

# Collateral and Capital Structure\*

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## Abstract

This paper develops a dynamic model of firm financing based on the need to collateralize promises to pay with tangible assets, leading to a unified theory of optimal investment, capital structure, leasing, and risk management. Tangible assets required for production restrict leverage. Leasing is costly, highly collateralized financing, which enables higher leverage and faster firm growth. Financing and risk management are connected as both involve promises to pay, making incomplete risk management optimal. In the cross section, more constrained firms lease more and engage in less risk management and may completely abstain, contrary to extant theory and consistent with the evidence. Dynamically, firms with low cash flows may sell assets and lease them back, and discontinue risk management. Empirically, tangible assets and leased assets are key determinants of the capital structure.

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# 1 Introduction

The determinants of capital structure have proved elusive. We argue that collateral determines the capital structure. We develop a dynamic agency based model of firm financing based on the need to collateralize promises to pay with tangible assets. Our model provides a unified theory of optimal firm financing in terms of optimal investment, capital structure, leasing, and risk management.

Financing is an inherently dynamic problem. Moreover, we think incentive problems, specifically, the enforcement of payments, is a critical determinant of the capital structure and develop a dynamic model of a firm with a standard neoclassical production function in which firm financing is subject to collateral constraints due to limited enforcement as in Rampini and Viswanathan (2009). Unlike previous work on dynamic agency models of the capital structure, we explicitly consider firms' ability to lease capital. We build on the model of Eisfeldt and Rampini (2009), who argue that leasing amounts to a particularly strong form of collateralization due the relative ease with which leased capital can be repossessed, and extend their work by considering a dynamic model. A frictionless rental market for capital would of course obviate financial constraints. Leasing in our model is however costly since the lessor incurs monitoring costs to avoid agency problems due to the separation of ownership and control and since limited enforcement implies that the leasing fee, which covers the user cost of leased capital, needs to be paid up front.

We provide a definition of the user cost of capital in our model of investment with financial constraints. For the frictionless neoclassical model of investment, Jorgenson (1963) defines the user cost of capital.<sup>1</sup> Our definition is closely related to Jorgenson's. Indeed, the user cost of capital is effectively the sum of Jorgenson's user cost and a term which captures the additional cost due to the scarcity of internal funds. We also provide a "weighted average cost of capital" type representation of the user cost of capital. We show how to define the user cost of capital for tangible, intangible, and leased capital. The leasing decision reduces to a comparison between the user costs of (owned) tangible capital and the user cost of leased capital.

Our model predicts that firms only pay out dividends when net worth exceeds a (state-contingent) cut off. In the model, firms require both tangible and intangible capital. The enforcement constraints imply that only tangible capital can be used as collateral. We show that, in the absence of leasing and uncertainty, higher tangibility is equivalent to a better ability to collateralize tangible assets, that is, only the extent to which assets overall can be collateralized matters. Firms with less tangible assets are more constrained or

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<sup>1</sup>Lucas and Prescott (1971), Abel (1983), and Abel and Eberly (1996) extend Jorgenson's definition of the user cost of capital to models with adjustment costs.

constrained for longer. When leasing is taken into account, financially constrained firms, that is, firms with low net worth, lease capital. And over time, as firms accumulate net worth, they grow in size and start to buy capital. Thus, the model predicts that small firms and young firms lease capital. We show that the ability to lease capital enables firms to grow faster. More generally we show that, even when productivity and hence cash flows are uncertain, firms with sufficiently low net worth optimally lease all their tangible capital. Dynamically, firms that are hit by a sequence of low cash flows may sell assets and lease them back, that is, sale-leaseback transactions may occur under the stationary distribution.

Our model also has implications for risk management. There is an important connection between the optimal financing and risk management policy that has not been previously recognized. Both financing and risk management involve promises to pay by the firm, which implies a trade off when firms' ability to promise is limited by collateral constraints. Indeed, we show that firms with sufficiently low net worth do not engage in risk management at all. For such firms, the need to finance investment overrides the hedging concerns. This result is in contrast to the extant theory, such as Froot, Scharfstein, and Stein (1993), and is consistent with the evidence.

When investment opportunities are constant, we show that incomplete hedging is optimal. That is, we show that it cannot be optimal to hedge net worth to the point where the marginal value of net worth is equated across all states. Furthermore, firms abstain from risk management with positive probability under the stationary distribution. Thus, if firms' net worth declines sufficiently due to low cash flows, firms optimally discontinue risk management.

When investment opportunities are stochastic, risk management depends not only on firms' net worth but also on firms' productivity. If productivity is persistent, the overall level of risk management is reduced, because cash flows and investment opportunities are positively correlated due to the positive correlation of current productivity and future expected productivity. There is less reason to hedge. Risk management is moreover lower when current productivity is high, as higher expected productivity implies higher investment and raises the opportunity cost of risk management. With sufficient persistence, the firm abstains from risk management altogether when productivity is high. Finally, there is an interesting interaction between leasing and risk management: leasing enables high implicit leverage; this leads firms to engage in risk management to reduce the volatility of net worth that such high leverage would otherwise imply.

In the data, we show that tangible assets are a key determinant of firm leverage. Leverage varies by a factor 3 from the lowest to the highest tangibility quartile for Compustat

firms. Moreover, tangible assets are an important explanation for the “low leverage puzzle” in the sense that firms with low leverage are largely firms with few tangible assets. We also take firms’ ability to deploy tangible assets by renting or leasing such assets into account. We show that accounting for leased assets reduces the fraction of low leverage firms drastically and that “true” tangibility, that is tangibility adjusted for leased assets, further strengthens our results that firms with low “true” leverage, that is, leverage adjusted for leased assets, are firms with few tangible assets. Finally, we show that accounting for leased capital changes the relation between leverage and size in the cross section of Compustat firms. This relation is essentially flat when leased capital is taken into account. In contrast, when leased capital is ignored, as is done in the literature, leverage increases in size, that is, small firms seem less levered than large firms. Thus, basic stylized facts about the capital structure need to be revisited.

Our paper is part of a recent and growing literature which considers dynamic incentive problems as the main determinant of the capital structure. The incentive problem in our model is limited enforcement of claims. Most closely related to our work is Albuquerque and Hopenhayn (2004) and Lorenzoni and Walentin (2007). Albuquerque and Hopenhayn (2004) study dynamic firm financing with limited enforcement. The specific limits on enforcement differ from our setting and they do not consider the standard neoclassical investment problem.<sup>2</sup> Lorenzoni and Walentin (2007) consider limits on enforcement similar to ours in a model with constant returns to scale. However, they assume that all enforcement constraints always bind, which is not the case in our model, and focus on the relation between investment and Tobin’s  $q$  rather than the capital structure. The aggregate implications of firm financing with limited enforcement are studied by Cooley, Marimon, and Quadrini (2004) and Jermann and Quadrini (2007). Schmid (2008) considers the quantitative implications for the dynamics of firm financing. None of these models consider intangible capital or the option to lease capital.

Capital structure and investment dynamics determined by incentive problems due to private information about cash flows or moral hazard are studied by Quadrini (2004), Clementi and Hopenhayn (2006), DeMarzo and Fishman (2007a), DeMarzo, Fishman, He, and Wang (2008), and Biais, Mariotti, Rochet, and Villeneuve (2009). Capital structure dynamics subject to similar incentive problems but abstracting from investment decisions are analyzed by DeMarzo and Fishman (2007b), DeMarzo and Sannikov (2006), and Biais, Mariotti, Plantin, and Rochet (2007).<sup>3</sup>

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<sup>2</sup>Hopenhayn and Werning (2007) consider a version of this model in which limits on enforcement are stochastic and private information, which results in default occurring in equilibrium.

<sup>3</sup>Relatedly, Gromb (1995) analyzes a multi-period version of Bolton and Scharfstein (1990)’s two period dynamic firm financing problem with privately observed cash flows. Atkeson and Cole (2008)

In Section 2 we report some stylized empirical facts about collateralized financing, tangibility, and leverage. We also show how to take leased capital into account and document the effect of doing so, in particular the striking effect on the relation between leverage and size. Section 3 describes the model, defines the user cost of tangible, intangible, and leased capital, and characterizes the optimal payout policy. Section 4 characterizes the optimal leasing and capital structure policy, Section 5 analyzes optimal risk management, and Section 6 concludes. All proofs are in Appendix B.

## 2 Stylized facts

This section provides some aggregate and cross-sectional evidence that highlights the first order importance of tangible assets as a determinant of the capital structure in the data. We first take an aggregate perspective and then document the relation between tangible assets and leverage across firms. We take leased capital into account explicitly and show that it has quantitatively and qualitatively large effects on basic stylized facts about the capital structure, such as the relation between leverage and size. Tangibility also turns out to be one of the few robust factors explaining firm leverage in the extensive empirical literature on capital structure, but we do not attempt to summarize this literature here.

### 2.1 Collateralized financing: the aggregate perspective

From the aggregate point of view, the importance of tangible assets is striking. Consider the balance sheet data from the Flow of Funds Accounts of the U.S. for (nonfinancial) corporate businesses, (nonfinancial) noncorporate businesses, and households reported in Table 1 for the years 1999 to 2008 (detailed definitions of variables are in the caption of the table). For businesses, tangible assets include real estate, equipment and software, and inventories, and for households mainly real estate and consumer durables.

Panel A documents that from an aggregate perspective, the liabilities of corporate and noncorporate businesses and households are less than their tangible assets and indeed typically considerably less, and in this sense all liabilities are collateralized. For corporate businesses, debt in terms of credit market instruments is 48.5% of tangible assets. Even total liabilities, which include also miscellaneous liabilities and trade payables, are only 83.0% of tangible assets. For noncorporate businesses and households, liabilities vary between 37.8% and 54.9% of tangible assets and are remarkably similar for the two sectors.

Note that we do not consider whether liabilities are explicitly collateralized or only  

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consider a two period firm financing problem with costly monitoring of cash flows.

implicitly in the sense that firms have tangible assets exceeding their liabilities. Our reasoning is that even if liabilities are not explicitly collateralized, they are implicitly collateralized since restrictions on further investment, asset sales, and additional borrowing through covenants and the ability not to refinance debt allow lenders to effectively limit borrowing to the value of collateral in the form of tangible assets. That said, households' liabilities are largely explicitly collateralized. Households' mortgages, which make up the bulk of households' liabilities, account for 41.2% of the value of real estate, while consumer credit amounts to 56.1% of the value of households' consumer durables.

Finally, aggregating across all balance sheets and ignoring the rest of the world implies that tangible assets make up 79.2% of the net worth of U.S. households, with real estate making up 60.2%, equipment and software 8.3%, and consumer durables 7.6% (see Panel B). While this provides a coarse picture of collateral, it highlights the quantitative importance of tangible assets as well as the relation between tangible assets and liabilities in the aggregate.

## 2.2 Tangibility and leverage

To document the relation between tangibility and leverage, we analyze data for a cross section of Compustat firms. We sort firms into quartiles by tangibility measured as the value of property, plant, and equipment divided by the market value of assets. The results are reported in Panel A of Table 2, which also provides a more detailed description of the construction of the variables. We measure leverage as long term debt to the market value of assets.

The first observation that we want to stress is that across tangibility quartiles, (median) leverage varies from 7.4% for low tangibility firms (that is, firms in the lowest quartile by tangibility) to 22.6% for high tangibility firms (that is, firms in the highest quartile by tangibility). This is a factor 3.<sup>4</sup> Tangibility also varies substantially across quartiles; the cut-off value of the first quartile is 6.3% and the cut-off value of the fourth quartile is 32.2%.

To assess the role of tangibility as an explanation for the observation that some firms have very low leverage (the so-called "low leverage puzzle"), we compute the fraction of firms in each tangibility quartile which have low leverage, specifically leverage less than 10%.<sup>5</sup> The fraction of firms with low leverage decreases from 58.3% in the low tangibility quartile to 14.9% in the high tangibility quartile. Thus, low leverage firms are largely firms with relatively few tangible assets.

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<sup>4</sup>Mean leverage varies somewhat less, by a factor 2.2 from 10.8% to 24.2%.

<sup>5</sup>We do not think that our results change if lower cutoff values are considered.

## 2.3 Leased capital and leverage

Thus far, we have ignored leased capital which is the conventional approach in the literature. To account for leased (or rented) capital, we simply capitalize the rental expense (Compustat item #47).<sup>6</sup> This allows us to impute capital deployed via operating leases, which are the bulk of leasing in practice.<sup>7</sup> To capitalize the rental expense, recall that Jorgenson (1963)’s user cost of capital is  $u \equiv r + \delta$ , that is, the user cost is the sum of the interest cost and the depreciation rate. Thus, the frictionless rental expense for an amount of capital  $k$  is

$$\text{Rent} = (r + \delta)k.$$

Given data on rental payments, we can hence infer the amount of capital rented by capitalizing the rental expense using the factor  $1/(r + \delta)$ . For simplicity, we capitalize the rental expense by a factor 10. We adjust firms’ assets, tangible assets, and liabilities by adding 10 times rental expense to obtain measures of “true” assets, “true” tangible assets, and “true” leverage.

We proceed as before and sort firms into quartiles by true tangibility. The results are reported in Panel B of Table 2. True debt leverage is somewhat lower as we divide by true assets here. There is a strong relation between true tangibility and true leverage (as before), with the median true debt leverage varying again by a factor of about 3. Rental leverage also increases with true tangibility by about a factor 2 for the median and more than 3 for the mean. Similarly, true leverage, which we define as the sum of debt leverage and rental leverage, also increases with tangibility by a factor 3.

Taking rental leverage into account reduces the fraction of firms with low leverage drastically, in particular for firms outside the low tangibility quartile. True tangibility is an even more important explanation for the “low leverage puzzle.” Indeed, less than 4% of firms with high tangibility have low true leverage.

It is also worth noting that the median rental leverage is on the order of half of debt leverage or more, and is hence quantitatively important. Overall, we conclude that tangibility, when adjusted for leased capital, emerges as a key determinant of leverage and the fraction of firms with low leverage.

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<sup>6</sup>In accounting this approach to capitalization is known as constructive capitalization and is frequently used in practice, with “8 x rent” being the most commonly used. For example, *Moody’s* rating methodology uses multiples of 5x, 6x, 8x, and 10x current rent expense, depending on the industry.

<sup>7</sup>Note that capital leases are already accounted for as they are capitalized on the balance sheet for accounting purposes. For a description of the specifics of leasing in terms of the law, accounting, and taxation see Eislefeldt and Rampini (2009) and the references cited therein.

## 2.4 Leverage and size revisited

Considering leased capital changes basic cross-sectional properties of the capital structure. Here we document the relationship between firm size and leverage (see Table 3 and Figure 1). We sort Compustat firms into deciles by size. We measure size by true assets here, although using unadjusted assets makes our results even more stark. Debt leverage is increasing in size, in particular for small firms, when leased capital is ignored. Rental leverage, by contrast, decreases in size, in particular for small firms.<sup>8</sup> Indeed, rental leverage is substantially larger than debt leverage for small firms. True leverage, that is, the sum of debt and rental leverage, is roughly constant across Compustat size deciles. In our view, this evidence provides a strong case that leased capital cannot be ignored if one wants to understand the capital structure.

## 3 Model

This section provides a dynamic agency based model to understand the first order importance of tangible assets and rented assets for firm financing and the capital structure documented above. Dynamic financing is subject to collateral constraints due to limited enforcement. We extend previous work by considering both tangible and intangible capital as well as firms' ability to lease capital. We define the user cost of tangible, intangible, and leased capital. We provide a weighted average cost of capital type representation of the user cost of capital. The user cost of capital definitions allow a very simple description of the leasing decision, which can be reduced to a comparison of the user cost of tangible capital and the user cost of leased capital. Finally, we characterize the dividend policy and show how tangibility and collateralizability of assets affect the capital structure in the special case without leasing.

### 3.1 Environment

A risk neutral firm, who is subject to limited liability and discounts the future at rate  $\beta \in (0, 1)$ , requires financing for investment. The investment problem has an infinite horizon and we write the problem recursively. The firm starts the period with net worth  $w$ . The firm has access to a standard neoclassical production function with decreasing returns to scale. An amount of invested capital  $k'$  yields stochastic cash flow  $A(s')f(k')$

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<sup>8</sup>Eisfeldt and Rampini (2009) show that this is even more dramatically the case in Census data, which includes firms that are not in Compustat and hence much smaller, and argue that for such firms renting capital may be the most important source of external finance.

next period, where  $A(s')$  is the realized total factor productivity of the technology in state  $s'$ , which we assume follows a Markov process described by the transition function  $\Pi(s, s')$  on  $s' \in S$ . Capital  $k'$  is the total amount of capital of the firm, which will have three components, intangible capital, purchased physical capital, and leased physical capital, described in more detail below. Capital depreciates at rate  $\delta \in (0, 1)$ .

There are two types of capital, physical capital and intangible capital ( $k'_i$ ). Either type of capital can be purchased at a price normalized to 1 and there are no adjustment costs. Physical and intangible capital are assumed to depreciate at the same rate  $\delta$ . Moreover, physical capital can be either purchased ( $k'_p$ ) or leased ( $k'_l$ ), while intangible capital can only be purchased. Physical capital which the firm owns can be used as collateral for state-contingent one period debt up to a fraction  $\theta \in (0, 1)$  of its resale value. These collateral constraints are motivated by limited enforcement. We assume that enforcement is limited in that firms can abscond with all cash flows, all intangible capital, and  $1 - \theta$  of purchased physical capital  $k'_p$ . We further assume that firms cannot abscond with leased capital  $k'_l$ , that is, leased capital enjoys a repossession advantage. Moreover, and importantly, we assume that firms who abscond cannot be excluded from the market for intangible capital, physical capital, or loans, nor can they be prevented from renting capital. That is, firms cannot be excluded from any market. Extending the results in Rampini and Viswanathan (2009), we show in Appendix A that these dynamic enforcement constraints imply the above collateral constraints, which are described in more detail below.<sup>9</sup> The motivation for our assumption about the lack of exclusion is two-fold. First, it allows us to provide a tractable model of dynamic collateralized firm financing. Second, a model based on this assumption has implications which are empirically plausible, in particular by putting the focus squarely on tangibility.

