Capital Structure, Compensation and Incentives

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This article illustrates an incentive-aligning role of debt in the presence of optimal compensation contracts. Owing to information asymmetry, value-maximizing compensation contracts allow managerial rents following high investment outcomes. The manager has an incentive to increase these rents by choosing investments that generate greater information asymmetry. An aptly chosen debt level mitigates this incentive, because investments that generate greater information asymmetry have more volatile outcomes. The greater volatility would make the debt risky, causing the shareholders to focus on high outcomes and therefore compensation contracts that reduce managerial rents. At the optimum, the manager avoids opportunistic investments, and the shareholders offer value-maximizing compensation contracts. Empirically, the analysis predicts a negative relationship between leverage and market-to-book that is reversed at extreme market-to-book ratios, a negative relationship between leverage and profitability, a negative relationship between leverage and pay-for-performance, and a positive relationship between pay-for-performance and investment opportunities.

The literature on corporate incentive conflicts provides considerable insight into the determinants of corporate capital structure. In their seminal papers, Fama and Miller (1972) and Jensen and Meckling (1976) illustrate that shareholders have an incentive to expropriate bondholder wealth by substituting into riskier investments, and Myers (1977) illustrates that shareholders have an incentive to under-invest when part of the return accrues to bondholders. Other studies incorporate managerial incentives (as distinct from shareholders) and illustrate the effects of capital structure on managerial decisions. For example, Jensen (1986) and Zwiebel (1996) illustrate that debt can focus managers on value maximization rather than personal objectives, and Stulz (1990) illustrates that debt can force the disbursement of cash flows to deter over-investment.

A potential criticism of this literature is that it does not explain why managerial decisions are influenced by capital structure rather than explicit managerial compensation contracts. Indeed, studies that focus on the explicit design of managerial incentive contracts have questioned the

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insights above. For example, Dybvig and Zender (1991) illustrate that if the owners can implement a long-term compensation contract, managerial decisions are in fact independent of capital structure (effectively resurrecting the Modigliani–Miller irrelevancy results). In response, Persons (1994) illustrates that such a long-term contract may not be dynamically consistent: the shareholders can profitably renegotiate the contract when the opportunity to expropriate bondholder wealth arises. While the implication is that capital structure is again relevant, Persons stops short of illustrating the capital structure that is optimal in the presence of dynamically consistent compensation contracts.

In this article, we formally investigate the interaction between capital structure and dynamically consistent compensation contracts and illustrate the optimal capital structure. The interaction between capital structure and compensation stems from managerial discretion over an initial investment choice that affects the manager's subsequent (second period) information advantages. These second-period information advantages include a hidden action and a hidden knowledge regarding the success of the investment chosen in the first period. As a result, the value-maximizing second-period compensation contract trades off managerial rents when the investment outcome is high with suboptimal managerial actions when the investment outcome is low. Recognizing this, the manager has an incentive to make a first-period investment choice that increases her second-period information advantages and therefore her second-period rents. Specifically, the manager has an incentive to choose an investment with greater dispersion in the privately observed second-period outcomes. The increased dispersion is presented as a mean preserving spread, so that the *manager's* incentive to choose such investments represents an adverse asset substitution incentive in the first period.

The manager's asset substitution incentive depends on the firm's debt level, because the second-period incentive contract that maximizes shareholder wealth depends on the level of debt outstanding. In particular, a risky debt level distorts the shareholders' incentive to choose an incentive contract that efficiently trades off the managerial rent when the investment outcome is high with the inefficiency of the action when the investment outcome is low—if the debt level becomes risky, the bondholders bear the cost of inefficient actions when the outcome is low, and the shareholders choose the compensation contract to minimize the manager's rent when the outcome is high [effectively, debt overhang leads to "under-investment" following low outcomes, similar to Myers (1977)]. This implies that a second-period debt level that becomes risky with asset substitution, but not otherwise, can deter the manager from asset substitution in the first period.

The effect of capital structure on the dynamically consistent compensation contract is based on the assumption that debt contracts are more costly to renegotiate than compensation contracts (which are negotiated in the presence of an outstanding debt level). In particular, the incentive alignment is based on a debt payment that is due at the end of the second period but issued at the beginning of the first. This implies that the ability to make the second-period debt payment also depends on interim uncertainty, which we incorporate via the realization of uncertain first-period cash flows. If the exogenous realization of first-period cash flow is particularly high, the manager is able to invest opportunistically (asset substitute) and still make the second-period debt payment. Alternatively, if the realization is particularly low, the second-period debt payment can become risky even without asset substitution and therefore cause under-investment by the shareholders.

