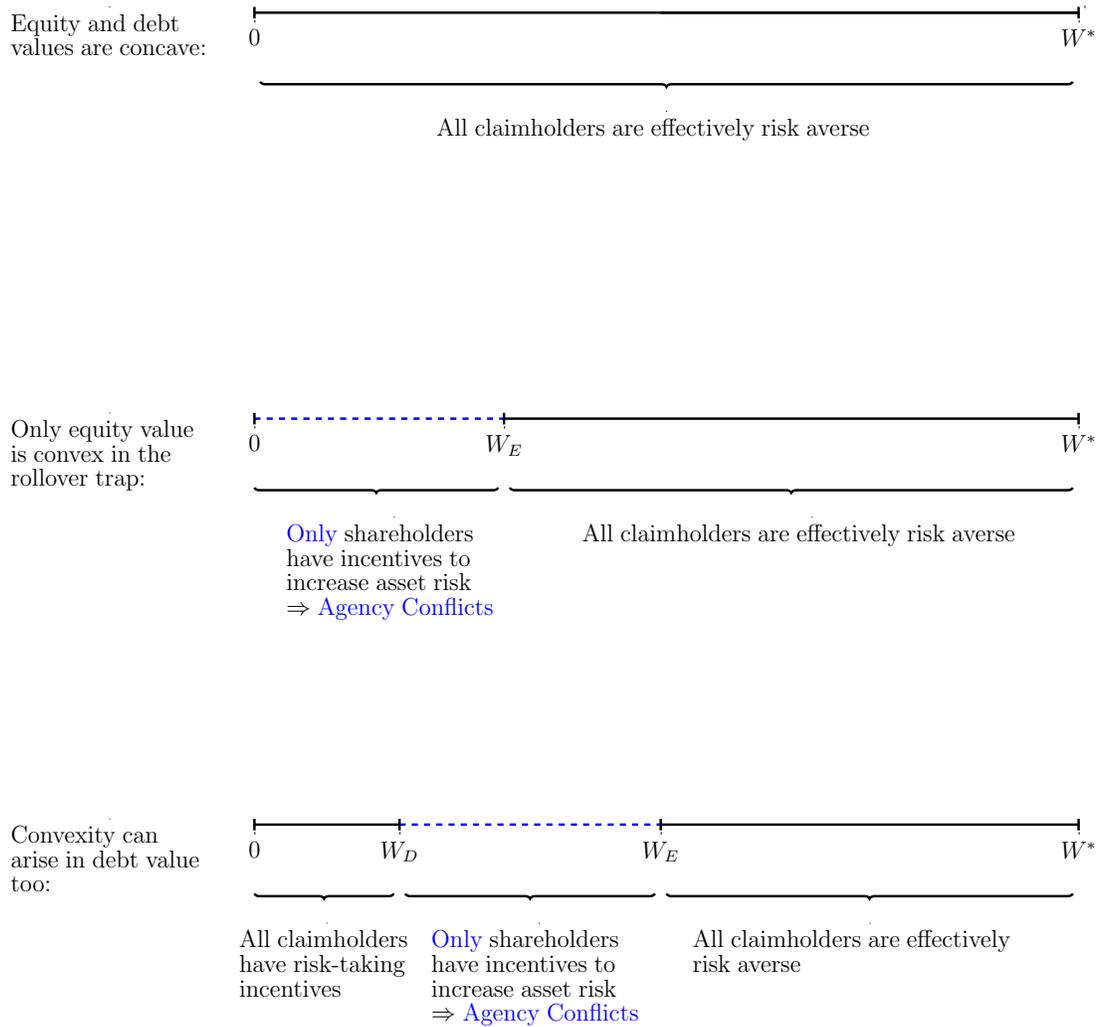


Figure 3: SHORT-TERM DEBT AND AGENCY CONFLICTS.

The figure illustrates shareholders' and debtholders' risk-taking incentives as a function of cash holdings  $[0, W^*]$ .