We assume that intangible capital can neither be collateralized nor leased. The idea is that intangible capital cannot be repossessed due to its lack of tangibility and can be deployed in production only by the owner, since the agency problems involved in separating ownership from control are too severe.<sup>10</sup>

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<sup>9</sup>These collateral constraints are very similar to the ones in Kiyotaki and Moore (1997), albeit state contingent. However, they are derived from an explicitly dynamic model of limited enforcement similar to the one considered by Kehoe and Levine (1993). The main difference to their limits on enforcement is that we assume that firms who abscond cannot be excluded from future borrowing whereas they assume that borrowers are in fact excluded from intertemporal trade after default. Similar constraints have been considered by Lustig (2007) in an endowment economy and by Lorenzoni and Walentin (2007) in a production economy with constant returns to scale. Krueger and Uhlig (2006) find that similar limits on enforcement in an endowment economy without collateral imply short-sale constraints, which would be true in our model in the special case where  $\theta = 0$ .

<sup>10</sup>Our assumption that intangible capital cannot be collateralized or leased *at all* simplifies the analysis,

Our model of leased capital extends the work of Eisfeldt and Rampini (2009) to a dynamic environment. The assumption that firms cannot abscond with leased capital captures the fact that leased capital can be repossessed more easily. Leased capital involves monitoring costs  $m$  per unit of capital incurred by the lessor at the beginning of the period, which are reflected in the user cost of leased capital  $u_l$ . Leasing separates ownership and control and the lessor must pay the cost  $m$  to ensure that the lessee uses and maintains the asset appropriately.<sup>11</sup> A competitive lessor with a cost of capital  $R \equiv 1 + r$  charges a user cost of

$$u_l \equiv R^{-1}(r + \delta) + m$$

per unit of capital at the beginning of the period.<sup>12</sup> Without loss of generality, the user cost of leased capital is charged up front due to the constraints on enforcement. Recall that in the frictionless neoclassical model, the rental cost of capital is Jorgenson (1963)'s user cost  $u = r + \delta$ . There are two differences to the rental cost in our model. First, there is a positive monitoring cost. Second, due to limited enforcement, the rental charge is paid in advance and hence discounted to time 0.<sup>13</sup>

The total amount of capital is  $k' \equiv k'_i + k'_p + k'_l$  and we refer to total capital  $k'$  often simply as capital. We assume that physical and intangible capital are required in fixed proportions and denote the fraction of physical capital required by  $\varphi$ , implying the constraints  $k'_i = (1 - \varphi)k'$  and  $k'_p + k'_l = \varphi k'$ . Using these two equations, the firm's investment problem simplifies to the choice of capital  $k'$  and leased capital  $k'_l$  only.

We assume that the firm has access to lenders who have deep pockets in all dates and states and discount the future at rate  $R \in (\beta, 1)$ . These lenders are thus willing to lend in a state-contingent way at an expected return  $R$ . The assumption that  $R > \beta$  implies that firms are less patient than lenders and will imply that firms will never be completely unconstrained in our model. This assumption is important to understand the

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but is not required for our main results. Assuming that intangible capital is less collateralizable and more costly to lease would suffice.

<sup>11</sup>In practice, there may be a link between the lessor's monitoring and the repossession advantage of leasing. In order to monitor the use and maintenance of the asset, the lessor needs to keep track of the asset which makes it harder for the lessee to abscond with it.

<sup>12</sup>Equivalently, we could instead assume that leased capital depreciates faster due to the agency problem; specifically, assuming that leased capital depreciates at rate  $\delta_l \equiv \delta + Rm$  implies  $u_l = R^{-1}(r + \delta_l)$ .

<sup>13</sup>To impute the amount of capital rented from rental payments, we should hence capitalize rental payments by  $1/(R^{-1}(r + \delta) + m)$ . In documenting the stylized facts, we assumed that this factor takes a value of 10. The implicit debt associated with rented capital is  $R^{-1}(1 - \delta)$  times the amount of capital rented, so in adjusting liabilities, we should adjust by  $R^{-1}(1 - \delta)$  times 10 to be precise. In documenting the stylized facts, we ignored the correction  $R^{-1}(1 - \delta)$ , implicitly assuming that it is approximately equal to 1.

dynamics of firm financing, in particular the fact that firms pay dividends even if they are not completely unconstrained and that firms may stop dividend payments and switch back to leasing capital, as we discuss below.<sup>14</sup>

### 3.2 Firm's problem

The firm's problem can hence be written as the problem of maximizing the discounted expected value of future dividends by choosing the current dividend  $d$ , capital  $k'$ , leased capital  $k'_l$ , net worth  $w(s')$  in state  $s'$ , and state-contingent debt  $b(s')$ :

$$V(w, s) \equiv \max_{\{d, k', k'_l, w(s'), b(s')\} \in \mathbb{R}_+^{3+S} \times \mathbb{R}^S} d + \beta \sum_{s' \in S} \Pi(s, s') V(w(s'), s') \quad (1)$$

subject to the budget constraints

$$w + \sum_{s' \in S} \Pi(s, s') b(s') \geq d + k' - (1 - u_l) k'_l \quad (2)$$

$$A(s') f(k') + (k' - k'_l)(1 - \delta) \geq w(s') + Rb(s'), \quad \forall s' \in S, \quad (3)$$

the collateral constraints

$$\theta(\varphi k' - k'_l)(1 - \delta) \geq Rb(s'), \quad \forall s' \in S, \quad (4)$$

and the constraint that only physical capital can be leased

$$\varphi k' \geq k'_l. \quad (5)$$

Note that the program in (1)-(5) requires that dividends  $d$  and net worth  $w(s')$  are non-negative which is due to limited liability. Furthermore, capital  $k'$  and leased capital  $k'_l$  have to be non-negative as well. We write the budget constraints as inequality constraints, despite the fact that they bind at an optimal contract, since this makes the constraint set convex as shown below. There are only two state variables in this recursive formulation, net worth  $w$  and the state of productivity  $s$ . This is due to our assumption that there are no adjustment costs of any kind and greatly simplifies the analysis. Net worth in state  $s'$  next period  $w(s') = A(s') f(k') + (k' - k'_l)(1 - \delta) - Rb(s')$ , that is, equals cash flow plus the depreciated resale value of owned capital minus the amount to be repaid on state  $s'$  contingent debt. Borrowing against state  $s'$  next period by issuing state  $s'$  contingent debt  $b(s')$  reduces net worth  $w(s')$  in that state. In other words, borrowing less than the

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<sup>14</sup>While we do not explicitly consider taxes here, our assumption about discount rates can also be interpreted as a reduced form way of taking into account the tax-deductibility of interest, which effectively lowers the cost of debt finance.

maximum amount which satisfies the collateral constraint (4) against state  $s'$  amounts to conserving net worth for that state and allows the firm to hedge the available net worth in that state.

We make the following assumptions about the stochastic process describing productivity and the production function:

**Assumption 1** For all  $\hat{s}, s \in S$  such that  $\hat{s} > s$ , **(i)**  $A(\hat{s}) > A(s)$  and **(ii)**  $A(s) > 0$ .

**Assumption 2**  $f$  is strictly increasing and strictly concave,  $f(0) = 0$  and  $\lim_{k \rightarrow 0} f'(k) = +\infty$ .

We first show that the firm financing problem is a well-behaved convex dynamic programming problem and that there exists a unique value function  $V$  which solves the problem. To simplify notation, we introduce the shorthand for the choice variables  $x$ , where  $x \equiv [d, k', k'_l, w(s'), b(s')]'$ , and the shorthand for the constraint set  $\Gamma(w, s)$  given the state variables  $w$  and  $s$ , defined as the set of  $x \in \mathbb{R}_+^{3+S} \times \mathbb{R}^S$  such that (2)-(5) are satisfied. Define operator  $T$  as

$$(Tf)(w, s) = \max_{x \in \Gamma(w, s)} d + \beta \sum_{s' \in S} \Pi(s, s') f(w(s'), s').$$

We prove the following result about the firm financing problem in (1)-(5):

**Proposition 1** **(i)**  $\Gamma(w, s)$  is convex, given  $(w, s)$ , and convex in  $w$  and monotone in the sense that  $w \leq \hat{w}$  implies  $\Gamma(w, s) \subseteq \Gamma(\hat{w}, s)$ . **(ii)** The operator  $T$  satisfies Blackwell's sufficient conditions for a contraction and has a unique fixed point  $V$ . **(iii)**  $V$  is continuous, strictly increasing, and concave in  $w$ . **(iv)** Without leasing,  $V(w, s)$  is strictly concave in  $w$  for  $w \in \text{int}\{w : d(w, s) = 0\}$ . **(v)** Assuming that for all  $\hat{s}, s \in S$  such that  $\hat{s} > s$ ,  $\Pi(\hat{s}, s')$  strictly first order stochastically dominates  $\Pi(s, s')$ ,  $V$  is strictly increasing in  $s$ .

The proofs of part (i)-(iii) of the proposition are relatively standard. Part (iii) however only states that the value function is concave, not strictly concave. The value function turns out to be linear in net worth when dividends are paid. The value function may also be linear in net worth on some intervals where no dividends are paid, due to the substitution between leased and owned capital. All our proofs below hence rely on weak concavity only. Nevertheless we can show that without leasing, the value function is strictly concave where no dividends are paid (see part (iv) of the proposition). Finally, we note that Assumption 1 is only required for part (v) of the proposition.

Consider the first order conditions of the firm financing problem in equations (1)-(5). Denote the multipliers on the constraints (2), (3), (4), and (5) by  $\mu$ ,  $\Pi(s, s')\mu(s')$ ,  $\Pi(s, s')\lambda(s')$ , and  $\bar{\nu}_l$ .<sup>15</sup> Let  $\nu_d$  and  $\underline{\nu}_l$  be the multipliers on the constraint  $d \geq 0$  and  $k'_l \geq 0$ .

<sup>15</sup>Note that we scale some of the multipliers by  $\Pi(s, s')$  to simplify the notation.

The first order conditions are

$$\mu = 1 + \nu_d \quad (6)$$

$$\mu = \sum_{s' \in S} \Pi(s, s') \{ \mu(s') [A(s') f'(k') + (1 - \delta)] + \lambda(s') \theta \varphi (1 - \delta) \} + \bar{\nu}_l \varphi \quad (7)$$

$$(1 - u_l) \mu = \sum_{s' \in S} \Pi(s, s') \{ \mu(s') (1 - \delta) + \lambda(s') \theta (1 - \delta) \} + \bar{\nu}_l - \underline{\nu}_l \quad (8)$$

$$\mu(s') = \beta V_w(w(s'), s'), \quad \forall s' \in S, \quad (9)$$

$$\mu = \mu(s') R + \lambda(s') R, \quad \forall s' \in S, \quad (10)$$

where we have assumed that the constraints  $k' \geq 0$  and  $w(s') \geq 0, \forall s' \in S$ , are slack as shown in Lemma 1 below. The envelope condition is

$$V_w(w, s) = \mu.$$

Since we assume that the marginal product of capital is unbounded as capital goes to zero, the amount of capital is strictly positive. Because the firm's ability to issue promises against capital is limited, this in turn implies that the firm's net worth is positive in all states in the next period, as the next lemma shows.

**Lemma 1** *Under Assumption 2, capital and net worth in all states are strictly positive,  $k' > 0$  and  $w(s') > 0, \forall s' \in S$ .*

### 3.3 User cost of capital

This section provides definitions for the user cost of intangible capital, purchased physical capital, and leased capital, extending Jorgenson (1963)'s definition to our model with collateral constraints. Lucas and Prescott (1971), Abel (1983), and Abel and Eberly (1996) define the user cost of capital for models with adjustment costs. The definitions clarify the main economic intuition behind our results and allow a very simple characterization of the leasing decision.

Our definition of the user cost of physical capital which is purchased  $u_p$  is

$$u_p \equiv R^{-1}(r + \delta) + \sum_{s' \in S} \Pi(s, s') \frac{\lambda(s')}{\mu} (1 - \theta)(1 - \delta)$$

where  $\lambda(s')$  is the Kuhn-Tucker multiplier on the state  $s'$  collateral constraint. Note that the user cost of purchased physical capital has two components. The first component is simply the Jorgensonian user cost of capital, paid in advance. The second component

captures the additional cost of internal funds, which command a premium due to the collateral constraints. Indeed,  $(1-\theta)(1-\delta)$  is the fraction of capital that needs to be financed internally, because the firm cannot credibly pledge that amount to lenders. Similarly, we define the user cost of intangible capital  $u_i$  as  $u_i \equiv R^{-1}(r + \delta) + \sum_{s' \in S} \Pi(s, s') \frac{\lambda(s')}{\mu} (1 - \delta)$ . The only difference is that all of intangible capital needs to be financed with internal funds and hence the second term involves fraction  $1 - \delta$  rather than only a fraction  $1 - \theta$  of that amount.

Using our definitions of the user cost of purchased physical and intangible capital, and (10), we can rewrite the first order condition for capital, equation (7), as

$$\varphi u_p + (1 - \varphi) u_i = \sum_{s' \in S} \Pi(s, s') \frac{\mu(s')}{\mu} A(s') f'(k') + \bar{v}_l \varphi.$$

Optimal investment equates the weighted average of the user cost of physical and intangible capital with the expected marginal product of capital.

The user cost of physical capital can also be written in a *weighted average cost of capital* form as

$$u_p = 1 - \left[ R^{-1} \theta + \sum_{s' \in S} \Pi(s, s') \frac{\mu(s')}{\mu} (1 - \theta) \right] (1 - \delta),$$

where the fraction of physical capital that can be financed with external funds,  $\theta$ , is discounted at  $R$ , while the fraction of physical capital that has to be financed with internal funds,  $1 - \theta$ , is discounted at  $(\sum_{s' \in S} \Pi(s, s') \mu(s') / \mu)^{-1}$ , which strictly exceeds  $R$  as long as  $\lambda(s') > 0$ , for some  $s' \in S$ .

Using the definitions of the user cost of physical capital above and (10), the first order condition with respect to leased capital, (8), simplifies to

$$u_l = u_p - \bar{v}_l / \mu + \underline{v}_l / \mu. \quad (11)$$

The decision between purchasing capital and leasing reduces to a straight comparison of the user costs. If the user cost of leasing exceeds the user cost of purchased capital, then  $\underline{v}_l > 0$  and the firm purchases all capital. If the reverse is true,  $\bar{v}_l > 0$  and all capital is leased. When  $u_l = u_p$ , the firm is indifferent between leasing and purchasing capital at the margin.

### 3.4 Dividend payout policy

We start by characterizing the firm's payout policy. The firm's dividend policy is very intuitive: there is a state-contingent cutoff level of net worth  $\bar{w}(s)$ ,  $\forall s \in S$ , above which

the firm pays dividends. Moreover, whenever the firm has net worth  $w$  exceeding the cutoff  $\bar{w}(s)$ , paying dividends in the amount  $w - \bar{w}(s)$  is optimal. All firms with net worth  $w$  exceeding the cutoff  $\bar{w}(s)$  in a given state  $s$ , choose the same level of capital. Finally, the investment policy is unique in terms of the choice of capital  $k'$ . The following proposition summarizes the characterization of firms' payout policy:

**Proposition 2 (Dividend policy)** *There is a state-contingent cutoff level of net worth, above which the marginal value of net worth is one and the firm pays dividends: (i)  $\forall s \in S$ ,  $\exists \bar{w}(s)$  such that,  $\forall w \geq \bar{w}(s)$ ,  $\mu(w, s) = 1$ . (ii) For  $\forall w \geq \bar{w}(s)$ ,*

$$[d_o(w, s), k'_o(w, s), k'_{l,o}(w, s), w_o(s'), b_o(s')] = [w - \bar{w}(s), \bar{k}'_o(s), \bar{k}'_{l,o}(s), \bar{w}_o(s'), \bar{b}_o(s')]$$

where  $\bar{x}_o \equiv [0, \bar{k}'_o(s), \bar{k}'_{l,o}(s)\bar{w}_o(s'), \bar{b}_o(s')]$  attains  $V(\bar{w}(s), s)$ . Indeed,  $k'_o(w, s)$  is unique for all  $w$  and  $s$ . (iii) Without leasing, the optimal policy  $x_o$  is unique.

### 3.5 Effect of tangibility and collateralizability without leasing

In the model, we distinguish between the fraction of tangible assets required for production,  $\varphi$ , and the fraction of tangible assets  $\theta$  that the borrower cannot abscond with and that is hence collateralizable. This distinction is important to understand differences in the capital structure across industries, as the fraction of tangible assets required for production varies considerably at the industry level whereas the fraction of tangible assets that is collateralizable primarily depends on the type of capital, such as structures versus equipment (which we do not distinguish here). That said, in the special case without leasing, higher tangibility and higher collateralizability are equivalent in our model.

**Proposition 3 (Tangibility and collateralizability)** *Without leasing, a higher fraction of physical capital  $\varphi$  is equivalent to a higher fraction  $\theta$  that can be collateralized.*

Thus, firms that operate in industries that require more intangible capital are more constrained and constrained for longer, all else equal. This result is immediate as without leasing,  $\varphi$  and  $\theta$  affect only (4) and only the product of the two matters. Nevertheless, industry variation in  $\varphi$  needs to be taken into account in empirical work.