The optimal capital structure minimizes the expected cost of these agency conflicts—i.e., the expected cost of managerial opportunism (asset substitution) following high cash flow realizations and shareholder opportunism (under-investment) following low cash flow realizations. In our analysis, under-investment is more costly than asset substitution, due to the complete disregard for inefficiency following low investment outcomes. Thus, the firm optimally chooses a relatively low debt level that avoids under-investment and allows managerial opportunism following the highest cash flows realizations.

Dewatripont and Tirole (1994) also present a model in which capital structure combines with an explicit managerial compensation contract to induce an efficient first-period action (effort choice) by the manager. In their model, the manager's effort choice depends on a non-contractible second-period asset substitution choice made by the controlling investor—specifically, the controlling party, shareholders or bondholders, can terminate existing investments, which reduces risk. (Berkovitch, Israel, and Speigel (2000) provide a similar analysis, except that terminating the current investment is framed as managerial replacement and assumed to increase rather than decrease risk.) The second-period asset substitution choice affects effort because the optimal compensation scheme provides pay for performance, so the incentive to provide effort reflects the probability of high performance. The debt level affects asset substitution because default transfers decision rights, and the shareholders and bondholders have different asset substitution preferences.

Our article differs from Dewatripont and Tirole [and Berkovitch, Israel, and Speigel (2000)] in many ways. First, building on the work of Dybvig and Zender (1991) and Persons (1994), we focus on the implications of capital structure when shareholders and bondholders have conflicting incentives with respect to the actions induced by managerial incentive contracts [in Dewatripont and Tirole (1994) and Berkovitch, Israel and Speigel (2000), both shareholders and bondholders prefer a compensation contract that induces high managerial effort]. Most significantly, however, we focus on the case where the manager's first-period action is designed to affect the subsequent contracting environment. This latter distinction is related to Dow and Raposo (2003) who examine a manager's incentive to pursue initial strategies that affect subsequent compensation contracts. While Dow and Raposo (2003) focus on the links between the firm's environment (the scope for opportunistic strategies) and the features of optimal compensation schemes (e.g., *ex ante* versus *ex post* contracting), our analysis focuses on the links between incentives and capital structure.[1]

The empirical implications of our analysis relate to leverage, investment opportunities, compensation contracts, and the firm's cash flow position. Leverage is affected by investment opportunities for two reasons. First, investment opportunities increase expected cash flows, so that leverage must increase to control asset substitution. Second, investment opportunities increase the manager's information rents and therefore the shareholders' incentive to encourage bondholder wealth expropriation, so that lower leverage is needed to ensure efficient compensation. For firms with "normal" opportunities (opportunities that are valuable but risky), the second effect dominates, producing a negative relationship between leverage and market-to-book (the empirical proxy for investment opportunities). For firms with exceptional opportunities, however, the first effect dominates and the relationship is reversed. The relationship is also reversed for firms that pursue value-decreasing opportunities (over-investing firms). The negative relationship for normal firms is consistent with the findings of Titman and Wessels (1988), Barclay, Smith, and Watts (1995), Rajan and Zingales (1995), and Johnson (2003). The reversal at extreme market-to-book ratios has yet to be fully investigated but is consistent with the positive relationship at low market-to-book ratios found by Rajan and Zingales (1995, note 32).

In addition, since higher managerial rents coincide with greater compensation following high investment outcomes, investment opportunities increase pay-for-performance under the optimal compensation contract. For value-increasing opportunities, this implies a positive relationship between pay-for-performance and market-to-book, as in Smith and Watts (1992), Gaver and Gaver (1993), Kole (1997), and Bryan, Hwang, and Lilien (2000). Again, the possibility of value-decreasing opportunities implies that the relationship may not hold for the lowest market-to-book

[1] A number of other papers link capital structure to explicit compensation contracts, but are less related to the analysis here. Notably, in John and John (1993), compensation serves as an *ex ante* commitment that offsets the shareholder incentive to expropriate bondholder wealth [similar to Dybvig and Zender (1991) and therefore subject to the same renegotiation concern in Persons (1994)]. In Chang (1993), managerial incentives are linked to capital structure because only financing variables (debt and dividend payments) are contractible. In Holmstrom and Tirole (1993), external equity affects the incentive to monitor managerial performance, and in Douglas (2002), capital structure offsets the manager's influence over the compensation setting process.

ratios. And coupled with the non-monotonic relationship between market-to-book and leverage, the analysis predicts that pay-for-performance is negatively related to leverage for all but very high market-to-book ratios, consistent with the negative relationship in Ortiz-Molina (2004).