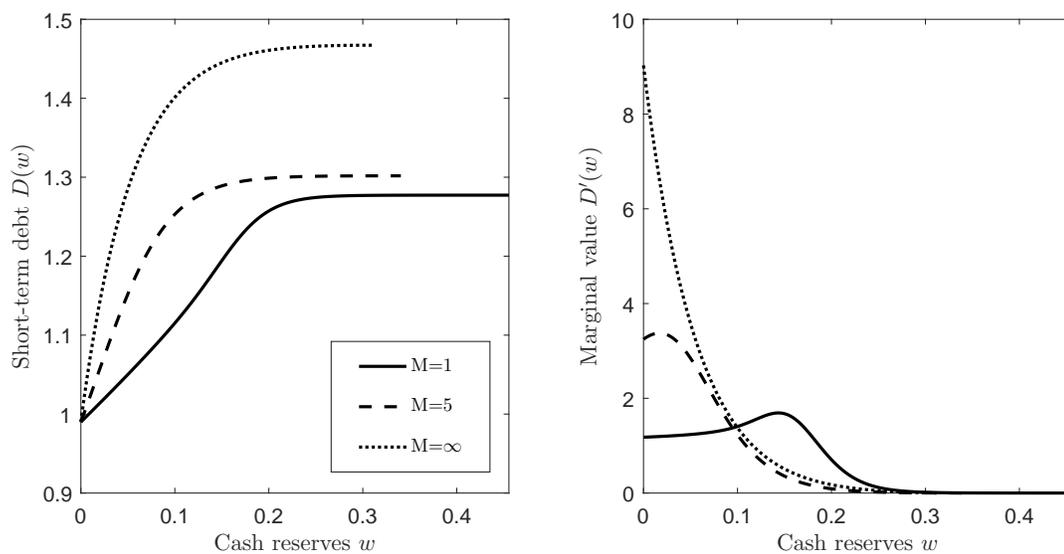


Figure 4: VALUE OF DEBT.

The figure plots the aggregate value of debt  $D(w)$  and the marginal value of cash for debtholders  $D'(w)$  as a function of cash reserves  $w \in [0, W^*]$  and for average debt maturities  $M$  of 1 year (solid line), 5 years (dashed line), and infinite (dotted line).