## 4 Leasing and the capital structure

This section analyzes the dynamic leasing decision in detail. We start by proving a general result about the optimality of leasing for firms with sufficiently low net worth.

We then focus on the deterministic case to highlight the economic intuition and facilitate explicit characterization, postponing a more detailed discussion of the stochastic case to Subsection 5.5. The deterministic analysis is simplified by the fact that the collateral constraint binds throughout. Specifically, we analyze the dynamic choice between leasing and secured financing. Finally, we show that leasing enables firms to grow faster.

## 4.1 Optimality of leasing

The following assumption ensures that the monitoring cost are such that leasing is neither dominated nor dominating, which rules out the uninteresting special cases in which firms never lease or always lease tangible assets:

**Assumption 3** *Leasing is neither dominated nor dominating, that is,*

$$R^{-1}(1 - \theta)(1 - \delta) > m > (R^{-1} - \beta)(1 - \theta)(1 - \delta).$$

We maintain this assumption throughout. The left most expression and the right most expression are the opportunity costs of the additional down payment requirement when purchasing capital, which depend on the firm's discount rate. The additional down payment requirement is  $R^{-1}(1 - \theta)(1 - \delta)$  which is recovered the next period. If the firm is very constrained, the recovered funds are not valued at all, which yields the expression on the left. If the firm is least constrained, the recovered funds are valued at  $\beta$ , the discount factor of the firm, and the opportunity cost is only the wedge between the funds discounted at the lenders' discount rate and the firm's discount rate.

We can now prove that severely constrained firms lease all their tangible assets:

**Proposition 4 (Optimality of leasing)** *Firms with sufficiently low net worth lease all (physical) capital, that is,  $\exists \underline{w}_l > 0$ , such that  $\forall w \leq \underline{w}_l$ ,  $k'_l = \varphi k'$ .*

The proposition holds for any Markov process for productivity, and hence cash flows, and does not require any further assumptions. It substantially generalizes the static result of Eisfeldt and Rampini (2009). The intuition is that when net worth is sufficiently low, the firm's investment must be very low and hence its marginal product very high. But then the firm's financing need must be so severe, that it must find the higher debt capacity of leasing worthwhile.

## 4.2 Dynamic deterministic choice between leasing and financing

In the rest of this section, we consider the capital structure dynamics in the deterministic case. To start, consider the deterministic dynamics of firm financing without leasing. As long as net worth is below a cutoff  $\bar{w}$ , firms pay no dividends and accumulate net worth over time which allows them to increase the amount of capital they deploy. Once net worth reaches  $\bar{w}$ , dividends are positive and firms no longer grow.

**Proposition 5 (Deterministic capital structure dynamics without leasing)** *For  $w \leq \bar{w}$ , no dividends are paid and capital is strictly increasing in  $w$  and over time. For  $w > \bar{w}$ , dividends are strictly positive and capital is constant at a level  $\bar{k}'$ .*

When leasing is an option, firms have to choose a leasing policy in addition to the investment, financing and payout policy. In this case, the financing dynamics are as follows: when firms have low net worth, they lease all the physical capital and purchase only the intangible capital. Over time, firms accumulate net worth and increase their total capital. When they reach a certain net worth threshold, they start to substitute owned capital for leased capital, continuing to accumulate net worth. Once firms own all their physical and intangible capital, they further accumulate net worth and increase the capital stock until they start to pay dividends. At that point, capital stays constant.

**Proposition 6 (Deterministic capital structure dynamics)** *For  $w \leq \bar{w}$ , no dividends are paid and capital is increasing in  $w$  and over time. For  $w > \bar{w}$ , dividends are strictly positive and capital is constant at a level  $\bar{k}'$ . There exist  $\underline{w}_l < \bar{w}_l < \bar{w}$ , such that for  $w \leq \underline{w}_l$  all physical capital is leased and for  $w < \bar{w}_l$  some capital is leased.*

The dynamics of capital structure in a stochastic environment are quite similar and are analyzed in Subsection 5.5 below.

## 4.3 Leasing and firm growth

Leasing allows constrained firms to grow faster. To see this note that the minimum amount of internal funds required to purchase one unit of capital is  $1 - R^{-1}\theta\varphi(1 - \delta)$ , since the firm can borrow against fraction  $\theta$  of the resale value of physical capital, which is fraction  $\varphi$  of capital. The minimum amount of internal funds required when physical capital is leased is  $1 - \varphi + u_l\varphi$ , since the firm has to finance all intangible capital with internal funds  $(1 - \varphi)$  and pay the leasing fee on physical capital up front  $(u_l\varphi)$ . Per unit of internal funds, the firm can hence buy capital in the amount of one over these minimum amounts of internal funds. Under Assumption 3, leasing allows higher leverage,

that is,  $1/(1 - \varphi + u_l\varphi) > 1/(1 - R^{-1}\theta\varphi(1 - \delta))$ . Thus, leasing allows firms to deploy more capital and hence to grow faster.

**Corollary 1 (Leasing and firm growth)** *Leasing enables firms to grow faster.*

The same economic intuition carries over to the stochastic case, which we analyze in Subsection 5.5 below, after considering the implications of our model for risk management. There however we show that the high leverage that leasing entails considerably affects firms' risk management policy.

## 5 Risk management and the capital structure

One advantage of our model is that firms have access to complete markets, subject to the collateral constraints due to limited enforcement. This is useful because it allows an explicit analysis of risk management. Thus, we are able to provide a unified analysis of optimal firm policies in terms of financing, investment, leasing, and risk management. Our model hence extends the work on risk management of Froot, Scharfstein, and Stein (1993) to a fully dynamic model of firm financing subject to financial constraints in the case of a standard neoclassical production function. We first provide a general result about the optimal absence of risk management for firms with sufficiently low net worth. We then show how to interpret the state-contingent debt in our model in terms of financial slack and risk management. Next, we prove the optimality of incomplete hedging with constant investment opportunities, that is, when productivity shocks are independently and identically distributed. Indeed, we show that firms abstain from risk management with positive probability under the stationary distribution. Moreover, we study the effect of stochastic investment opportunities on optimal risk management and show that persistent shocks further reduce risk management. Finally, we study the interaction between leasing and risk management and show that firms may engage in risk management when they lease so as to reduce falls in net worth due to the high leverage leasing enables.

### 5.1 Optimal absence of risk management

Severely constrained firms optimally abstain from risk management altogether:

**Proposition 7 (Optimal absence of risk management)** *Firms with sufficiently low net worth do not engage in risk management, that is,  $\exists \underline{w}_h > 0$ , such that  $\forall w \leq \underline{w}_h$  and any state  $s$ , all collateral constraints bind,  $\lambda(s') > 0, \forall s' \in S$ .*

Collateral constraints imply that there is an opportunity cost to issuing promises to pay in high net worth states next period to hedge low net worth states next period, as such promises can also be used to finance current investment. The proposition shows that when net worth is sufficiently low, the opportunity cost of risk management due to the financing needs must exceed the benefit. Hence, the firm optimally does not hedge at all. The proposition builds on Rampini and Viswanathan (2009), who analyze a two period model, and extends their result to an environment with a general Markov process for productivity and an infinite horizon. The result is consistent with the evidence and in contrast to the conclusions from static models in the extant literature, such as Froot, Scharfstein, and Stein (1993). The key difference is that our model explicitly considers dynamic financing needs for investment as well as the limits on firms' ability to promise to pay.

In order to characterize risk management and corporate hedging policy, define financial slack for state  $s'$  as

$$h(s') \equiv \theta(\varphi k' - k'_i)(1 - \delta) - Rb(s'). \quad (12)$$

The collateral constraints (4) can then be rewritten as

$$h(s') \geq 0, \quad \forall s' \in S, \quad (13)$$

implying that financial slack has to be non-negative. Our model with state-contingent debt  $b(s')$  thus is equivalent to a model in which firms borrow as much as they can against each unit of physical capital which they purchase, that is, borrow  $R^{-1}\theta(1 - \delta)$  per unit of capital, and keep financial slack by purchasing Arrow securities with a payoff of  $h(s')$  for state  $s'$ . Under this interpretation, firm's debt is not state-contingent, since we assume that the price of capital is constant for all states. Our model with state-contingent borrowing is hence a model of financing and risk management. The proposition above states that all collateral constraints bind, which means that the firm does not purchase any Arrow securities at all. In this sense, the firm does not engage in risk management. In the numerical example below, we show that the extent to which firms hedge low states is in fact increasing in net worth. Before doing so, we provide a characterization of the optimal hedging policy when productivity shocks are independent and identically distributed.

In our model, we do not explicitly take a stand on whether the productivity shocks are firm specific or aggregate. Since all states are observable, as the only friction considered is limited enforcement, our analysis applies either way. Hedging in this section can hence be interpreted either as using for example loan commitments to hedge idiosyncratic shocks to a firm's net worth or as using traded assets to hedge aggregate shocks which affect

firms' cash flows.<sup>16</sup>

## 5.2 Risk management with constant investment opportunities

We analyze the case of independent productivity shocks here. This allows us to study the firm's hedging policy explicitly, as investment opportunities do not vary with independent shocks, in the sense that, all else equal, the expected productivity of capital does not vary with the current realization of the state  $s$ . More generally, both cash flows and investment opportunities vary, and the correlation between the two affects the desirability of hedging, as we show below.

When productivity is independent across time, that is,  $\Pi(s, s') = \Pi(s')$ ,  $\forall s, s' \in S$ , the state  $s$  is no longer a state variable. This implies that the value of net worth across states is ordered as follows:

**Proposition 8 (Value of internal funds and collateral constraints)** *Suppose that  $\Pi(s, s') = \Pi(s')$ ,  $\forall s, s' \in S$ . The marginal value of net worth is (weakly) decreasing in the state  $s'$ , and the multipliers on the collateral constraints are (weakly) increasing in the state  $s'$ , that is,  $\forall s', s'_+ \in S$  such that  $s'_+ > s'$ ,  $\mu(s'_+) \leq \mu(s')$  and  $\lambda(s'_+) \geq \lambda(s')$ .*

Thus, the marginal value of net worth is higher in states with low cash flows due to low realizations of productivity. We can now show that complete hedging is never optimal.

**Proposition 9 (Optimality of incomplete hedging)** *Suppose that  $\Pi(s, s') = \Pi(s')$ ,  $\forall s, s' \in S$ . Incomplete hedging is optimal, that is,  $\exists s' \in S$ , such that  $\lambda(s') > 0$ . Indeed,  $\exists s', \hat{s}' \in S$ , such that  $w(s') \neq w(\hat{s}')$ . Moreover, the firm never hedges the highest state, that is, is always borrowing constrained against the highest state,  $\lambda(\bar{s}') > 0$  where  $\bar{s}' = \max\{s' : s' \in S\}$ . The firm hedges a lower interval of states,  $[\underline{s}', \dots, s'_h]$ , where  $\underline{s}' = \min\{s' : s' \in S\}$ , if at all.*

The intuition for this result is the following. Complete hedging would imply that all collateral constraints are slack and consequently the marginal value of net worth is equalized across all states next period. But hedging involves conserving net worth in a state-contingent way at a return  $R$ . Given the firm's relative impatience, it can never be optimal to save in this state-contingent way for all states next period. This implies the optimality of incomplete hedging.

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<sup>16</sup>See Rampini and Viswanathan (2009) for an interpretation of our state-contingent financing in terms of loan commitments.

The second aspect in the proposition is that, since the marginal value of net worth is higher in states with low cash flow realizations, it is optimal to hedge the net worth in these states, if it is optimal to hedge at all. Firms' optimal hedging policy implicitly ensures a minimum level of net worth in all states next period. When firms' productivity follows a general Markov process, both net worth and investment opportunities vary, and the hedging policy needs to take the shortfall between financing needs and available funds across states into account. Nevertheless, Proposition 7 shows that severely constrained firms do not hedge at all, even in the general case.

We emphasize that our explicit dynamic model of collateral constraints due to limited enforcement is essential for this result. If the firm's ability to pledge were not limited, then the firm would always want to pledge more against high net worth states next period to equate net worth across all states. However, in our model the ability to credibly pledge to pay is limited and there is an opportunity cost to pledging to pay in high net worth states next period, since such pledges are also required for financing current investment. This opportunity cost implies that the firm never chooses to fully hedge net worth shocks.

To illustrate the interaction between financing needs and risk management, we compute a numerical example. We assume that productivity is independent and moreover assume for simplicity that productivity takes on two values only,  $A(s_1) < A(s_2)$ , and that there is no leasing. The details of the parameterization are described in the caption of Figure 3 and the results are reported in Figures 3 through 5.

Investment as a function of net worth is shown in Panel A of Figure 3, which illustrates Proposition 2. Above a threshold  $\bar{w}$ , firms pay dividends and investment is constant. Below the threshold, investment is increasing in net worth and dividends are zero.

The dependence of the risk management policy on net worth is illustrated in Panel B of Figure 3. Since we assume independent shocks, Proposition 9 implies that the firm never hedges the high state, that is,  $h(s'_2) = 0$ , where  $h(s')$  is defined as in equation (12). Panel B thus displays the extent to which the firm hedges the low state only, that is, the payoff of the Arrow claims that the firm purchases to hedge the low state,  $h(s'_1)$ . Most importantly, note that the hedging policy is increasing in firm net worth, that is, better capitalized firms hedge more. This illustrates the main conclusion from our model for risk management. Above the threshold  $\bar{w}$ , risk management is constant (as Proposition 2 shows). Below the threshold, hedging is increasing, and for sufficiently low values of net worth  $w$ , the firm does not hedge at all, as Proposition 7 shows more generally. Note that hedging is zero until net worth reaches a value of around 0.1 in the example, that is, for a sizable range of values of net worth, then increases, and then is constant above  $\bar{w}$ .

The implied values of net worth are displayed in Figure 4. Panel A illustrates the

optimality of incomplete hedging from Proposition 9. Net worth next period is higher in state  $s'_2$  than in state  $s'_1$  despite the fact that firms have access to complete markets (except for collateral constraints). Indeed, when the difference in net worth across the two states is scaled by expected net worth next period, as shown in Panel B, we find that the scaled difference is larger for lower net worth. Thus, firms with lower net worth engage in less risk management and their net worth is more variable across states tomorrow. More constrained firms are less well insured. Panel A moreover plots the 45 degree line (dotted), that is, the locus where  $w = w'$ . The ergodic set of net worth must be bounded below by the intersection of  $w(s'_1)$  and the 45 degree line, which we denote  $\underline{w}(s_1)$ , and above by the intersection of  $w(s'_2)$  and the 45 degree line, which we denote  $\bar{w}(s_2)$ . The support of the invariant distribution is a subset of the interval  $[\underline{w}(s_1), \bar{w}(s_2)]$ . Levels of net worth below  $\underline{w}(s_1)$  and above  $\bar{w}(s_2)$  are transient. Indeed, firms with net worth above  $\bar{w}(s_2)$  will pay out the extra net worth and start the next period within the ergodic set. Moreover, evaluating the first order condition (10) for  $b(s')$  at  $\underline{w}(s_1)$  and  $s' = s_1$ , we have

$$V_w(\underline{w}(s_1)) = R\beta V_w(\underline{w}(s_1)) + R\lambda(\underline{w}(s_1))$$

and thus  $\lambda(\underline{w}(s_1)) > 0$ . This means that the firm abstains from risk management altogether at  $\underline{w}(s_1)$ . By continuity, the absence of risk management is optimal for sufficiently low values of net worth in the ergodic distribution. This is, in fact, a general result, as Propositions 10 and 11 below show.

The marginal value of current net worth  $\mu$  (which equals  $V_w(w)$ ) and scaled marginal value of net worth in states  $s'$  next period  $R\mu(s')$  (which equal  $R\beta V_w(w(s'))$ ) are shown in Panel A of Figure 5. Moreover, the multipliers on the collateral constraints  $\lambda(s')$  are shown in Panel B. Recall that the first order conditions (10) for  $b(s')$  imply that

$$R^{-1}\mu = \mu(s'_1) + \lambda(s'_1) = \mu(s'_2) + \lambda(s'_2).$$

The firm thus does not simply equate the marginal value of net worth across states, but the sum of the marginal value of net worth and the multiplier on the collateral constraint. From Proposition 9 we know that  $\lambda(s'_2) > 0$  for all  $w$ . From Proposition 8 we moreover know that  $\lambda(s'_2) \geq \lambda(s'_1)$  as Panel B shows and that  $\mu \geq R\mu(s'_1) \geq R\mu(s'_2)$  as Panel A shows. Moreover, for levels of  $w$  at which the firm (partially) hedges the low state, the multiplier on the collateral constraint for the low state  $\lambda(s'_1) = 0$  and  $\mu = R\mu(s'_1) > R\mu(s'_2)$  as the figure illustrates. For lower levels of net worth  $w$  the firm abstains from risk management, implying that  $\lambda(s'_1) > 0$  and  $\mu > R\mu(s'_1) \geq R\mu(s'_2)$ . Collateral constraints result in a trade off between financing and risk management.

### 5.3 Risk management under the stationary distribution

We now show that firms abstain from risk management at the lower bound of the ergodic distribution as we observed in the example above.