Our analysis also predicts that firms with higher expected cash flows or less volatile cash flows are more levered, since the leverage required to deter managerial opportunism increases with expected cash flows, and the leverage level that avoids under-investment decreases with cash flow volatility. The latter prediction is consistent with the finding of Bradley, Jarrell, and Kim (1984) that leverage decreases with the volatility of EBITDA (earnings before interest, taxes, depreciation, and amortization). In addition, our analysis predicts a negative relationship between *realized* cash flows and the debt/value ratio, consistent with the negative relationship between leverage and profitability (EBITDA) in Rajan and Zingales (1995). In our model, this reflects the relationship between profitability and value—debt is insensitive to realized cash flow because the same debt level is optimal for a range of cash flow realizations and because debt adjustment is costly (reflecting our assumption that debt contracts are more costly to renegotiate than compensation contracts). This is consistent with Welch's (2004) finding that the profitability–leverage relationship is driven by the effect of profitability on market value.

The remainder of the article is organized as follows. Section 1 presents the basic model. The dynamically consistent second-period compensation contracts are characterized in Section 1.1, and the asset substitution and under-investment problems are presented in Sections 1.2 and 1.3 respectively. Section 2 presents the optimal capital structure. Section 3 discusses empirical implications and extensions, and Section 4 concludes.

1. Model

In this section, we outline the basic model and then present the analysis. The sequence of events and description of variables is presented in Figure 1.

At $t = 0$, the firm's owners choose the second-period debt level, F_2. Next, first-period cash flow, $c_1 \sim \text{unif}[\underline{c}, \overline{c}]$, is realized. The exogenous realization of c_1 is observable but not contractible, reflecting that it is costly to verify accounting reports similar to Townsend (1979), Chang (1993), Fluck (1998), Gorton and Kahn (2000), and Myers (2000).[2] After

[2] In our model, c_1 represents the firm's performance in the first period. In general, firm performance reflects both current and future cash flows (and both affect the firm's ability to make future debt payments). Our analysis extends immediately to the case where first-period cash flow also affects the expectation of second-period cash flow, provided that the change in expectation is observable but non-contractible (like c_1). To maintain focus, however, we omit this extension. The possibility that first-period cash flow (performance) is contractible, and the use of contractible accounting proxies, is discussed in Section 3.

t = 0 — Second period debt level, F_2, chosen by owners

— Exogenous 1st period cash flow c_1 realized – commonly observed but not contractible

— Asset substitution choice Δy made by manager – commonly observed but not contractible

t = 1 — 2nd period compensation contract offered by shareholders

— Investment outcome (^{i} realized – privately observed by manager, not contractible

— Managerial action *a* chosen – privately observed by manager, not contractible

t = 2 — Final value realized – commonly observed and contractible

Figure 1
Sequence of events and description of variables.

c_1 is realized, the manager makes an investment choice that determines the dispersion of the investment outcomes in the second period. Similar to Jensen and Meckling (1976) and Gorton and Kahn (2000), this is modeled as an observable but non-contractible asset substitution choice, reflecting that it is costly to verify the *distribution* of future returns. In our model, there are two possible investment outcomes in the second period (represented by the realization of ε), and the dispersion between the high and low outcomes is denoted by $\Delta\varepsilon \equiv \varepsilon^{\mathrm{H}} - \varepsilon^{\mathrm{L}}$. The manager can choose the efficient level of dispersion, in which case $\Delta\varepsilon = \Delta x$, or add a mean preserving spread Δy, such that $\Delta\varepsilon = \Delta x + \Delta y$ (where $\Delta x \equiv x^{\mathrm{H}} - x^{\mathrm{L}}$ and $\Delta y \equiv y^{\mathrm{H}} - y^{\mathrm{L}}$). Thus, asset substitution refers to the addition of Δy. In contrast to standard analyses, this choice reflects the association between dispersion and information advantages, because the manager privately observes ε in the second period. More precisely, the manager's choice reflects the impact of $\Delta\varepsilon$ on the dynamically consistent second-period compensation contract.