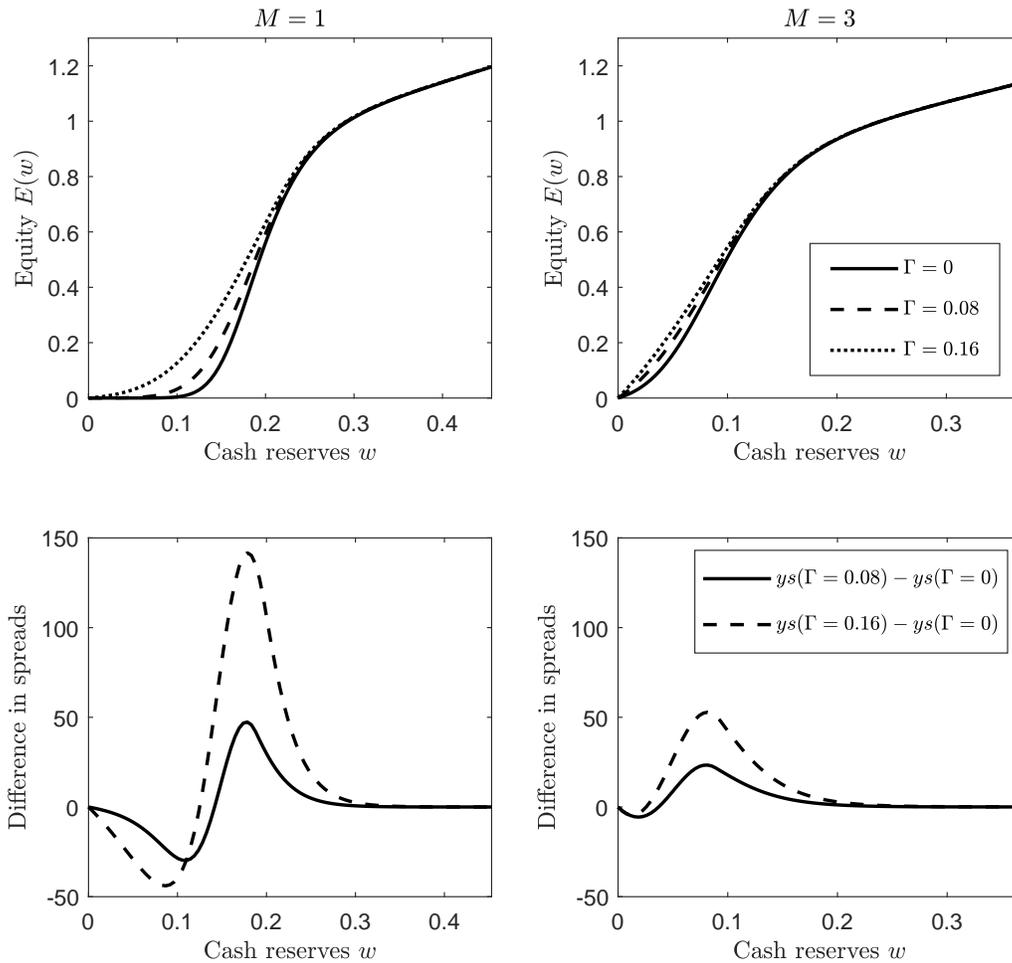


Figure 5: RISK-TAKING.

The figure plots the value of equity  $E(w)$  (top panel) and the difference in yield spreads when shareholders do and do not engage in risk-taking strategies (bottom panel) as a function of cash reserves  $w \in [0, W^*]$  under different risk-taking strategies and for maturity  $M = 1$  (left panel) and  $M = 3$  (right panel).

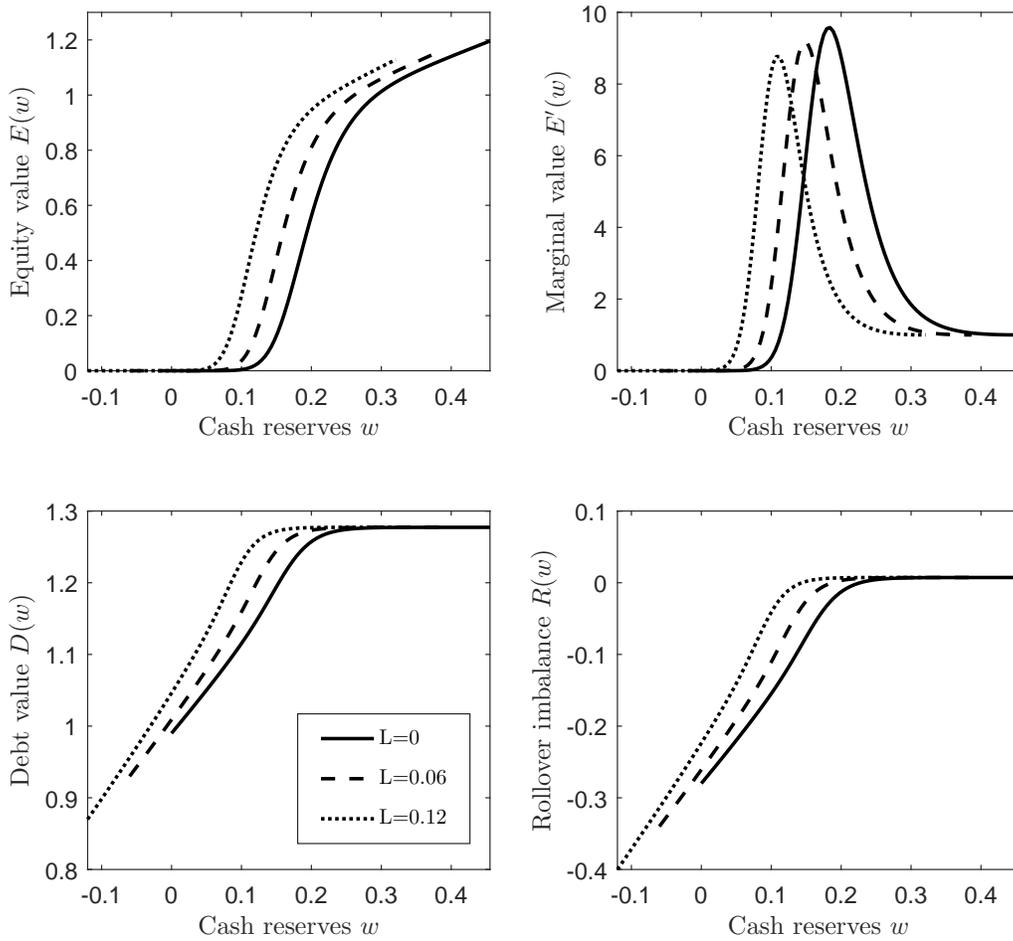


Figure 6: CREDIT LINE.