**Proposition 10 (Net worth transition dynamics)** *Suppose  $\Pi(s, s') = \Pi(s')$ ,  $\forall s, s' \in S$ , and  $m = +\infty$  (no leasing). (i)  $\forall s', s'_+ \in S$ , such that  $s'_+ > s'$ ,  $w(s'_+) \geq w(s')$ , with strict inequality iff  $s'_+ > s'_h$  where  $s'_h$  is defined in Proposition 9. (ii)  $w(s')$  is increasing in  $w$ ,  $\forall s' \in S$ ; for  $w$  sufficiently small,  $w(s') > w$ ,  $\forall s' \in S$ ; and for  $w$  sufficiently large,  $w(s') < w$ ,  $\forall s' \in S$ . (iii)  $\forall s' \in S$ ,  $\exists w$  dependent on  $s'$  such that  $w(s') = w$ . (iv) For the lowest state  $\underline{s}'$ , the wealth level  $\underline{w}$  for which  $w(\underline{s}') = \underline{w}$  is unique and the firm abstains from risk management at  $\underline{w}$ .*

Indeed, there is a unique stationary distribution and firms abstain from risk management with positive probability under the stationary distribution.

### Proposition 11 (Absence of risk management under the stationary distribution)

*Suppose that  $\Pi(s, s') = \Pi(s')$ ,  $\forall s, s' \in S$ , and  $m = +\infty$  (no leasing). There exists a unique stationary distribution of firm net worth, and under the stationary distribution the firm abstains from risk management with positive probability.*

Proposition 11 implies that even if a firm is currently relatively well capitalized and paying dividends, a sufficiently long sequence of low cash flows will leave the firm so constrained that it chooses to discontinue risk management.

### 5.4 Risk management with stochastic investment opportunities

We analyze the effect of stochastic investment opportunities numerically, by reconsidering the numerical example with a two state symmetric Markov process for productivity from the previous subsection. The results are reported in Figure 6. To study persistence, we increase the transition probabilities  $\Pi(s_1, s_1) = \Pi(s_2, s_2)$ , which are 0.5 when investment opportunities are constant, first to 0.55 and then further to 0.6. Given the symmetry, the stationary distribution of the productivity process over the two states is 0.5 and 0.5 across all our examples, and the unconditional expected productivity is hence the same as well. Panel A of Figure 6 displays the investment and hedging policies in the case without persistence from the previous subsection (see also Figure 3). With constant investment opportunities, the policy functions are independent of the state of productivity  $s$  and hence there is only one function for each policy. Panel B shows the investment and hedging policies with positive persistence. The solid lines denote the policies when current

productivity is low ( $s_1$ ) and the dashed lines the ones when current productivity is high ( $s_2$ ). The figure on the left shows that, for given net worth  $w$ , investment is higher when current productivity is higher, which is intuitive. The figure on the right shows that hedging decreases relative to the case of constant investment opportunities, but more so when current productivity is high. Most notably, for given net worth, the firm keeps less financial slack when current productivity is high than when it is low. The economic intuition has two aspects. First, hedging decreases relative to the case of constant investment opportunities because persistent shocks reduce the marginal value of net worth when productivity is low (since the conditional expected productivity is low then too) while raising the marginal value of net worth when productivity is high. Thus, there is less reason to hedge. Second, with persistence, high current productivity implies high expected productivity (as well as weakly higher opportunity cost of risk management) and higher investment, which raises net worth next period, further reducing the hedging need when current productivity is high. In contrast, when current productivity is low (and expected productivity and the opportunity cost of risk management are low), investment and hence net worth next period is reduced, which would raise the need for risk management all else equal. However, the first effect goes the other way and dominates the second effect in our example.

When persistence is raised further, as illustrated in Panel C, the firm abstains from hedging completely when current productivity is high. Persistent productivity shocks thus further reduce the optimal amount of risk management.

## 5.5 Interaction of leasing, leverage, and risk management

To study the interaction between the leasing, financing, and risk management policy, we consider the example with constant investment opportunities analyzed above and introduce leasing. The parameters are mostly as before, with details in the caption of Figure 7, which displays the results. The figure on the left in Panel A displays the investment and leasing policy, which is very similar to the one in the deterministic case in Figure 2. One difference is that investment is no longer constant when the substitution away from leased capital occurs.

Particularly noteworthy are the implications for risk management in the figure on the right. For high values of net worth the figure shows the by now familiar pattern for risk management, with risk management increasing in net worth until the dividend paying region is reached and constant from there on. However, for lower values of net worth at which the firm leases a substantial amount of capital, risk management first increases and then drops quite dramatically and in fact drops back to zero. To understand this result,

recall that leasing allows higher leverage and hence firms which are very constrained choose to lease to be able to lever up more. But the high implicit leverage reduces firms' net worth in the low state, and, if this effect is sufficiently strong, firms undo some of it by keeping some financial slack for the low cash flow state next period. Effectively, firms use leasing to borrow more from the high state next period while at least partially undoing the effects of higher leverage for the low state next period via risk management. The figure on the right of Panel B shows that the multiplier on the collateral constraint for the low state next period ( $\lambda(s_1)$ ) is non-monotone. It is positive for sufficiently low values of net worth, consistent with Proposition 4 (and Proposition 7). It is zero for an interval in which firms engage in risk management when leasing a substantial amount of capital. It then is positive again when firms purchases enough of their capital and finally goes back to zero for sufficiently well capitalized firms.

The transition function of net worth is displayed in the figure on the left of Panel B and is reminiscent of Panel A of Figure 4. What is remarkable however is that the solid line which denotes  $w(s'_1)$  crosses the 45 degree line below the point where firms lease the maximal amount. Recall that this intersection bounds the support of the invariant distribution from below. This implies that firms which are hit by a sequence of low productivity shocks eventually will return to leasing capital, that is, firms engage in sale-leaseback transactions under the stationary distribution.

## 6 Conclusion

We argue that collateral determines the capital structure. We provide a dynamic agency based model of the capital structure of a firm with a standard neoclassical production function subject to collateral constraints due to limited enforcement. In the model firms require both tangible and intangible capital, and the fraction of tangible assets required is a key determinant of leverage and the dynamics of firm financing.

Firms' ability to lease capital is explicitly taken into account in contrast to previous dynamic models of firm financing and investment with financial constraints. The extent to which firms lease is determined by firms' financial condition, and more constrained firms lease more. Indeed, severely constrained firms lease all their tangible capital. We show that leasing enables firms to grow faster. Using definitions of the user cost of purchased tangible capital and leased capital, the leasing decision reduces to a simple comparison of these user costs. The user cost of purchased physical capital moreover has a weighted average cost of capital representation.

The model has implications for risk management. There is an important connection

between firms' financing and risk management policy, since both involve promises to pay by firms, and financing needs can override hedging concerns. In fact, poorly capitalized firms optimally do not engage in risk management and firms abstain from risk management with positive probability under the stationary distribution. Our dynamic model which allows explicit analysis of the financing needs for investment and the limits on firms' ability to promise to pay is critical for this result. Moreover, we prove the optimality of incomplete hedging. It is not optimal for the firm to hedge to the point that the marginal value of internal funds is equal across all states.

We also provide stylized empirical facts that highlight the importance of tangibility as a determinant of the capital structure in the data. Firm leverage changes substantially with the fraction of assets which is tangible. Moreover, the lack of tangible assets largely explains why some firms have low leverage, and hence addresses the "low leverage puzzle." Leased capital is quantitatively important and further reduces the fraction of firms with low leverage.

We conclude that the tangibility of assets and firms' ability to lease capital are critical ingredients for studies of the capital structure. Calibrated versions of our model and empirical work are required to assess the extent to which our model of collateralized financing only is able to capture key features of the data. The simple form of the optimal contract in our dynamic agency based capital structure model may facilitate the empirical implementation, which has remained a challenge for other such agency based models. Moreover, due to its simplicity, our model may also prove to be a useful framework to address other theoretical questions in dynamic corporate finance.

## Appendix A: Enforcement versus collateral constraints

In this appendix we prove the equivalence of enforcement constraints and collateral constraints. For simplicity, we abstract from the option to lease capital, but the proof can be extended in a straightforward way by recognizing that the firm cannot abscond with leased capital. The firm's problem with limited enforcement at any time  $\tau \geq 0$ , denoted  $P_\tau(w(s^\tau))$ , is the problem of maximizing the discounted expected value of future dividends by choosing the sequence of dividends, capital levels, and net payments to the lender  $\{x(s^t)\}_{t \geq \tau}$ , where  $x(s^t) = \{d(s^t), k'(s^t), p(s^t)\}$  and  $s^t \equiv \{s_0, s_1, \dots, s_t\}$ , given current net worth  $w(s^\tau)$  and history  $s^\tau$  to maximize

$$E_\tau \left[ \sum_{t=\tau}^{\infty} \beta^{(t-\tau)} d_t \right] \quad (14)$$

subject to the budget constraints

$$w(s^\tau) \geq d(s^\tau) + k'(s^\tau) + p(s^\tau), \quad (15)$$

$$A(s^t)f(k'(s^{t-1})) + k'(s^{t-1})(1 - \delta) \geq d(s^t) + k'(s^t) + p(s^t), \quad \forall t > \tau, \quad (16)$$

the lender's participation constraint,

$$E_\tau \left[ \sum_{t=\tau}^{\infty} R^{-(t-\tau)} p_t \right] \geq 0 \quad (17)$$

and the enforcement constraints

$$E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} \beta^{(t-\tau')} d_t \right] \geq E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} \beta^{(t-\tau')} \hat{d}_t \right], \quad \forall \tau' \geq \tau, \text{ and } \forall \{\hat{d}(s^t)\}_{t=\tau'}^{\infty}, \quad (18)$$

where  $\{\hat{d}(s^t)\}_{t=\tau'}^{\infty}$  together with  $\{\hat{k}'(s^t)\}_{t=\tau'}^{\infty}$  and  $\{\hat{p}(s^t)\}_{t=\tau'}^{\infty}$  solve  $P_{\tau'}(w(s^{\tau'}))$  given net worth  $w(s^{\tau'}) = A(s^{\tau'})f(k'(s^{\tau'-1})) + (1 - \theta\varphi)k'(s^{\tau'-1})(1 - \delta)$ , that is, the same problem with a different level of net worth. We say a sequence of net payments is implementable if it satisfies the lender's participation constraint and the enforcement constraints.

**Proposition 12 (Equivalence of enforcement and collateral constraints)** (i) Any sequence of net payments  $\{p(s^t)\}_{t=\tau}^{\infty}$  to the lender is implementable in problem  $P_\tau(w(s^\tau))$  iff

$$\theta\varphi k(s^{\tau'-1})(1 - \delta) \geq E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} R^{-(t-\tau')} p_t \right], \quad \forall \tau' \geq \tau, \quad (19)$$

that is, the present value of the remaining net payments never exceeds the current collateral value. (ii) Moreover, the set of sequences of net payments that satisfy (19) is equivalent to the set of sequences of one period state contingent claims  $\{b(s^t)\}_{t=\tau}^{\infty}$  which satisfy

$$\theta\varphi k(s^{t-1})(1 - \delta) \geq Rb(s^t), \quad \forall t > \tau, \quad (20)$$

**Proof of Proposition 12.** Part (i): Suppose the sequence  $\{p(s^t)\}_{t=\tau}^\infty$  is such that (19) is violated for some  $s^{\tau'}$ ,  $\tau' > \tau$ , that is,

$$\theta\varphi k(s^{\tau'-1})(1-\delta) < E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} R^{-(t-\tau')} p_t \right].$$

Without loss of generality, assume  $\tau' = \tau + 1$ . Suppose the firm defaults in state  $s^{\tau+1}$  at time  $\tau + 1$  and issues a new sequence of net payments  $\{\hat{p}(s^t)\}_{t=\tau+1}^\infty$  such that

$$E_{\tau+1} \left[ \sum_{t=\tau+1}^{\infty} R^{-(t-(\tau+1))} \hat{p}_t \right] = 0$$

with  $\hat{p}(s^t) = p(s^t)$ ,  $\forall t > \tau + 1$ , and  $\hat{p}(s^{\tau+1}) = -E_{\tau+1} \left[ \sum_{t=\tau+2}^{\infty} R^{-(t-(\tau+1))} \hat{p}_t \right]$  (which has zero net present value by construction), keeping the dividend and investment policies the same, except for the dividend in state  $s^{\tau+1}$  at time  $\tau + 1$ . This dividend increases since the firm makes payment  $\hat{p}(s^{\tau+1})$  instead of  $p(s^{\tau+1})$  while buying back the tangible assets which have been seized, that is,  $\theta\varphi k(s^\tau)(1-\delta)$ , and thus

$$\begin{aligned} \hat{d}(s^{\tau+1}) &= d(s^{\tau+1}) + (p(s^{\tau+1}) - \hat{p}(s^{\tau+1}) - \theta\varphi k'(s^\tau)(1-\delta)) \\ &= d(s^{\tau+1}) + \left( E_{\tau+1} \left[ \sum_{t=\tau+1}^{\infty} R^{-(t-(\tau+1))} \hat{p}_t \right] - \theta\varphi k'(s^\tau)(1-\delta) \right) > d(s^{\tau+1}). \end{aligned}$$

Such a deviation would hence constitute an improvement, a contradiction. Conversely, if (19) is satisfied  $\forall \tau' \geq \tau$ , then defaulting cannot make the firm better off.

Part (ii): Take any sequence of net payments  $\{p(s^t)\}_{t=\tau}^\infty$  and define

$$Rb(s^{\tau'}) \equiv E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} R^{-(t-\tau')} p_t \right] \leq k(s^{\tau'-1})(1-\delta), \quad \forall \tau' > \tau.$$

Then

$$Rb(s^{\tau'}) = p(s^{\tau'}) + R^{-1} E_{\tau'} \left[ Rb(s^{\tau'+1}) \right]$$

and thus  $p(s^{\tau'}) = Rb(s^{\tau'}) - E_{\tau'} \left[ b(s^{\tau'+1}) \right]$  and equation (16) can be rewritten as

$$A(s^t) f(k'(s^{t-1})) + k'(s^{t-1})(1-\delta) + E_t \left[ b(s^{t+1}) \right] \geq d(s^t) + k'(s^t) + Rb(s^t), \quad \forall t > \tau. \quad (21)$$

Thus, any sequence of net payments satisfying (19) can be implemented with a sequence of one period contingent claims satisfying (20).

Conversely, take any sequence  $\{b(s^t)\}_{t=\tau}^\infty$  satisfying (20) and define  $p(s^t) = Rb(s^t) - E_t \left[ b(s^{t+1}) \right]$ ,  $\forall t \geq \tau$ . Then,  $\forall \tau' > \tau$ ,

$$E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} R^{-(t-\tau')} p_t \right] = E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} R^{-(t-\tau')} (Rb^{\tau'} - b^{\tau'+1}) \right] = Rb(s^{\tau'}) \leq \theta\varphi k(s^{\tau'-1})(1-\delta),$$

that is, the sequence of one period contingent claims satisfying (20) can be implemented with a sequence of net payments satisfying (19).  $\square$

Given Proposition 12, the sequence problem  $P_\tau$  in equations (14)-(18) is equivalent to the problem of maximizing (14) subject to  $w(s^\tau) \geq d(s^\tau) + k'(s^\tau) - E_\tau [b(s^{\tau+1})]$ , (20), and (21). Defining the net worth after repayment of the one period claims issued the previous period as  $w(s^t) \equiv A(s^t)f(k'(s^{t-1})) + k'(s^{t-1})(1 - \delta) - Rb(s^t)$ ,  $\forall t > \tau$ , the problem can be written recursively as in equations (1)-(5).

## Appendix B: Proofs

**Proof of Proposition 1.** The proposition is proved in Lemma 2-6 below.

**Lemma 2**  $\Gamma(w, s)$  is convex, given  $(w, s)$ , and convex in  $w$  and monotone in the sense that  $w \leq \hat{w}$  implies  $\Gamma(w, s) \subseteq \Gamma(\hat{w}, s)$ .

**Proof of Lemma 2.** Suppose  $x, \hat{x} \in \Gamma(w, s)$ . For  $\phi \in (0, 1)$ , let  $x_\phi \equiv \phi x + (1 - \phi)\hat{x}$ . Then  $x_\phi \in \Gamma(w, s)$  since equations (2), (4), and (5), as well as the right hand side of equation (3) are linear and, since  $f$  is concave,

$$\begin{aligned} A(s')f(k'_\phi) + (k'_\phi - k'_{i,\phi})(1 - \delta) &\geq \phi[A(s')f(k') + (k' - k'_i)(1 - \delta)] \\ &\quad + (1 - \phi)[A(s')f(\hat{k}') + (\hat{k}' - \hat{k}'_i)(1 - \delta)]. \end{aligned}$$

Let  $x \in \Gamma(w, s)$  and  $\hat{x} \in \Gamma(\hat{w}, s)$ . For  $\phi \in (0, 1)$ , let  $x_\phi \equiv \phi x + (1 - \phi)\hat{x}$ . Since equations (3), (4), and (5) do not involve  $w$  and  $\hat{w}$ , respectively, and  $\Gamma(w, s)$  is convex given  $w$ ,  $x_\phi$  satisfies these equations. Moreover, since  $x$  and  $\hat{x}$  satisfy equation (2) at  $w$  and  $\hat{w}$ , respectively, and equation (2) is linear in  $x$  and  $w$ ,  $x_\phi$  satisfies the equation at  $w_\phi$ . Thus,  $x_\phi \in \Gamma(\phi w + (1 - \phi)\hat{w}, s)$ . In this sense,  $\Gamma(w, s)$  is convex in  $w$ .

If  $w \leq \hat{w}$ , then  $\Gamma(w, s) \subseteq \Gamma(\hat{w}, s)$ .  $\square$

**Lemma 3** The operator  $T$  satisfies Blackwell's sufficient conditions for a contraction and has a unique fixed point  $V$ .