The second-period compensation contract is designed to maximize $t = 1$ shareholder wealth. We focus on contracts designed at $t = 1$ to ensure dynamic consistency, and because there is no loss of generality from focusing on $t = 1$ contracts in our model (i.e., $t = 0$ contracts are suboptimal in our model).[3] The optimal contract maximizes $t = 1$ shareholder wealth subject to the manager's second-period information advantages. These information advantages include the private observation of the investment outcome ε^i and a hidden second-period action a. The second-period investment outcomes, $\varepsilon \in \{\varepsilon^{\mathrm{L}}, \varepsilon^{\mathrm{H}}\}$, are equally likely

[3] In general, $t = 0$ contracts might be beneficial because the option to retain the $t = 0$ contract can increase the manager's utility requirement in a $t = 1$ renegotiation. In our model, however, the manager earns strictly positive rents at $t = 1$, so the ability to further increase his utility is not beneficial and there is no loss from excluding $t = 0$ contracts. For models where $t = 0$ contracts can add value, see Aghion, Dewatripont and Tirole (1994) and Dow and Raposo (2003).

with $\varepsilon^{\mathrm{H}} > \varepsilon^{\mathrm{L}} \geq 0$, and the dispersion $\Delta\varepsilon \equiv \varepsilon^{\mathrm{H}} - \varepsilon^{\mathrm{L}}$ determines the degree of the manager's information advantage.

At $t = 2$, final firm value $v_2 = c_1 + \varepsilon + a$ is distributed to the shareholders, debt holders, and managers according to the contracts outstanding. The manager receives the payment w according to her compensation contract, and the investors receive the remainder—the debt holders receive up to the face value F_2 in the debt contract and shareholders receive the residual. The shareholders and bondholders are risk-neutral and concerned only with their expected returns. The manager, however, has utility given by $u(w, a) = w - A(a)$, where $A(a)$ is the disutility of the managerial action (e.g., effort or foregone perquisites). The possible effort levels are given by $a \in [\underline{a}, \bar{a}]$, and to simplify, the disutility function is given by[4]

$$A(a) = \begin{cases} \frac{ka^2}{2} & \text{if } a \geq 0 \\ 0 & \text{if } a < 0. \end{cases}$$

Thus, the manager is risk-neutral with respect to her monetary returns but exhibits increasing marginal disutility of the action ($A'(= k > 0)$. Finally, the manager's reservation utility, denoted u, is normalized to zero, as is her outside wealth.

The remainder of this section presents the analysis. Section 1.1 presents the optimal second-period compensation contract when the outstanding debt (F_2) is risk free. Section 1.2 illustrates the managerial asset substitution problem associated with this debt level, Section 1.3 illustrates how risky debt alters the shareholders' compensation design problem (i.e., presents the shareholders' under-investment incentive), and Section 1.4 illustrates the interaction between the asset substitution and under-investment incentives. Section 2 presents the optimal $t = 0$ capital structure.

1.1 Second-period incentive contracts with risk-free debt

In our model, the ability to make the second-period debt payment depends on three factors: (i) the value of F_2, (ii) the exogenous realization of first-period cash flow, c_1, and (iii) the first-period investment choice, as represented by $\Delta\varepsilon$. For illustrative purposes, we begin with the contract design problem when the second-period debt level is risk free—i.e., for combinations of F_2, c_1, and $\Delta\varepsilon$ such that F_2 is risk free at $t = 1$. When the outstanding debt is risk free, there is no shareholder–bondholder conflict, and the compensation contract reflects only the manager–owner conflict. We present the case of risky debt (due to a higher F_2, lower c_1, or higher $\Delta\varepsilon$) below.