The figure plots the value of equity, the marginal value of equity, the aggregate value of short-term debt, and the rollover imbalance in the absence (solid line) and in the presence of credit line availability (dashed line for  $L = 0.06$  and dotted line for  $L = 0.12$ ).

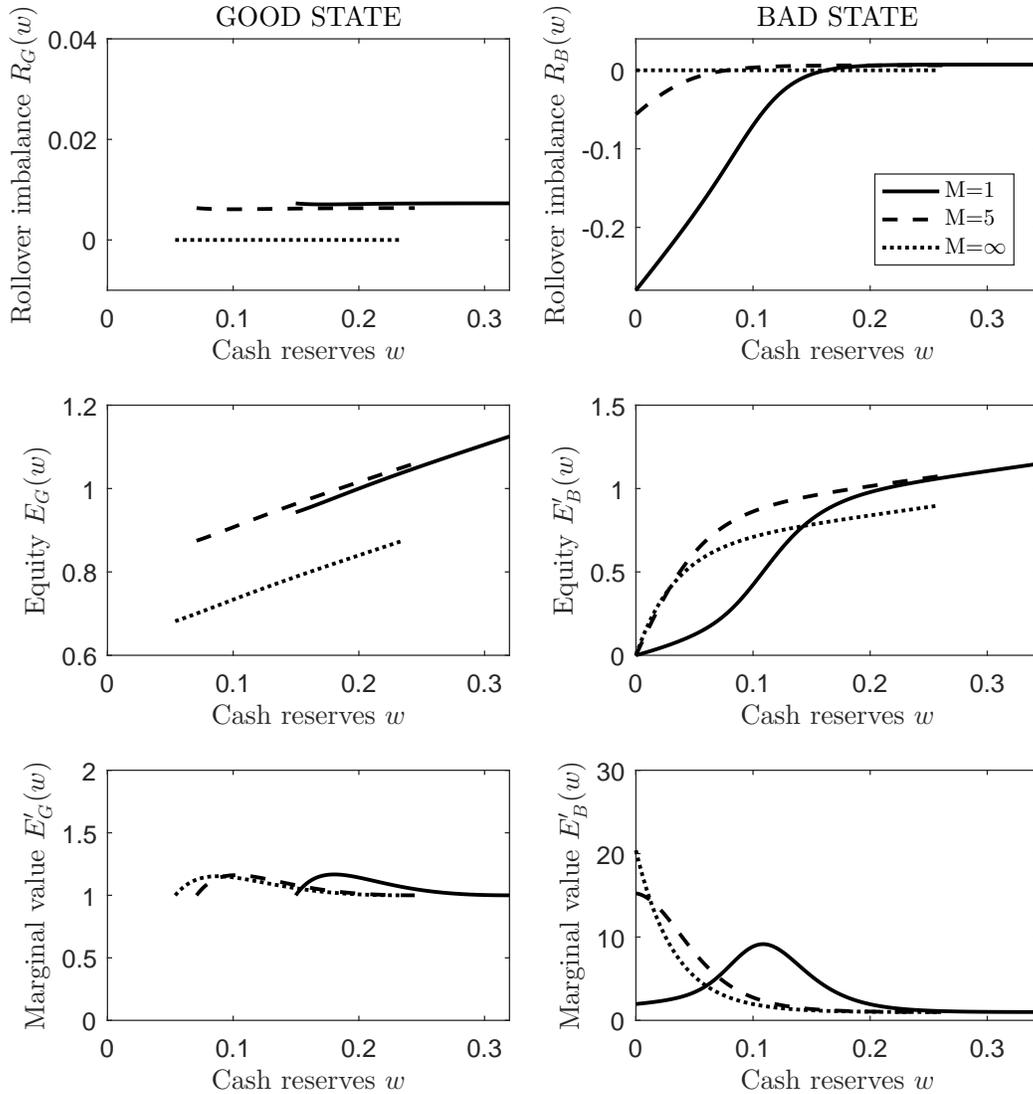


Figure 7: TIME-VARYING FUNDING LIQUIDITY.