**Proof of Lemma 3.** Suppose  $g(w, s) \geq f(w, s)$ , for all  $(w, s) \in \mathbf{R}_+ \times S$ . Then, for any  $x \in \Gamma(w, s)$ ,

$$(Tg)(w, s) \geq d + \beta \sum_{s' \in S} \Pi(s, s')g(w(s'), s') \geq d + \beta \sum_{s' \in S} \Pi(s, s')f(w(s'), s').$$

Hence,

$$(Tg)(w, s) \geq \max_{x \in \Gamma(w, s)} d + \beta \sum_{s' \in S} \Pi(s, s')f(w(s'), s') = (Tf)(w, s)$$

for all  $(w, s) \in \mathbf{R}_+ \times S$ . Thus,  $T$  satisfies monotonicity.

Operator  $T$  satisfies discounting since

$$T(f + a)(w, s) \geq \max_{x \in \Gamma(w, s)} d + \beta \sum_{s' \in S} \Pi(s, s')(f + a)(w(s'), s') = (Tf)(w, s) + \beta a.$$

Therefore, operator  $T$  is a contraction and, by the contraction mapping theorem, has a unique fixed point  $V$ .  $\square$

**Lemma 4**  $V$  is strictly increasing and concave in  $w$ .

**Proof of Lemma 4.** Let  $x_o \in \Gamma(w, s)$  and  $\hat{x}_o \in \Gamma(\hat{w}, s)$  attain  $(Tf)(w, s)$  and  $(Tf)(\hat{w}, s)$ , respectively. Suppose  $f$  is increasing in  $w$  and suppose  $w \leq \hat{w}$ . Then,

$$(Tf)(\hat{w}, s) = \hat{d}_o + \beta \sum_{s' \in S} \Pi(s, s')f(\hat{w}_o(s'), s') \geq d + \beta \sum_{s' \in S} \Pi(s, s')f(w(s'), s').$$

Hence,

$$(Tf)(\hat{w}, s) \geq \max_{x \in \Gamma(w, s)} d + \beta \sum_{s' \in S} \Pi(s, s')f(w(s'), s') = (Tf)(w, s),$$

that is,  $Tf$  is increasing in  $w$ . Moreover, suppose  $w < \hat{w}$ , then

$$(Tf)(\hat{w}, s) \geq (\hat{w} - w) + d_o + \beta \sum_{s' \in S} \Pi(s, s')f(w_o(s'), s') > (Tf)(w, s),$$

implying that  $Tf$  is strictly increasing. Hence,  $T$  maps increasing functions into strictly increasing functions, which implies that  $V$  is strictly increasing.

Suppose  $f$  is concave. Then, for  $\phi \in (0, 1)$ , let  $x_{o,\phi} \equiv \phi x_o + (1 - \phi)\hat{x}_o$  and  $w_\phi \equiv \phi w + (1 - \phi)\hat{w}$ , we have

$$\begin{aligned} (Tf)(w_\phi, s) &\geq d_{o,\phi} + \beta \sum_{s' \in S} \Pi(s, s')f(w_{o,\phi}(s'), s') \\ &\geq \phi \left[ d_o + \beta \sum_{s' \in S} \Pi(s, s')f(w_o(s'), s') \right] + (1 - \phi) \left[ \hat{d}_o + \beta \sum_{s' \in S} \Pi(s, s')f(\hat{w}_o(s'), s') \right] \\ &= \phi(Tf)(w, s) + (1 - \phi)(Tf)(\hat{w}, s). \end{aligned}$$

Thus,  $Tf$  is concave, and  $T$  maps concave functions into concave functions, which implies that  $V$  is concave. Since  $V$  is increasing and concave in  $w$ , it must be continuous in  $w$ .  $\square$

**Lemma 5** Without leasing,  $V(w, s)$  is strictly concave in  $w$  for  $w \in \text{int}\{w : d(w, s) = 0\}$ .

**Proof of Lemma 5.** Without leasing,  $k'_l$  is set to zero throughout and all the prior results continue to hold. Suppose  $w, \hat{w} \in \text{int}\{w : d(w, s) = 0\}$ ,  $\hat{w} > w$ . There must exist some state  $s_*^t$ , where  $s^t = \{s_0, s_1, \dots, s_t\}$ , which has strictly positive probability and in which the capital stock choice at  $\hat{w}$  is different from the choice at  $w$ , i.e.,  $\hat{k}'(s_*^t) \neq k'(s_*^t)$ . Suppose instead that  $\hat{k}(s^t) = k(s^t)$ ,  $\forall s^t \in S^t, t = 0, 1, \dots$ . Then there must exist some state  $s_{**}^t$  with strictly positive probability in which  $\hat{d}_o(s_{**}^t) > d_o(s_{**}^t)$  and for which borrowing is not

constrained along the path of  $s_{**}^t$ . Reducing  $\hat{d}_o(s_{**}^t)$  by  $\eta$  and paying out the present value at time 0 instead changes the objective by  $(R^{-t} - \beta^t)(\hat{d}_o(s^t) - d_o(s^t)) > 0$ , contradicting the optimality of  $d(\hat{w}, s) = 0$ .

Assume, without loss of generality, that  $\hat{k}'_o(s'_*) \neq k'_o(s'_*)$ , for some  $s'_* \in S$ . Rewrite the Bellman equation as

$$V(w, s) = \max_{\substack{x \in \Gamma(w, s), \\ x(s') \in \Gamma(w(s'), s'), \forall s' \in S}} d + \beta \sum_{s' \in S} \Pi(s, s') \left\{ d(s') + \beta \sum_{s'' \in S} \Pi(s', s'') V(w(s''), s'') \right\}$$

and note the convexity of the constraint set. Using the fact that  $\hat{k}'_o(s'_*) \neq k'_o(s'_*)$ , that  $V$  is concave and strictly increasing, and that  $f(k)$  is strictly concave, we have, for  $\phi \in (0, 1)$ , and denoting  $x_{o,\phi} = \phi x_o + (1 - \phi)\hat{x}_o$  and analogously for other variables,

$$\begin{aligned} V(w_\phi, s) &> d_{o,\phi} + \beta \sum_{s' \in S} \Pi(s, s') \left\{ d_{o,\phi}(s') + \beta \sum_{s'' \in S} \Pi(s', s'') V(w_{o,\phi}(s''), s'') \right\} \\ &\geq \phi V(w, s) + (1 - \phi)V(\hat{w}, s). \end{aligned}$$

The first (strict) inequality is due to the fact that for  $s''$  following  $s'_*$  equation (3) is slack and hence a net worth  $w(s'') > w_{o,\phi}(s'')$  is feasible. The second inequality is due to concavity of  $V$ .  $\square$

**Lemma 6** *Assuming that for all  $\hat{s}, s \in S$  such that  $\hat{s} > s$ ,  $\Pi(\hat{s}, s')$  strictly first order stochastically dominates  $\Pi(s, s')$ ,  $V$  is strictly increasing in  $s$ .*

**Proof of Lemma 6.** Let  $S = \{s_1, \dots, s_n\}$ , with  $s_{i-1} < s_i$ ,  $\forall i = 2, \dots, n$  and  $N = \{1, \dots, n\}$ . Define the step function on the unit interval  $b : [0, 1] \rightarrow \mathbb{R}$  as

$$b(\omega) = \sum_{i=1}^n b(s'_i) \mathbf{1}_{B_i}(\omega), \quad \forall \omega \in [0, 1],$$

where  $\mathbf{1}$  is the indicator function,  $B_1 = [0, \Pi(s, s'_1)]$ , and

$$B_i = \left( \sum_{j=1}^{i-1} \Pi(s, s'_j), \sum_{j=1}^i \Pi(s, s'_j) \right], \quad i = 2, \dots, n.$$

For  $\hat{s}$ , define  $\hat{B}_i$ ,  $\forall i \in N$ , analogously. Let  $B_{ij} = B_i \cap \hat{B}_j$ ,  $\forall i, j \in N$ , of which at most  $2n - 1$  are non-empty. Then, we can define the step function  $\hat{b} : [0, 1] \rightarrow \mathbb{R}$  as

$$\hat{b}(\omega) = \sum_{j=1}^n \sum_{i=1}^n b(s'_i) \mathbf{1}_{B_{ij}}(\omega), \quad \forall \omega \in [0, 1].$$

We can then define the stochastic debt policy for  $\hat{B}_j, \forall j \in N$ , with positive Lebesgue measure ( $\lambda(\hat{B}_j) > 0$ ), as  $\hat{b}(s'_i|s'_j) = b(s'_i)$  with conditional probability  $\pi(s'_i|s'_j) = \lambda(B_{ij})/\lambda(\hat{B}_j)$ . Moreover, this implies a stochastic net worth

$$\begin{aligned}\hat{w}(s'_i|s'_j) &= A(s'_j)f(k') + (k' - k'_i)(1 - \delta) - R\hat{b}(s'_i|s'_j) \\ &\geq A(s'_i)f(k') + (k' - k'_i)(1 - \delta) - R\hat{b}(s'_i) = w(s'_i), \quad a.e.,\end{aligned}$$

with strict inequality when  $i < j$ , since under the assumption in the statement of the lemma,  $\lambda(B_{ij}) = 0$  whenever  $i > j$ . Moreover,  $\hat{w}(s'_i|s'_j) > w(s'_i)$  with positive probability given that assumption.

Now suppose  $\hat{s} > s$  and  $f(w, \hat{s}) \geq f(w, s), \forall w \in \mathbb{R}_+$ . Let  $x_o$  attain the  $(Tf)(w, s)$ . Then

$$\begin{aligned}(Tf)(w, \hat{s}) &\geq d_o + \beta \sum_{\hat{s}' \in S} \Pi(\hat{s}, \hat{s}') \sum_{s' \in S} \pi(s'|s') f(\hat{w}_o(s'|s'), \hat{s}') \\ &> d_o + \beta \sum_{s' \in S} \Pi(s, s') f(w_o(s'), s') = (Tf)(w, s).\end{aligned}$$

Thus,  $T$  maps increasing functions into strictly increasing functions, implying that  $V$  is strictly increasing in  $s$ .  $\square$

**Proof of Lemma 1.** We first show that if  $k' > 0$ , then  $w(s') > 0, \forall s' \in S$ . Note that (3) holds with equality. Using (4) we conclude

$$w(s') = A(s')f(k') + (k' - k'_i)(1 - \delta) - Rb(s') \geq A(s')f(k') + ((k' - k'_i) - \theta(\varphi k' - k'_i))(1 - \delta) > 0.$$

To show that  $k' > 0$ , note that (7) and (10) imply that

$$\mu(1 - R^{-1}\theta\varphi(1 - \delta)) \geq \sum_{s' \in S} \Pi(s, s')\mu(s') [A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)]. \quad (22)$$

Suppose that  $\mu = 1$ . Then  $k' > 0$  since  $\mu(s') \geq \beta V_w(w(s'), s') \geq \beta$  and hence the right hand side goes to  $+\infty$  as  $k' \rightarrow 0$ , a contradiction. Suppose instead that  $\mu > 1$  and hence  $d = 0$ . For  $k'$  sufficiently small,  $\exists \hat{s}' \in S$ , such that  $\mu(\hat{s}') = R^{-1}\mu$ . But then

$$\begin{aligned}0 &\geq \sum_{s' \in S \setminus \hat{s}} \Pi(s, s')\mu(s') [A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)] \\ &\quad + \{ \Pi(s, \hat{s}')R^{-1}[A(\hat{s}')f'(k') + (1 - \theta\varphi)(1 - \delta)] - (1 - R^{-1}\theta\varphi(1 - \delta)) \} \mu.\end{aligned}$$

where the first term is positive and the second term goes to  $+\infty$  as  $k' \rightarrow 0$ , a contradiction.  $\square$

**Proof of Proposition 2.** Part (i): By the envelope condition,  $\mu(w, s) = V_w(w, s)$ . By Lemma 4,  $V$  is concave in  $w$  and hence  $\mu(w, s)$  is decreasing in  $w$ . The first order condition (6) implies that  $\mu(w, s) \geq 1$ . If  $d(\hat{w}, s) > 0$ , then  $\mu(\hat{w}, s) = 1$  and  $\mu(w, s) = 1$  for all  $w \geq \hat{w}$ . Let  $\bar{w}(s) = \inf\{w : d(w, s) > 0\}$ .

Part (ii): Suppose  $w > \hat{w} \geq \bar{w}(s)$  and let  $\hat{x}_o$  attain  $V(\hat{w}, s)$ . Since  $V_w(w, s) = 1$  for  $w \geq \bar{w}(s)$ ,  $V(w, s) = V(\hat{w}, s) + \int_{\hat{w}}^w dv$ . The choice  $x_o = [w - \hat{w} + \hat{d}_o, \hat{k}'_o, \hat{k}'_{l,o}, \hat{w}_o(s'), \hat{b}_o(s')]$  attains  $V(w, s)$  and thus is weakly optimal.

The optimal choice  $\hat{x}_o$  is unique in terms of the capital stock  $\hat{k}'_o$ . To see this, suppose instead that  $\hat{x}_o$  and  $\tilde{x}_o$  both attain  $V(\hat{w}, s)$ , but  $\hat{k}'_o \neq \tilde{k}'_o$ . Recalling that  $\Gamma(\hat{w}, s)$  is convex and noting that

$$\begin{aligned} A(s')f(k'_{o,\phi}) + (k'_{o,\phi} - k'_{l,o,\phi})(1 - \delta) &> \phi[A(s')f(\hat{k}'_o) + (\hat{k}'_o - \hat{k}'_{l,o})(1 - \delta)] \\ &+ (1 - \phi)[A(s')f(\tilde{k}'_o) + (\tilde{k}'_o - \tilde{k}'_{l,o})(1 - \delta)], \end{aligned}$$

where  $x_{o,\phi}$  is defined as usual, we conclude that at  $x_{o,\phi}$ , (3) is slack, and hence there exists a feasible choice that attains a strictly higher value, a contradiction. Indeed,  $x_o(w, s)$  is unique in terms of  $k'_o(w, s)$ , for all  $w$  and  $s$ .

Now take  $w > \hat{w}$  and let  $x_o$  attain  $V(w, s)$ . By part (i) of Proposition 1,  $x_{o,\phi} \in \Gamma(w_\phi, s)$ . Moreover, if  $k'_o \neq \hat{k}'_o$ , then there exists a feasible choice such that  $V(w_\phi) > \phi V(w, s) + (1 - \phi)V(\hat{w}, s)$  contradicting the linearity of  $V$ . Thus,  $k'_o(w, s) = \hat{k}'_o(s)$ ,  $\forall w \geq \bar{w}(s)$ .

Part (iii): We now show that without leasing the optimal policy is unique also in terms of state-contingent net worth, state-contingent borrowing, and the dividend. Define  $\hat{S}^0 = \{s' : \hat{w}_o(s') < \bar{w}(s')\}$  and  $\hat{S}^+ = S \setminus \hat{S}^0$ . Then  $\forall s' \in \hat{S}^0$ ,  $\hat{w}_o(s')$  is unique. To see this suppose instead that there is a  $\tilde{x}_o$  with  $\tilde{w}_o(s') \neq \hat{w}_o(s')$  for some  $s' \in \hat{S}$  that also attains  $V(\hat{w}, s)$ . Then a convex combination  $x_{o,\phi}$  is feasible and attains a strictly higher value due to strict concavity of  $V(w, s')$  for  $w < \bar{w}(s')$  (part (iv) of Proposition 1). For the alternative optimal policy  $\tilde{x}_o$  define  $\tilde{S}^0$  and  $\tilde{S}^+$  analogously to  $\hat{S}^0$  and  $\hat{S}^+$ . By above,  $\tilde{S}^0 \supseteq \hat{S}^0$ . For any  $s' \in \tilde{S}^+$ ,  $\tilde{w}_o(s') \geq \bar{w}(s')$ . For suppose instead that  $\tilde{w}_o(s') < \bar{w}(s')$ , then by strict concavity of  $V$  for  $w < \bar{w}(s')$  a convex combination would again constitute a feasible improvement. Thus,  $\tilde{S}^+ \supseteq \hat{S}^+$  and as a consequence  $S^+ \equiv \tilde{S}^+ = \hat{S}^+$  and  $S^0 \equiv \tilde{S}^0 = \hat{S}^0$ . For  $s' \in S^0$ ,  $b_o(s')$  is uniquely determined by (3). For  $s' \in S^+$ , equation (4) holds with equality and determines  $b_o(s')$  uniquely, and  $w_o(s')$  is then uniquely determined by (3). Hence, the optimal policy is unique. Moreover, the policy determined by part (ii) (with  $k'_{l,o}(w, s)$  set to 0) is the unique optimal policy for  $w > \bar{w}(s)$ .  $\square$

**Proof of Proposition 4.** Using the first order conditions for investment (7) and substituting for  $\lambda(s')$  using (10) we have

$$\begin{aligned} 1 &\geq \sum_{s' \in S} \Pi(s, s') \frac{\mu(s')}{\mu} \frac{[A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)]}{1 - R^{-1}\theta\varphi(1 - \delta)} \\ &\geq \Pi(s, s') \frac{\mu(s')}{\mu} \frac{A(s')f'(k')}{1 - R^{-1}\theta\varphi(1 - \delta)}. \end{aligned} \tag{23}$$

Using the budget constraint (2) and the collateral constraints (4), we have

$$w \geq (1 - \varphi)k' + (\varphi k' - k'_l)(1 - R^{-1}\theta(1 - \delta)) + u_l k'_l,$$

and thus as  $w \rightarrow 0$ , investment  $k' \rightarrow 0$ . But then the marginal product of capital  $f'(k') \rightarrow +\infty$ , which implies by (23) that  $\mu(s')/\mu \rightarrow 0$ , and using (10)

$$\frac{\lambda(s')}{\mu} = R^{-1} - \frac{\mu(s')}{\mu} \rightarrow R^{-1} > 0, \quad \forall s' \in S.$$