At $t = 1$, the firm's investment choice, $\Delta\varepsilon \in \{\Delta x, \Delta x + \Delta y\}$, and existing cash flow, $c_1 \in [\underline{c}, \bar{c}]$, are known to the shareholders, and the optimal

[4] We specify $A(a) = 0$ for $a < 0$ to avoid corner solutions. As seen below, this further requires $\underline{a} \leq -\Delta\varepsilon$ and $\bar{a} \geq 1/k$.

compensation contract is designed to induce efficient second-period actions a subject to the manager's private knowledge of the investment outcome ε. The second-period contracting problem is similar to that in Baron and Myerson (1982), Laffont and Tirole (1986), and Kofman and Lawarree (1993). Specifically, the shareholders observe only the combined outcome $\varepsilon + a$ (or equivalently, total value $v_2 = c_1 + \varepsilon + a$), knowing that each realization ε^i was equally likely. Thus, they design the incentive contract to maximize their $t = 1$ expected payoff

$$.5(c_1+\varepsilon^{\mathrm{H}}+a^{\mathrm{H}}-w^{\mathrm{H}})+.5(c_1+\varepsilon^{\mathrm{L}}+a^{\mathrm{L}}-w^{\mathrm{L}}) - F_2,$$

where a^i denotes the incentive compatible action for each realization of ε^i. The incentive contract must satisfy the manager's reservation utility constraint for each possibility ($w^i - A(a^i) \geq u$) to ensure the manager's participation when there is a good or bad outcome. It must also satisfy the manager's incentive compatibility constraints for each possibility, given by[5]

$$w^{\mathrm{L}} - A(a^{\mathrm{L}}) \geq w^{\mathrm{H}} - A(a^{\mathrm{H}} + \Delta\varepsilon)$$

and

$$w^{\mathrm{H}} - A(a^{\mathrm{H}}) \geq w^{\mathrm{L}} - A(a^{\mathrm{L}} + \Delta\varepsilon).$$

These incentive compatibility constraints ensure that the manager in fact chooses the intended levels of a^i, given his ability to claim either value of ε^i.

Some important features of the optimal contract follow immediately from the constraints. In particular, the incentive compatibility constraint for the high state ($i = \mathrm{H}$) enables the manager to obtain rents, as seen by substituting $w^{\mathrm{L}} = u + A(a^{\mathrm{L}})$ into the constraint, yielding

$$w^{\mathrm{H}} - A(a^{\mathrm{H}}) \geq u + A(a^{\mathrm{L}}) - A(a^{L} - \Delta\varepsilon).$$

That is, the simultaneous information advantages provide the manager with an information rent equal to $A(a^{\mathrm{L}}) - A(a^{\mathrm{L}} - \Delta\varepsilon)$ in the high state, and the reservation utility constraint for $i = \mathrm{H}$ does not bind. Additionally, the two incentive compatibility constraints cannot simultaneously bind, as seen by rewriting them as

[5] Of course, the incentive compatible values of a associated with each value of ε must still be preferred to any other a, which in our setting would be immediately detectable and therefore result in the minimum compensation payment of zero—formally, the compensation contract is given by

$$w(v_2) = \begin{cases} w^{\mathrm{L}} & \text{if } v_2 = c_1 + \varepsilon^{\mathrm{L}} + a^{\mathrm{L}} \\ w^{\mathrm{H}} & \text{if } v_2 = c_1 + \varepsilon^{\mathrm{H}} + a^{\mathrm{H}} \\ 0 & \text{otherwise.} \end{cases}$$

$$w^{\mathrm{H}} - w^{\mathrm{L}} \leq A(a^{\mathrm{H}} + \Delta\varepsilon) - A(a^{\mathrm{L}})$$

and

$$w^{\mathrm{H}} - w^{\mathrm{L}} \geq A(a^{\mathrm{H}}) - A(a^{\mathrm{L}} - \Delta\varepsilon).$$

Since $A' > 0$ and $A'' > 0$ imply $A(a^{\mathrm{H}} + \Delta\varepsilon) - A(a^{\mathrm{L}}) > A(a^{\mathrm{H}}) - A(a^{\mathrm{L}} - \Delta\varepsilon)$, only one constraint can bind. To induce efficient actions with the lowest possible payments, it is the constraint for the high state that binds (otherwise the shareholders would pay the manager more than necessary when $i = \mathrm{H}$).