The figure plots the rollover imbalance  $R_i(w)$ , the value of equity  $E_i(w)$ , and the marginal value of cash for shareholders  $E'_i(w)$  as a function of cash reserves  $w \in [0, W_i^*]$  in the good state (left panel) and in the bad state (right panel) for average debt maturities  $M$  of 1 year (solid line), 5 years (dashed line), and infinite (dotted line).

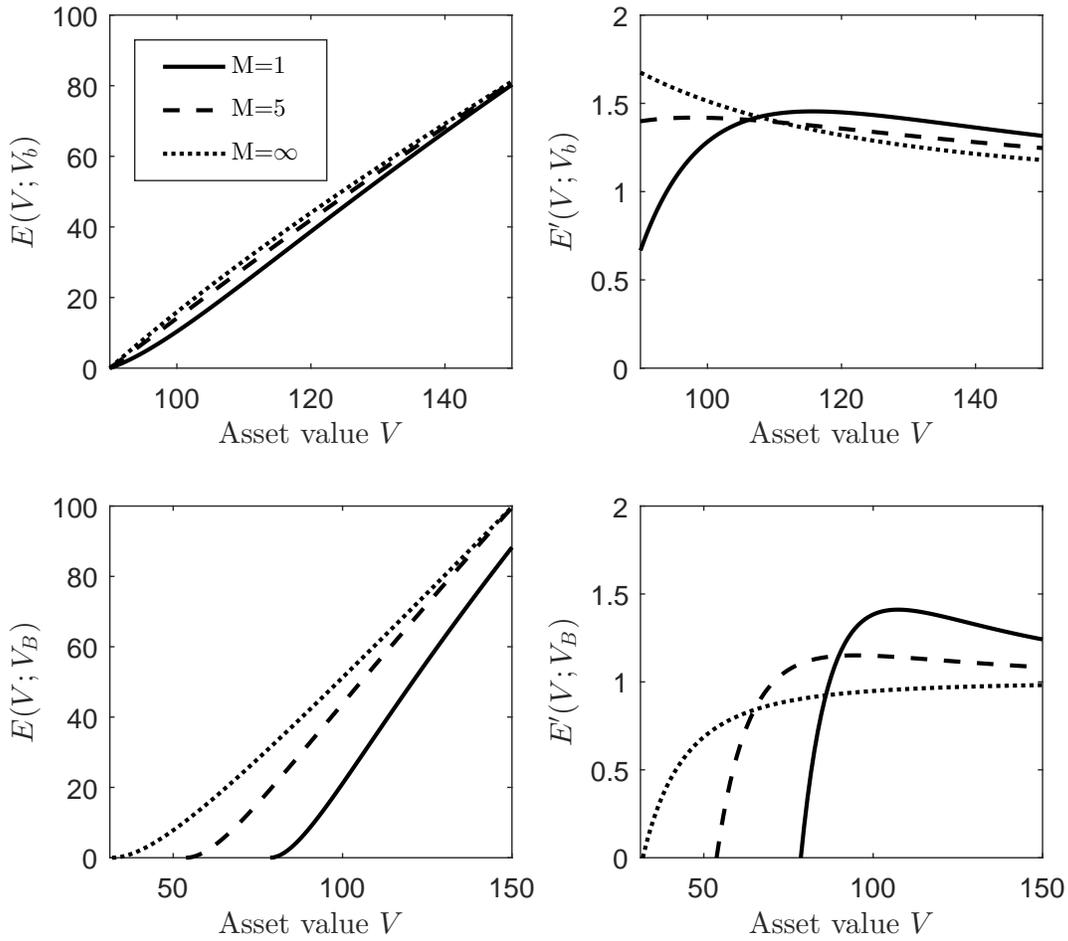


Figure 8: LELAND SETUP.

The figure plots the value of equity  $E(V)$  and its sensitivity to asset value  $E'(V)$  when the default threshold is exogenous (top panel) or endogenously chosen to maximize equity value (bottom panel), for average debt maturities  $M$  of 1 year (solid line), 5 years (dashed line), and infinite (dotted line).