Therefore, given Assumption 3, the user cost of owned physical capital must exceed to user cost of leased capital in the limit

$$\begin{aligned} u_p &\equiv R^{-1}(r + \delta) + \sum_{s' \in S} \Pi(s, s') \frac{\lambda(s')}{\mu} (1 - \theta)(1 - \delta) \rightarrow R^{-1}(r + \delta) + R^{-1}(1 - \theta)(1 - \delta) \\ &> R^{-1}(r + \delta) + m = u_l. \end{aligned}$$

By continuity,  $\exists \underline{w}_l$ , such that  $\forall w \leq \underline{w}_l$ ,  $u_p > u_l$ .  $\square$

**Proof of Proposition 5.** Denote with a prime variables which in the stochastic case were a function of the state tomorrow, that is,  $w'$ ,  $b'$ ,  $\mu'$ , and  $\lambda'$ . We first characterize a steady state. From (9) and the envelope condition we have  $\mu' = \beta\mu$ . Then (10) implies  $\lambda' = (R^{-1} - \beta)\mu > 0$ , that is, the firm is constrained in the steady state, and (7) can be written as

$$1 - [R^{-1}\theta\varphi + \beta(1 - \theta\varphi)](1 - \delta) = \beta A' f'(k')$$

which implicitly defines  $\bar{k}'$ , the steady state value of capital. Denoting steady state variables with a bar, using (4) and (3) at equality, we have  $\bar{b} = R^{-1}\theta\varphi\bar{k}'(1 - \delta)$  and the cum-dividend net worth in the steady state  $\bar{w}_{cum} = A' f(\bar{k}') + \bar{k}'(1 - \theta\varphi)(1 - \delta)$ . Dividends in the steady state are

$$\begin{aligned} \bar{d} &= A' f(\bar{k}') - \bar{k}'(1 - [R^{-1}\theta\varphi + (1 - \theta\varphi)](1 - \delta)) \\ &> A' f(\bar{k}') - \beta^{-1}\bar{k}'(1 - [R^{-1}\theta\varphi + \beta(1 - \theta\varphi)](1 - \delta)) \\ &= \int_0^{\bar{k}'} \{A' f'(k') - \beta^{-1}(1 - [R^{-1}\theta\varphi + \beta(1 - \theta\varphi)](1 - \delta))\} dk' > 0 \end{aligned}$$

and hence  $\bar{\mu} = 1$ . The lowest level of net worth for which  $\bar{k}'$  is feasible is  $\bar{w} \equiv \bar{w}_{cum} - \bar{d}$ , and  $\bar{w}$  is the ex-dividend net worth in the steady state. Thus, for  $w < \bar{w}$ ,  $k' < \bar{k}'$ . Using the first order conditions and the envelope condition we have

$$\frac{V_w(w)}{V_w(w')} = \beta \frac{\mu}{\mu'} = \beta \frac{A' f'(k') + (1 - \theta\varphi)(1 - \delta)}{1 - R^{-1}\theta\varphi(1 - \delta)}.$$

Note that the right hand side equals 1 at  $\bar{k}'$  and is decreasing in  $k'$ . Thus, if  $k' < (>) \bar{k}'$ ,  $V_w(w) > (<) V_w(w')$  and  $w < (>) w'$ . Since  $k' < \bar{k}'$  for  $w < \bar{w}$ ,  $w < w'$  and  $w$  increases over time. If  $w > \bar{w}$ , then either  $d > 0$  (and  $V_w(w) = 1$ ) or  $d = 0$  and  $k' > \bar{k}'$ . In the first case, concavity and the fact that  $V_w(w') \geq 1$  imply  $V_w(w') = 1$  and hence  $k' = \bar{k}'$ . In the second case,  $w > w'$ , but simply saving  $w$  at  $R$  would result in higher net worth and hence  $k' > \bar{k}'$  cannot be optimal.  $\square$

**Proof of Proposition 6.** Consider the optimal policy without leasing from Proposition 5. The user cost of physical capital at  $\bar{w}$  is  $\bar{u}_p = R^{-1}(r+\delta) + (R^{-1} - \beta)(1-\theta)(1-\delta) < u_l$  under Assumption 3. Thus, there is no leasing at  $\bar{w}$  and the solution is as before as long as  $w$  is sufficiently high. Recall that as  $w$  decreases  $\mu'/\mu$  decreases and hence  $\lambda'/\mu$  increases. Note also that under Assumption 2, as  $w$  goes to zero,  $k'$  and  $\mu'/\mu$  go to zero and hence  $\lambda'/\mu$  goes to  $R^{-1}$  and  $u_p$  goes to  $R^{-1}(r+\delta) + R^{-1}(1-\theta)(1-\delta) > u_l$  given Assumption 3. When  $\lambda'/\mu = m/((1-\theta)(1-\delta))$ ,  $u_l = u_p$  and (7) simplifies to

$$1 - R^{-1}\theta\varphi(1-\delta) = \left( R^{-1} - \frac{m}{(1-\theta)(1-\delta)} \right) [Af'(k') + (1-\theta\varphi)(1-\delta)],$$

which defines  $\underline{k}'$ . At  $\bar{w}_l \equiv (1 - R^{-1}\theta\varphi(1-\delta))\underline{k}'$  all the physical capital is owned and at  $\underline{w}_l \equiv (1 - \varphi + u_l\varphi)\underline{k}'$  all the physical capital is leased. For  $w \in [\underline{w}_l, \bar{w}_l]$ , leased capital is

$$k'_l = \frac{(1 - R^{-1}\theta\varphi(1-\delta))\underline{k}' - w}{1 - R^{-1}\theta(1-\delta) - u_l}$$

which is linear and decreasing in  $w$ . Moreover,  $w'$  is linearly decreasing in  $k'_l$  and hence linearly increasing in  $w$ . For  $w < \underline{w}_l$ ,  $k' = w/(1-\varphi+u_l\varphi)$  and  $w' = A'f(k') + k'(1-\varphi)(1-\delta)$ .  $\square$

**Proof of Proposition 7.** Proceeding as in the proof of Proposition 4, using the first order conditions for investment (7) and substituting for  $\lambda(s')$  using (10) we have

$$\begin{aligned} 1 &\geq \sum_{s' \in S} \Pi(s, s') \frac{\mu(s')}{\mu} \frac{[A(s')f'(k') + (1-\theta\varphi)(1-\delta)]}{1 - R^{-1}\theta\varphi(1-\delta)} \\ &\geq \Pi(s, s') \frac{\mu(s')}{\mu} \frac{A(s')f'(k')}{1 - R^{-1}\theta\varphi(1-\delta)}. \end{aligned} \quad (24)$$

Using the budget constraint (2) and the collateral constraints (4), we have

$$w \geq (1-\varphi)k' + (\varphi k' - k'_l)(1 - R^{-1}\theta(1-\delta)) + u_l k'_l,$$

and thus as  $w \rightarrow 0$ , investment  $k' \rightarrow 0$ . But then the marginal product of capital  $f'(k') \rightarrow +\infty$ , which implies by (24) that  $\mu(s')/\mu \rightarrow 0$ , and using (10)

$$\frac{\lambda(s')}{\mu} = R^{-1} - \frac{\mu(s')}{\mu} \rightarrow R^{-1} > 0, \quad \forall s' \in S.$$

Therefore, by continuity,  $\exists \underline{w}_h$ , such that  $\forall w \leq \underline{w}_h$  and any state  $s$ ,  $\lambda(s') > 0$ ,  $\forall s' \in S$ .  $\square$

**Proof of Proposition 8.** If  $w(s') \leq w(s'_+)$ , then  $\mu(s') \geq \mu(s'_+)$  by concavity. Moreover,  $\mu(s') + \lambda(s') = \mu(s'_+) + \lambda(s'_+)$ , so  $\lambda(s') \leq \lambda(s'_+)$ . Suppose instead that  $w(s') > w(s'_+)$ . Then  $\lambda(s') = 0$  since otherwise net worth in state  $s'$  could not be larger than in state  $s'_+$ . But then  $\mu(s') = \mu(s'_+) + \lambda(s'_+)$ , implying  $\mu(s'_+) \leq \mu(s')$ . If  $\mu(s'_+) = \mu(s')$ , then  $\lambda(s'_+) = \lambda(s')$  and the assertion is true. If instead  $\mu(s'_+) < \mu(s')$ , then by concavity  $w(s'_+) \geq w(s')$ , a

contradiction.  $\square$

**Proof of Proposition 9.** Suppose that  $\lambda(s') = 0, \forall s' \in S$ . Then (9), (10), and the envelope condition imply that  $V_w(w) = \mu = \mu(s')R = V_w(w(s'))\beta R < V_w(w(s'))$  and, by concavity,  $w > w(s'), \forall s' \in S$ .

If  $d = 0$ , then saving the entire net worth  $w$  at  $R$  would imply net worth  $Rw > w(s')$  in all states next period and hence attain a higher value of the objective, contradicting optimality.

Suppose  $d > 0$  and hence  $w > \bar{w}$  as defined in Proposition 2. That proposition also implies that  $V(w)$  can be attained by the same optimal policy as at  $\bar{w}$  except that  $d = w - \bar{w}$ . Since  $V_w(w(s')) > 1$ , we conclude that  $w(s') < \bar{w}$ . But then paying out  $d = w - \bar{w}$  as before and saving  $\bar{w}$  at  $R$  raises net worth in all states next period and hence improves the value of the objective, a contradiction.

Hence,  $\exists s' \in S$  such that  $\lambda(s') > 0$ , and, since  $\lambda(s')$  is increasing in  $s'$  by Proposition 8,  $\lambda(\bar{s}') > 0$  where  $\bar{s}' = \max\{s' : s' \in S\}$ . If  $\lambda(s') > 0, \forall s'$ , then  $w(s') = A(s')f(k') + k'(1 - \theta\varphi)(1 - \delta) - k'_l(1 - \theta)(1 - \delta)$  and hence  $w(s') \neq w(\hat{s}'), s \neq \hat{s}'$ . If  $\lambda(\hat{s}') = 0$  for some  $\hat{s}'$ , then  $\mu(\hat{s}') = \mu(\bar{s}') + \lambda(\bar{s}') > \mu(\bar{s}')$  and  $w(\hat{s}') < w(\bar{s}')$ .

Suppose  $\lambda(s') = 0$  for some  $s' \in S$ . For any  $s'_- < s'$ ,  $\mu(s'_-) \geq \mu(s')$  by Proposition 8, and  $\mu(s'_-) \leq \mu(s'_-) + \lambda(s'_-) = \mu(s')$ , implying  $\mu(s'_-) = \mu(s')$ . Thus, the firm hedges all states below  $s'_h = \max\{s' : \lambda(s') = 0\}$ . Note that the set may be empty, that is, the firm may not hedge at all.  $\square$

**Proof of Proposition 10.** Part (i): By part (iv) of Proposition 1  $V(w)$  is strictly concave unless  $w > \bar{w}$ . By Proposition 9, the firm hedges a lower set of states  $[s'_-, \dots, s'_h]$  if at all. If  $s'_+ \leq s'_h$ , then  $\mu(s') = \mu(s'_+) > 1$  and hence  $w(s') = w(s'_+) < \bar{w}$ . If  $s'_+ > s'_h$ , then either  $\lambda(s') = 0$  and  $\mu(s') > \mu(s'_+)$ , implying  $w(s'_+) > w(s')$ , or  $\lambda(s') > 0$ , which together with (3) and (4) at equality implies  $w(s'_+) > w(s')$ .

Part (ii): If  $d > 0$ , then  $w(s')$  is constant by Proposition 2 and hence (weakly) increasing. If  $d = 0$ , then  $w(s')$  is strictly increasing in  $w$  for  $\{s' | \lambda(s') = 0\}$  using strict concavity of  $V$  and the fact that  $V_w(w) = R\beta V_w(w(s'))$ . For  $\{s' | \lambda(s') > 0\}$ , (3) and (4) hold with equality and hence  $w(s')$  is increasing in  $w$  if  $k'$  is. We now show that  $k'$  is strictly increasing in  $w$  for  $w \leq \bar{w}$ . If  $\lambda(s') > 0, \forall s \in S$ , then  $k' = w/(1 - R^{-1}\theta\varphi(1 - \delta))$  and  $k'$  is hence strictly increasing. Suppose  $\lambda(s') = 0$ , some  $s \in S$ . Then using the first order conditions for investment (7) and substituting for  $\lambda(s')$  using (10) we have

$$\begin{aligned}
1 &= \sum_{s' \in S} \Pi(s') \frac{\mu(s')}{\mu} \frac{[A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)]}{1 - R^{-1}\theta\varphi(1 - \delta)} \\
&= \sum_{\{s' | \lambda(s') > 0\}} \Pi(s') \frac{\mu(s')}{\mu} \frac{[A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)]}{1 - R^{-1}\theta\varphi(1 - \delta)} \\
&\quad + \sum_{\{s' | \lambda(s') = 0\}} \Pi(s') \frac{\mu(s')}{\mu} \frac{[A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)]}{1 - R^{-1}\theta\varphi(1 - \delta)}. \tag{25}
\end{aligned}$$

Take  $w^+ > w$  and suppose that  $k'^+ \leq k'$  with the usual abuse of notation. Then  $f'(k'^+) \geq f'(k')$ . Moreover, for  $\{s' | \lambda(s') = 0\}$ ,  $\mu(s')/\mu = R^{-1}$ . Since  $\mu^+ < \mu$ , (25) implies that  $\exists s'$  such that  $\mu^+(s') < \mu(s')$ . But  $k'^+ \leq k'$  implies that for  $\{s' | \lambda(s') > 0\}$ ,  $w^+(s') \leq w(s')$  and hence  $\mu^+(s') \geq \mu(s')$ , a contradiction. Hence,  $k'$  and  $w(s')$  are strictly increasing in  $w$  for  $w \leq \bar{w}$ .

To show that  $\exists w$  such that  $w(s') > w$ ,  $\forall s' \in S$ , note that Proposition 7 implies that for  $w$  sufficiently small,  $\lambda(s') > 0$ ,  $\forall s' \in S$ , and thus  $w = k'/(1 - R^{-1}\theta\varphi(1 - \delta))$  and  $w(s') = A(s')f(k') + k'(1 - \theta\varphi)(1 - \delta)$ . But then

$$\frac{dw(s')}{dw} = \frac{A(s')f'(k') + (1 - \theta\varphi)(1 - \delta)}{1 - R^{-1}\theta\varphi(1 - \delta)} = \frac{A(s')f'(k')k' + k'(1 - \theta\varphi)(1 - \delta)}{k'(1 - R^{-1}\theta\varphi(1 - \delta))} < \frac{w(s')}{w},$$

where the inequality uses the strict concavity of  $f(\cdot)$ . Moreover, as  $w \rightarrow 0$ ,  $f'(k') \rightarrow +\infty$  and thus  $dw(s')/dw \rightarrow +\infty$  and  $w(s')/w > 1$  for  $w$  sufficiently low.

To show that  $\exists w$  such that  $w(s') < w$ ,  $\forall s' \in S$ , it is sufficient to show that such a  $w$  exists for  $w(\bar{s}')$  given part (i). By Proposition 2,  $\forall w \geq \bar{w}$ , the optimal policy  $x_o$  is independent of  $w$  (except for the current dividend), and thus  $w_o(\bar{s}') = A(\bar{s}')f(\bar{k}'_o) + \bar{k}'_o(1 - \delta) - R\bar{b}_o(\bar{s}') < +\infty$ , and hence for  $w > w_o(\bar{s}')$  the assertion holds.

Part (iii): By the theorem of the maximum  $w(s')$  is continuous in  $w$ , and the intermediate value theorem and part (ii) hence imply the result.

Part (iv): Denoting the wealth level as defined in part (iii) for the lowest state  $\underline{s}'$  by  $\underline{w}$  and using  $w(\underline{s}') = \underline{w}$ , (9), (10), and the envelope condition, we have

$$V_w(\underline{w}) = R\beta V_w(\underline{w}) + R\lambda(\underline{s}')$$

and thus  $\lambda(\underline{s}') > 0$ , and by Proposition 9 the firm abstains from risk management altogether at  $\underline{w}$ . The level of net worth  $\underline{w}$  is unique, since either  $d > 0$  at  $\underline{w}$ , and hence  $w(\underline{s}')$  is constant, or  $d = 0$  and then using  $\lambda(s') > 0$ ,  $\forall s \in S$ , and evaluating  $dw(\underline{s}')/dw$  as in part (ii) at  $\underline{w}$

$$\left. \frac{dw(\underline{s}')}{dw} \right|_{w=\underline{w}} = \left. \frac{A(\underline{s}')f'(k')k' + k'(1 - \theta\varphi)(1 - \delta)}{k'(1 - R^{-1}\theta\varphi(1 - \delta))} \right|_{w=\underline{w}} < \frac{w(\underline{s}')}{\underline{w}} = 1.$$

Thus the locus of  $w(\underline{s}')$  crosses the 45 degree line from above, that is, at most once. Moreover,  $w(\underline{s}')/w < 1$ ,  $\forall w > \underline{w}$ .  $\square$

**Proof of Proposition 11.** We adapt Theorem 12.12 from Stokey, Lucas, and Prescott (1989). Let  $\varepsilon_w > 0$  and  $w_{\text{bnd}} = A(\bar{s}')f(k_{\text{bnd}}) + k_{\text{bnd}}(1 - \delta)$  where  $k_{\text{bnd}}$  such that  $A(\bar{s}')f'(k_{\text{bnd}}) = r + \delta$ . Define the induced state space  $W = [\varepsilon_w, w_{\text{bnd}}] \subset \mathbb{R}$  with its Borel subsets  $\mathcal{W}$ . Take  $P$  to be the induced transition function on  $(W, \mathcal{W})$ , with the associated operator on bounded continuous functions  $T : B(W, \mathcal{W}) \rightarrow B(W, \mathcal{W})$  and the associated operator on probability measures  $T^* : \mathcal{P}(W, \mathcal{W}) \rightarrow \mathcal{P}(W, \mathcal{W})$ .