The optimal contract therefore maximizes the shareholders' expected return subject to the incentive compatibility constraint for the high state and the reservation utility constraint for the low state. The Lagrangian is

$$\begin{aligned} \max_{<w^i, a^i>} L =& .5(c_1 + \varepsilon^{\mathrm{L}} + a^{\mathrm{L}} - w^{\mathrm{L}}) + .5(c_1 + \varepsilon^{\mathrm{H}} + a^{\mathrm{H}} - w^{\mathrm{H}}) - F_2 \\ &+ \theta^{\mathrm{L}}_{\mathrm{RU}}\big(w^{\mathrm{L}} - A\big(a^{\mathrm{L}}\big) - u\big) + \theta^{\mathrm{H}}_{\mathrm{IC}}\big(w^{\mathrm{H}} - A\big(a^{\mathrm{H}}\big) - w^{\mathrm{L}} + A\big(a^{\mathrm{L}} - \Delta\varepsilon\big)\big). \end{aligned}$$

The first-order conditions for w^{L} and w^{H} yield $\theta^{\mathrm{L}}_{\mathrm{RU}} = 1$ and $\theta^{\mathrm{H}}_{\mathrm{IC}} = .5$, and the first-order condition for a^{H} yields

$$\frac{\partial L}{\partial a^{\mathrm{H}}} = .5\big(1 - A'\big(a^{\mathrm{H}}\big)\big) = 0 \Rightarrow A'\big(a^{\mathrm{H}}\big) = 1,$$

illustrating that the optimal contract induces the first best action if $i = \mathrm{H}$, $a^{\mathrm{H}} = a^{\mathrm{FB}}$. However, the contract induces a lower level of the action in the bad state, as seen from the first-order condition for a^{L}

$$\frac{\partial L}{\partial a^{\mathrm{L}}} = .5 - A'(a^{\mathrm{L}}) + .5A'(a^{\mathrm{L}} - \Delta\varepsilon) = 0,$$

so that

$$1 - A'(a^{\mathrm{L}}) = A'(a^{\mathrm{L}}) - A'(a^{\mathrm{L}} - \Delta\varepsilon) \Rightarrow A'(a^{\mathrm{L}}) < 1. \tag{1}$$

The optimal contract induces $a^{\mathrm{L}} < a^{\mathrm{FB}}$ to reduce the information rent $A(a^{\mathrm{L}}) - A(a^{\mathrm{L}} - \Delta\varepsilon)$ required to satisfy the incentive compatibility constraint for the high state. The information rent decreases when a^{L} is reduced because $A'' = k > 0$.[6] Intuitively, the lower action reduces the marginal disutility of the action, so that the manager has less incentive to

[6] The result that the agent receives a rent to deter mimicry of lower states in the presence of simultaneous hidden knowledge and hidden actions is well established in the contracting literature. As mentioned above, the analysis here is closest to Kofman and Lawarree (1993), who present a simplified (two state) version of the contracting problems in Maskin and Riley (1984) and Laffont and Tirole (1986).

mimic the low state (which requires further reducing the action by $\Delta\varepsilon$). As the incentive to conceal value decreases, so does the information rent that must be offered to deter concealment. Thus, the reduction in a^{L} reflects a trade-off between managerial rents in the high state and the inefficient actions in the low state.

In sum, the cost of the manager's second-period information advantage consists of two components: (i) the manager's information rent if $i = \mathrm{H}$, denoted by

$$\rho(a^{\mathrm{L}}, \Delta\varepsilon) \equiv A(a^{\mathrm{L}}) - A(a^{\mathrm{L}} - \Delta\varepsilon),$$

and (ii) the inefficiency cost of $a^{\mathrm{L}} < a^{\mathrm{FB}}$, given by

$$a^{\mathrm{FB}} - A(a^{\mathrm{FB}}) - (a^{\mathrm{L}} - A(a^{\mathrm{L}})).$$

The optimal compensation contract minimizes the expected contracting costs, denoted

$$\kappa(a^{\mathrm{L}}, \Delta\varepsilon) \equiv .5[\rho(a^{\mathrm{L}}, \Delta\varepsilon)] + .5[a^{\mathrm{FB}} - A(a^{\mathrm{FB}}) - (a^{\mathrm{L}} - A(a^{\mathrm{L}}))],$$

as seen by re-writing the expression for the optimal value of a^{L} in Equation (1) as

$$\frac{\partial \kappa}{\partial a^{\mathrm{L}}} = .5[A'(a^{\mathrm{L}}) - A'(a^{\mathrm{L}} - \Delta\varepsilon) - (1 - A'(a^{\mathrm{L}}))] = 0 \qquad (1')$$

The optimal value of a^{L} in Equation (1) characterizes the value-maximizing second-period compensation contract in our model and is denoted a^{L^*} (i.e., a^{L^*} characterizes the contract that maximizes the value available to investors, given the unavoidable managerial information advantages).