We need to show that  $P$  is monotone (that is, for any bounded, increasing function  $f$ , the function  $Tf$  defined by  $(Tf)(w) = \int f(w')P(w, dw')$ ,  $\forall w$ , is also increasing), has the Feller property (that is, for any bounded, continuous function  $f$ , the function  $Tf$  is

also continuous), and  $\exists w^o \in W$ ,  $\varepsilon > 0$ , and  $N \geq 1$ , such that  $P^N(\varepsilon_w, [w^o, w_{\text{bnd}}]) \geq \varepsilon$  and  $P^N(w_{\text{bnd}}, [\varepsilon_w, w^o]) \geq \varepsilon$ .

Take any bounded, increasing function  $f$ . Then  $(Tf)(w) = \sum_{s' \in S} \Pi(s')f(w(s')(w))$  is increasing since  $w(s')(w)$  is increasing by part (ii) of Proposition 10. For any bounded, continuous function  $f$ ,  $(Tf)(w)$  is moreover continuous as  $w(s')(w)$  is continuous by the theorem of the maximum.

From Proposition 10 we know that levels of net worth below  $\underline{w}$  and above  $w_o(\bar{s}')$  are transient. We now provide an explicit characterization of the stationary solution when  $\bar{w} \leq \underline{w}$  and then show that otherwise  $w^o$  can be set to  $w^o = \bar{w}$ , where  $\bar{w}$  is the level of net worth above which the firm pays dividends (see Proposition 2).

If  $\bar{w} \leq \underline{w}$ , then the stationary distribution is a subset of the dividend paying set and the solution is quasi-deterministic, in the sense that capital  $\bar{k}'_o$  is constant under the stationary distribution. In this case,  $\bar{k}'_o$  solves

$$1 = \beta \frac{\sum_{s' \in S} \Pi(s')A(s')f'(\bar{k}'_o) + (1 - \theta\varphi)(1 - \delta)}{1 - R^{-1}\theta\varphi(1 - \delta)}.$$

Then  $\bar{w} = \bar{k}'_o(1 - R^{-1}\theta\varphi(1 - \delta))$  and

$$\begin{aligned} \underline{w} &= w(\underline{s}') = A(\underline{s}')f(\bar{k}'_o) + \bar{k}'_o(1 - \theta\varphi)(1 - \delta) \\ &\geq \bar{w} = \bar{k}'_o(1 - R^{-1}\theta\varphi(1 - \delta)) = \beta \left( \sum_{s' \in S} \Pi(s')A(s')f'(\bar{k}'_o)\bar{k}'_o + \bar{k}'_o(1 - \theta\varphi)(1 - \delta) \right). \end{aligned}$$

The condition for  $\bar{w} \leq \underline{w}$  is thus

$$(1 - \beta)(1 - \theta\varphi)(1 - \delta) \geq \beta \sum_{s' \in S} \Pi(s')A(s')f'(\bar{k}'_o) - A(\underline{s}')\frac{f(\bar{k}'_o)}{\bar{k}'_o}. \quad (26)$$

Concavity implies that  $f(\bar{k}'_o)/\bar{k}'_o > f'(\bar{k}'_o)$  and thus a sufficient condition is that  $A(\underline{s}') \geq \beta \sum_{s' \in S} \Pi(s')A(s')$ . If  $f(k) = k^\alpha$ , a sufficient condition is  $A(\underline{s}') \geq \alpha\beta \sum_{s' \in S} \Pi(s')A(s')$ . Note that in the quasi-deterministic case the firm abstains from risk management with probability 1 under the stationary distribution.

If (26) is violated, then  $\underline{w} < \bar{w}$ . Moreover, the firm cannot be paying dividends in the lowest state next period if it currently is paying dividends, for if it paid dividends, it would choose  $\bar{k}'_o$  as determined above and

$$\begin{aligned} w(\underline{s}') &= A(\underline{s}')f(\bar{k}'_o) + \bar{k}'_o(1 - \theta\varphi)(1 - \delta) \\ &< \beta \left( \sum_{s' \in S} \Pi(s')A(s')f'(\bar{k}'_o)\bar{k}'_o + \bar{k}'_o(1 - \theta\varphi)(1 - \delta) \right) = \bar{k}'_o(1 - R^{-1}\theta\varphi(1 - \delta)) = \bar{w}, \end{aligned}$$

a contradiction. Thus, if  $w^o = \bar{w}$ , then  $P(w_{\text{bnd}}, [\varepsilon_w, \bar{w}]) \geq \Pi(\underline{s}')$  and  $N_1 = 1$  and  $\exists \varepsilon_1 > 0$  such that  $\Pi(\underline{s}') > \varepsilon_1 > 0$ .

Now given  $w = \varepsilon_w$ , and since the net worth could be paid out, the objective has to exceed the value of net worth,

$$0 < \varepsilon_w = w \leq E \left[ \sum_{t=0}^{\infty} \beta^t d_t \right] = E \left[ \sum_{t=0}^N \beta^t d_t \right] + E \left[ \sum_{t=N+1}^{\infty} \beta^t d_t \right].$$

Note that  $d_t \leq d_o(\bar{s}') = w_o(\bar{s}') - \bar{w}$  and the last expectation above is thus bounded by  $\beta^{N+1} d_o(\bar{s}') / (1 - \beta)$ . For any  $\varepsilon_d > 0$  such that  $\varepsilon_w > \varepsilon_d$ ,  $\exists N_2 < \infty$  such that the last expectation is less than  $\varepsilon_d$ . But then  $P^{N_2}(\varepsilon_w, [\bar{w}, w_{\text{bnd}}]) \geq (\varepsilon_w - \varepsilon_d) / d_o(\bar{s}') > 0$ . Let  $\varepsilon_2 \equiv (\varepsilon_w - \varepsilon_d) / d_o(\bar{s}')$ ,  $\varepsilon = \min\{\varepsilon_1, \varepsilon_2\}$ , and  $N = \max\{N_1, N_2\}$ . Finally, when  $\underline{w} < \bar{w}$ ,  $dw(\underline{s}') / dw < 1$  at  $\underline{w}$  and  $w(\underline{s}') < w$  for all  $w \geq \underline{w}$ , and thus a sufficiently long sequence of the lowest productivity realization results in a net worth in a neighborhood of  $\underline{w}$  and hence the firm abstains from risk management with positive probability.  $\square$

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**Table 1: Tangible assets and liabilities**

This table reports balance sheet data on tangible assets and liabilities from the Flow of Funds Accounts of the United States for the 10 years from 1999 to 2008 [Federal Reserve Statistical Release Z.1], Tables B.100, B.102, B.103, and L.229. Panel A measures liabilities two ways. Debt is *Credit Market Instruments* which for (nonfinancial) businesses are primarily corporate bonds, other loans, and mortgages and for households are primarily home mortgages and consumer credit. Total liabilities are *Liabilities*, which, in addition to debt as defined before, include for (nonfinancial) businesses primarily miscellaneous liabilities and trade payables and for households primarily the trade payables (of nonprofit organizations) and security credit. For (nonfinancial) businesses, we subtract *Foreign Direct Investment in the U.S.* from Table L.229 from reported miscellaneous liabilities as Table F.229 suggests that these claims are largely equity. For households, real estate is mortgage debt divided by the value of real estate, and consumer durables is consumer credit divided by the value of consumer durables. Panel B reports the total tangible assets of households and noncorporate and corporate businesses relative to the total net worth of households. The main types of tangible assets, real estate, consumer durables, equipment and software, and inventories are also separately aggregated across the three sectors.

**Panel A: Liabilities (% of tangible assets)**

Sector	Debt (% of tangible assets)	Total liabilities (% of tangible assets)
(Nonfinancial) corporate businesses	48.5%	83.0%
(Nonfinancial) noncorporate businesses	37.8%	54.9%
Households and nonprofit organizations		
Total tangible assets	45.2%	47.1%
Real estate	41.2%	
Consumer durables	56.1%	

**Panel B: Tangible assets (% of household net worth)**

Assets by type	Tangible assets (% of household net worth)
Total tangible assets	79.2%
Real estate	60.2%
Equipment and software	8.3%
Consumer durables	7.6%
Inventories	3.1%

**Table 2: Tangible assets and debt, rental, and true leverage**

Panel A displays the relation between tangibility and (debt) leverage and Panel B displays the relation between tangibility and leverage adjusted for rented assets.

**Panel A: Tangible assets and debt leverage**

Tangibility: Property, Plant, and Equipment – Total (Net) (Item #8) divided by Assets; Assets: Assets – Total (Item #6) plus Price – Close (Item #24) times Common Shares Outstanding (Item #25) minus Common Equity – Total (Item #60) minus Deferred taxes (Item #74); Leverage: Long-Term Debt – Total (Item #9) divided by Assets. Annual firm level Compustat data for 2007 are used excluding financial firms.

Tangibility quartile	Quartile cutoff (%)	Leverage (%)		Low leverage firms (%) (leverage $\leq$ 10%)
		median	mean	
1	6.3	7.4	10.8	58.3
2	14.3	9.8	14.0	50.4
3	32.2	12.4	15.5	40.6
4	n.a.	22.6	24.2	14.9

**Panel B: Tangible assets and debt, rental, and true leverage**

True Tangibility: Property, Plant, and Equipment – Total (Net) (Item #8) plus 10 times Rental Expense (#47) divided by True Assets; True Assets: Assets – Total (Item #6) plus Price – Close (Item #24) times Common Shares Outstanding (Item #25) minus Common Equity – Total (Item #60) minus Deferred taxes (Item #74) plus 10 times Rental Expense (#47); Debt Leverage: Long-Term Debt – Total (Item #9) divided by True Assets; Rental Leverage: 10 times Rental Expense (#47) divided by True Assets; True Leverage: Debt Leverage plus Rental Leverage. Annual firm level Compustat data for 2007 are used excluding financial firms.

True tangibility quartile	Quartile cutoff (%)	Leverage (%)						Low leverage firms (%) (leverage $\leq$ 10%)		
		Debt leverage		Rental leverage		True leverage		Debt leverage	Rental leverage	True leverage
		median	mean	median	mean	median	mean			
1	13.2	6.5	10.4	3.7	4.2	11.4	14.6	61.7	97.7	46.0
2	24.1	9.8	12.9	6.9	8.1	18.4	21.0	50.1	68.2	16.1
3	40.1	13.1	14.8	8.0	10.5	24.2	25.3	41.7	60.6	12.0
4	n.a.	18.4	20.4	7.2	13.8	32.3	34.2	24.4	57.3	3.7

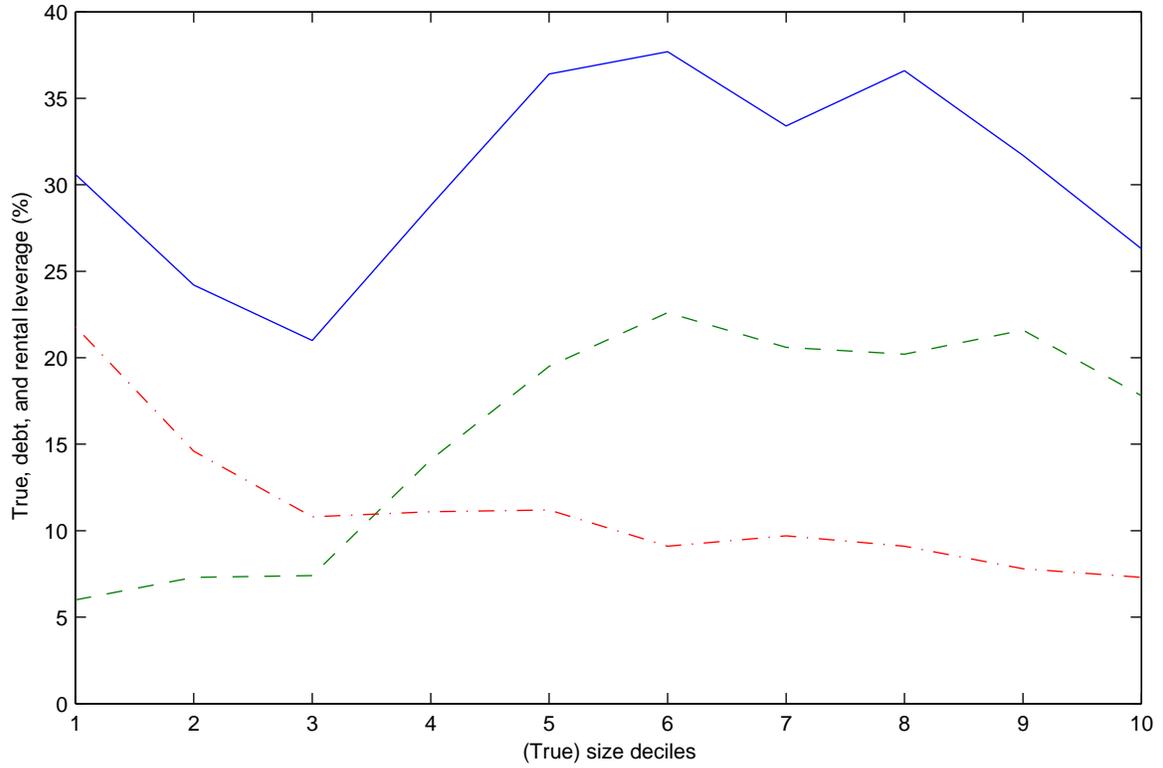
**Table 3: Leverage and size revisited**

This table displays debt and rental leverage across size deciles (measured by true book assets). True Book Assets: Assets – Total (Item #6) plus 10 times Rental Expense (#47); Debt Leverage: Long-Term Debt – Total (Item #9) divided by True Book Assets; Rental Leverage: 10 times Rental Expense (#47) divided by True Book Assets; True Leverage: Debt Leverage plus Rental Leverage. Annual firm level Compustat data for 2007 are used excluding financial firms.

Decile	Size deciles									
	1	2	3	4	5	6	7	8	9	10
Median debt leverage	6.0	7.3	7.4	14.1	19.5	22.6	20.6	20.2	21.6	17.8
Median rental leverage	21.8	14.6	10.8	11.1	11.2	9.1	9.7	9.1	7.8	7.3
Median true leverage	30.6	24.2	21.0	28.8	36.4	37.7	33.4	36.6	31.7	26.3

**Figure 1: Leverage versus size revisited**

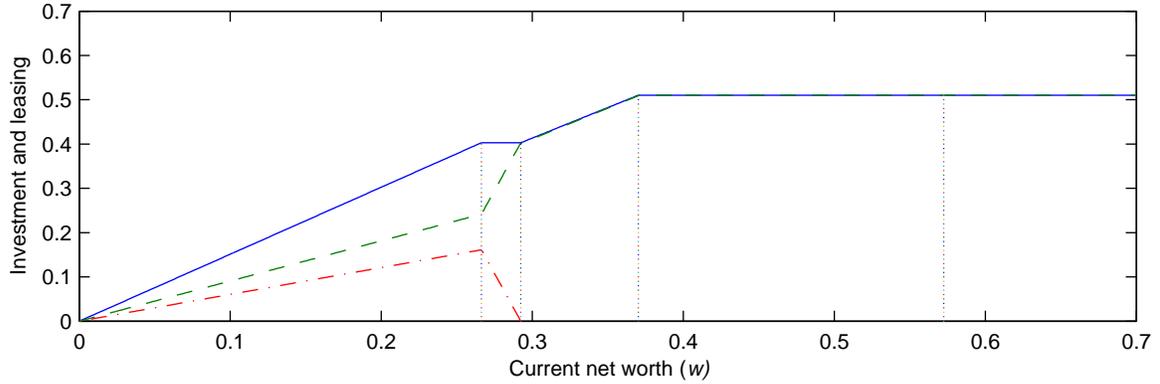
Total (true) leverage (solid), debt leverage (dashed), and rental leverage (dash dotted) across size deciles for Compustat firms. For details see caption of Table 3.



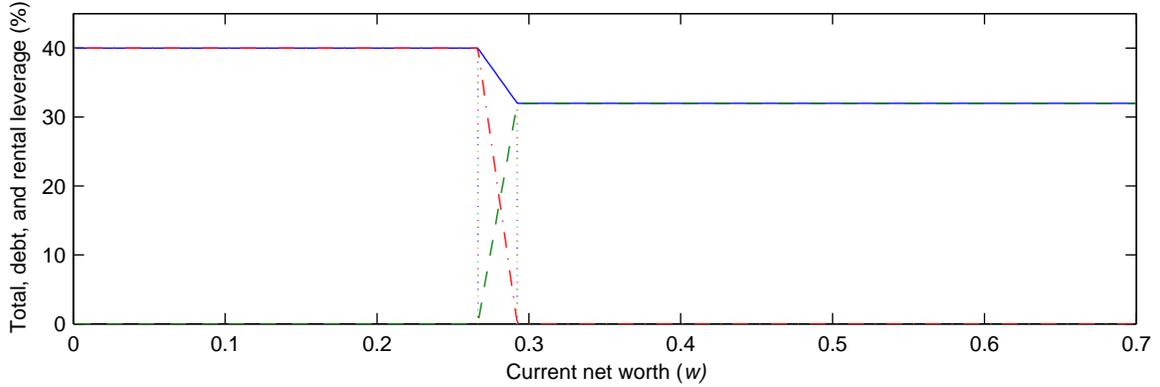
**Figure 2: Investment and leasing policy**

Panel A: Total capital  $k'$  (solid), leased capital  $k'_l$  (dash dotted), and purchased capital  $k' - k'_l$  (dashed) as a function of current net worth ( $w$ ) in the deterministic case. The kinks and vertical lines are (from left to right) at  $\underline{w}_l$ ,  $\bar{w}_l$ ,  $\bar{w}$ , and  $\bar{w}_{cum}$ , respectively. Panel B: Total leverage  $(Rb' + k'_l(1 - \delta))/(k'(1 - \delta))$  (solid), debt leverage  $Rb'/(k'(1 - \delta))$  (dashed), and rental leverage  $k'_l(1 - \delta)/(k'(1 - \delta))$  (dash dotted) as a function of current net worth ( $w$ ) in the deterministic case. The parameter values are:  $\beta = 0.93$ ,  $r = 0.05$ ,  $\delta = 0.10$ ,  $m = 0.01$ ,  $\theta = 0.80$ ,  $\varphi = 0.40$ ,  $A' = 0.325$ , and  $\alpha = 0.333$ .

**Panel A: Investment ( $k'$ ) and leasing policy ( $k'_l$ )**



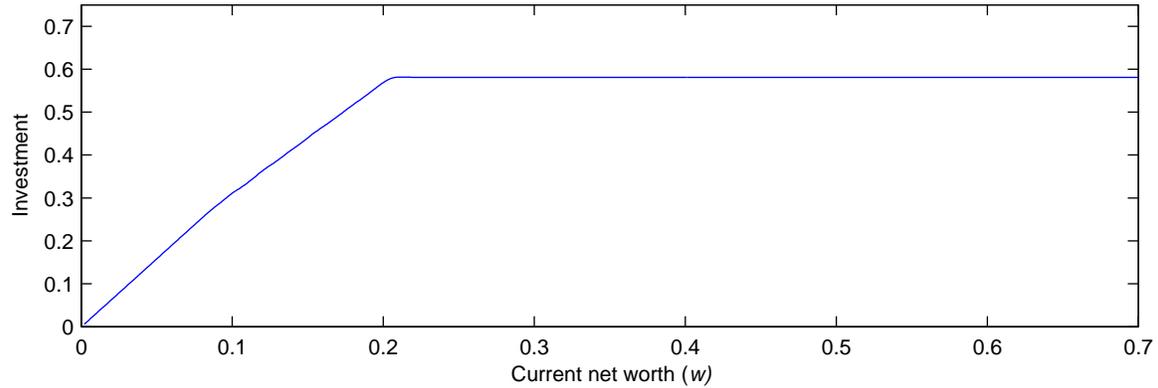
**Panel B: Total leverage, debt leverage, and rental leverage**



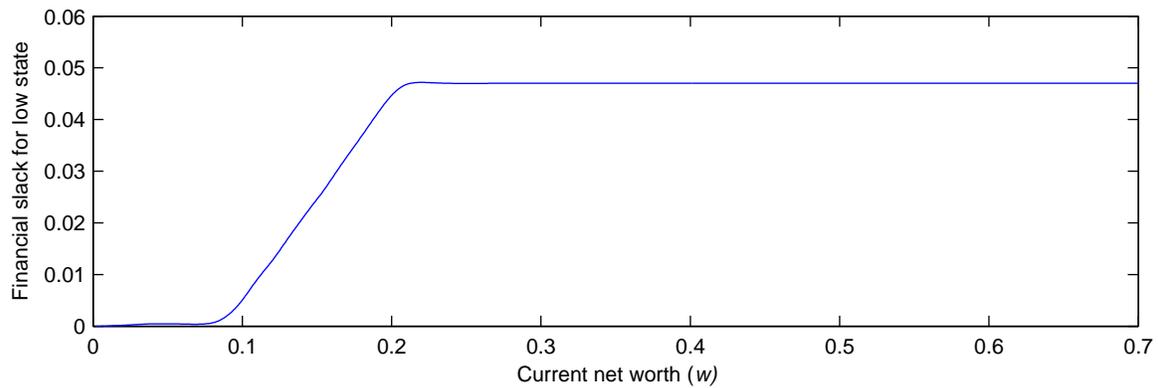
### Figure 3: Investment and risk management policy

Panel A: Investment  $k'$  as a function of current net worth  $w$ . Panel B: Financial slack in the low state  $h(s'_1) = \theta\varphi k'(1 - \delta) - Rb(s'_1)$  as a function of current net worth  $w$ . The parameter values are:  $\beta = 0.93$ ,  $r = 0.05$ ,  $\delta = 0.10$ ,  $\theta = 0.80$ ,  $\varphi = 1$ ,  $A(s_2) = 0.6$ ,  $A(s_1) = 0.05$ ,  $\Pi(s, s') = 0.5$ ,  $\forall s, s' \in S$ , and  $\alpha = 0.333$ .

**Panel A: Investment policy ( $k'$ )**



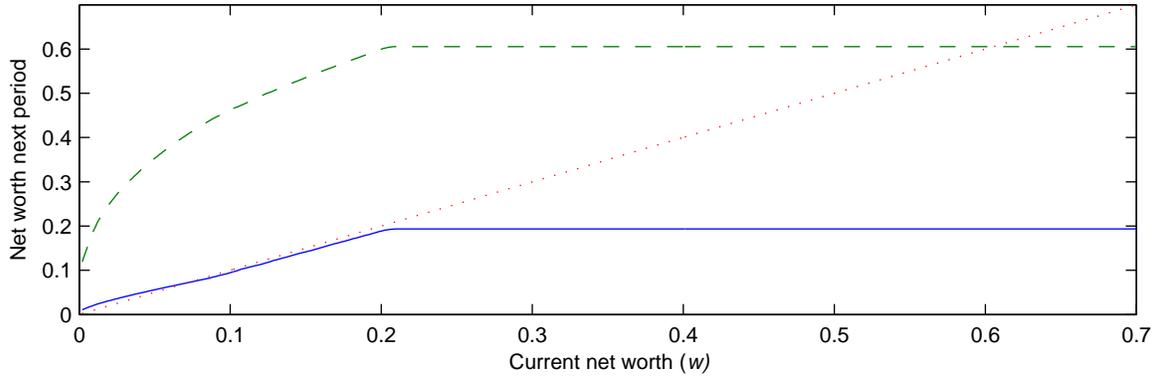
**Panel B: Risk management policy ( $h(s'_1)$ )**



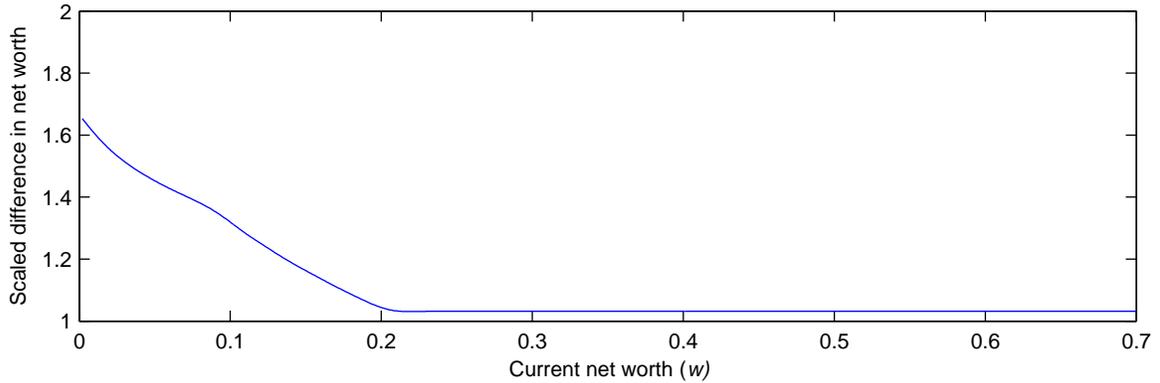
### Figure 4: Incomplete risk management of net worth next period

Panel A: Net worth in low state next period  $w(s'_1)$  (solid) and in high state next period  $w(s'_2)$  (dashed). Panel B: Difference between net worth in high state and low state next period scaled by expected net worth next period, that is,  $(w(s'_2) - w(s'_1)) / \sum_{s' \in S} \Pi(s, s') w(s')$ . For the parameter values see the caption of Figure 3.

**Panel A:** State-contingent net worth ( $w(s')$ )



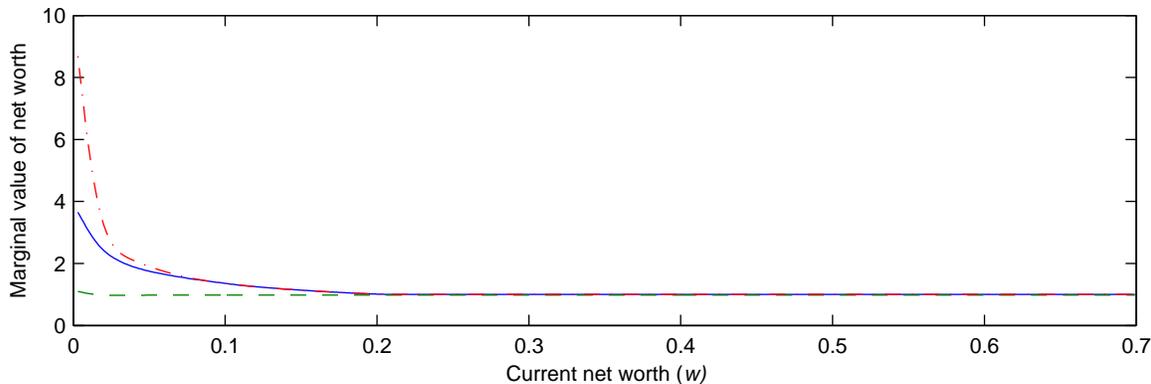
**Panel B:** Difference in net worth across states scaled by expected net worth



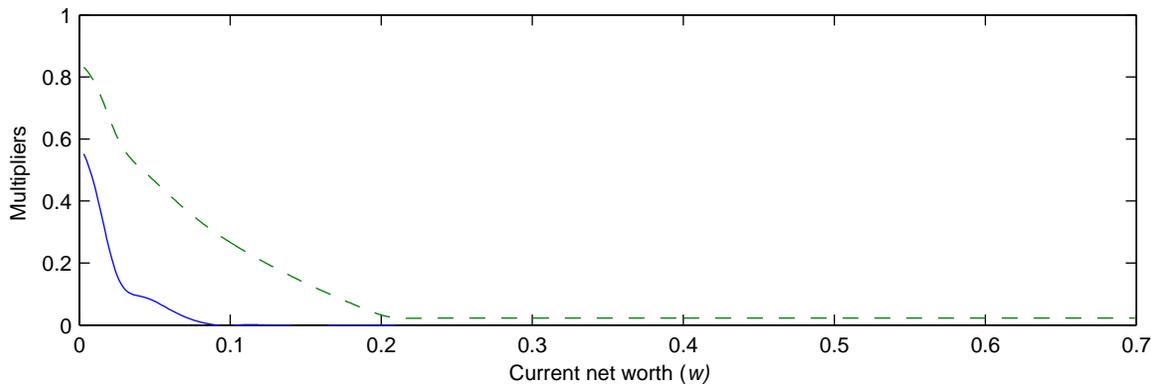
### Figure 5: Marginal value of net worth and multiplier on collateral constraints

Panel A: Scaled marginal value of net worth in the low state next period  $R\mu(s'_1) = R\beta V_w(w(s'_1))$  (solid) and in the high state next period  $R\mu(s'_2) = R\beta V_w(w(s'_2))$  (dashed), and current marginal value of net worth  $\mu = V_w(w)$  (dash dotted). Panel B: Scaled multipliers on the collateral constraint for the low state next period  $\lambda(s'_1)/\mu$  (solid) and for the high state next period  $\lambda(s'_2)/\mu$  (dashed). For the parameter values see the caption of Figure 3.

**Panel A:** Marginal value of net worth



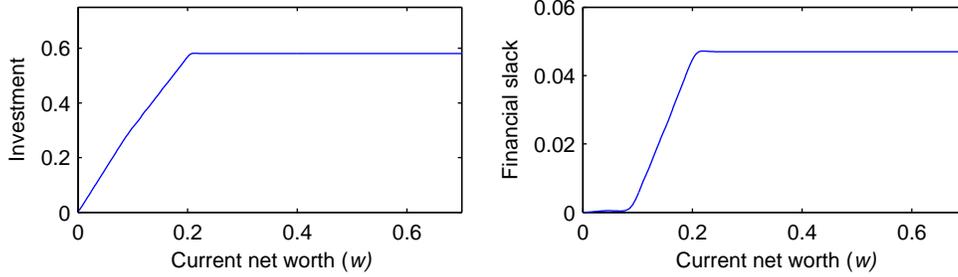
**Panel B:** Multipliers on collateral constraints



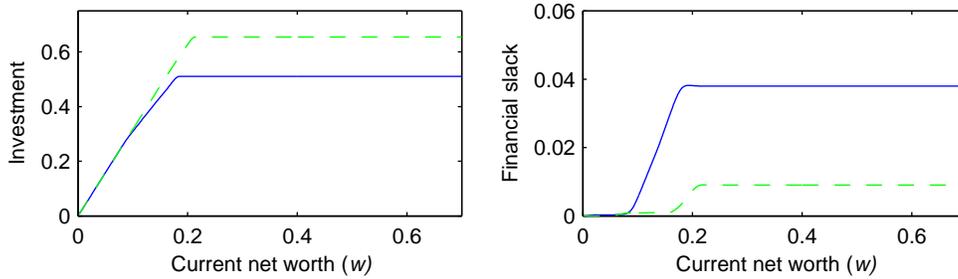
### Figure 6: Risk management with stochastic investment opportunities

Investment ( $k'$ ) and financial slack for the low state ( $h_1(s')$ ) as a function of current net worth  $w$  depending on current productivity  $s$ . Solid lines are for low current productivity ( $s_1$ ) and dashed lines are for high current productivity ( $s_2$ ). Panel A:  $\Pi(s_1, s_1) = \Pi(s_2, s_2) = 0.5$  (no persistence). Panel B:  $\Pi(s_1, s_1) = \Pi(s_2, s_2) = 0.55$ . Panel C:  $\Pi(s_1, s_1) = \Pi(s_2, s_2) = 0.60$ . For other parameter values see the caption of Figure 3.

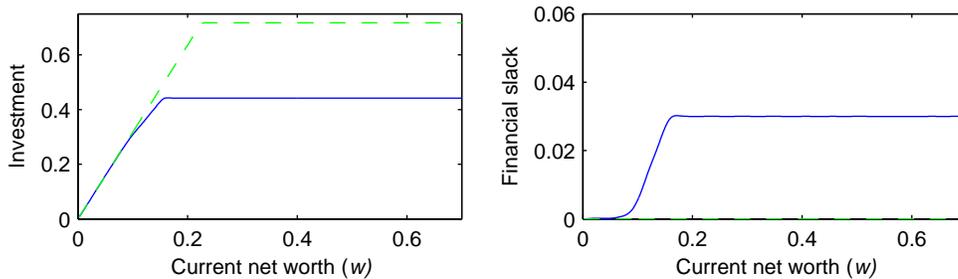
**Panel A:** No persistence  $\Pi(s_1, s_1) = \Pi(s_2, s_2) = 0.5$



**Panel B:** Persistence  $\Pi(s_1, s_1) = \Pi(s_2, s_2) = 0.55$



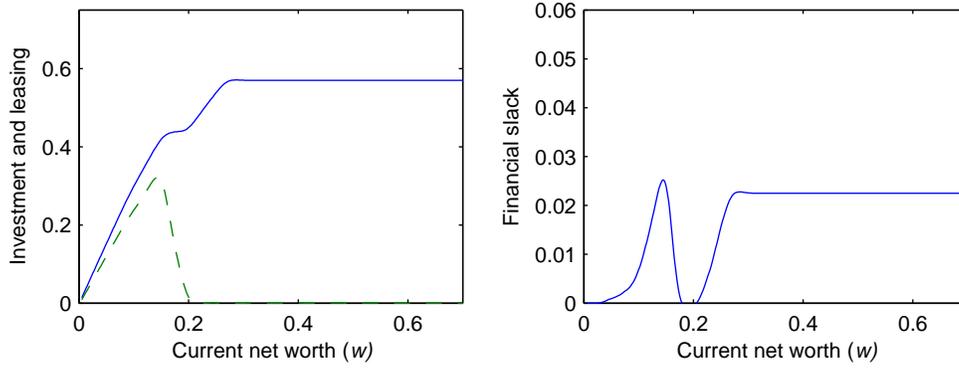
**Panel C:** Persistence  $\Pi(s_1, s_1) = \Pi(s_2, s_2) = 0.6$



### Figure 7: Interaction of leasing, leverage, and risk management

Panel A: Left-hand figure shows investment ( $k'$ ) (solid) and leasing ( $k'_l$ ) (dashed), and right-hand figure shows financial slack for the low state ( $h_1(s')$ ) as a function of current net worth  $w$ . Panel B: Left-hand figure shows net worth next period in the low state next period ( $w(s'_1)$ ) (solid) and in the high state next period ( $w(s'_2)$ ) (dashed), and right-hand figure shows the multipliers on the collateral constraints for the low state ( $\lambda(s'_1)$ ) (solid) and for the high state ( $\lambda(s'_2)$ ) (dashed) as a function of current net worth  $w$ . For other parameter values see the caption of Figure 3 except that  $\varphi = 0.8$  and  $m = 0.01$ .

#### Panel A: Investment ( $k'$ ), leasing ( $k'_l$ ), and risk management ( $h'(s_1)$ )



#### Panel B: Net worth next period ( $w(s')$ ) and multipliers on collateral constraints ( $\lambda(s')$ )