It is optimal for the shareholders to induce a^{L^*} when F_2 is *risk free* as above, since maximizing shareholder wealth is equivalent to maximizing firm value. In our model, however, a risk-less second-period debt level leaves the manager with an opportunistic asset substitution incentive in the first period, as seen next.

1.2 The asset substitution choice

As discussed above, asset substitution is modeled as a mean preserving spread in project outcomes, such that $\Delta\varepsilon$ increases from Δx to $\Delta x + \Delta y$. Similar to the standard analysis, asset substitution is an observable but non-contractible investment decision. Here, however, the asset substitution incentive reflects a positive association between outcome dispersion and the manager's information advantages, which arises because the manager asymmetrically observes ε. In particular, the first-period asset substitution choice reflects the effect on the value-maximizing second-period compensation contract characterized by Equation (1).

Asset substitution is costly in our model, because it increases the manager's information advantage and therefore the cost to the owners of contracting with the manager. The increase in contracting costs can be seen by totally differentiating $\kappa(a^{L^*}(\Delta\varepsilon), \Delta\varepsilon)$, where $a^{L^*}(\Delta\varepsilon)$ reflects that the optimal reduction in a^L from the first best increases with the manager's information advantage (as seen formally by differentiating Equation (1) with $A'(a) = ka$, which yields $da^{L^*}/d\Delta\varepsilon = -1$. The effect of $\Delta\varepsilon$ on expected contracting costs is therefore given by

$$\frac{d\kappa(a^{L^*}(\Delta\varepsilon), \Delta\varepsilon)}{d\Delta\varepsilon} = \frac{\partial\kappa}{\partial a^{L^*}}\frac{\partial a^{L^*}}{\partial\Delta\varepsilon} + \frac{\partial\kappa}{\partial\Delta\varepsilon} = .5A'(a^{L^*} - \Delta\varepsilon) > 0.$$

The effect of asset substitution on firm value at $t = 1$ is seen by substituting the compensation levels under the optimal contract back into the objective function. Recalling that the manager's reservation utility is normalized to zero, the optimal compensation levels are $w^H = A(a^{FB}) + \rho(a^{L^*}, \Delta\varepsilon)$ and $w^L = A(a^{L^*})$, so that $t = 1$ firm value is given by

$$\begin{aligned} v_1(c_1, a^{L^*}, \Delta\varepsilon) = {} & .5[c_1 + \varepsilon^H + a^{FB} - A(a^{FB}) - \rho(a^{L^*}(\Delta\varepsilon), \Delta\varepsilon)] \\ & + .5[c_1 + \varepsilon^L + a^{L^*} - A(a^{L^*})] = c_1 + E[\varepsilon] + a^{FB} - A(a^{FB}) \\ & - \kappa(a^{L^*}(\Delta\varepsilon), \Delta\varepsilon). \end{aligned}$$

Since asset substitution is a mean preserving increase in $\Delta\varepsilon$ that increases contracting costs, it decreases firm value.[7] We present this result formally as lemma 1.

Lemma 1. *A mean preserving spread in investment outcomes (asset substitution) increases the level of contracting costs under the value-maximizing second-period compensation contract to* $\kappa(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y) > \kappa(a^{L^*}(\Delta x), \Delta x)$, *reducing* $t = 1$ *firm value.*

Despite the adverse effect on firm value, the manager may pursue asset substitution to increase the information rents she receives under the value-maximizing second-period compensation contract, i.e., to increase $\rho(a^{L^*}(\Delta\varepsilon), \Delta\varepsilon) \equiv A(a^{L^*}(\Delta\varepsilon)) - A(a^{L^*}(\Delta\varepsilon) - \Delta\varepsilon)$. The effect of $\Delta\varepsilon$ on the manager's information rents is given by

$$\begin{aligned} \frac{d\rho}{d\Delta\varepsilon} &= A'(a^{L^*} - \Delta\varepsilon) + \left(\frac{da^{L^*}}{d\Delta\varepsilon}\right)\left(A'\left(a^{L^*}\right) - A'\left(a^{L^*} - \Delta\varepsilon\right)\right) \\ &= A'\left(a^{L^*} - \Delta\varepsilon\right) - k\Delta\varepsilon. \end{aligned}$$

[7] The result that asset substitution is *endogenously* suboptimal further contrasts our model from standard analyses, where an exogenous cost is often required to make the mean preserving spread inefficient [Gorton and Kahn (2000)].

The first term represents the direct effect of $\Delta\varepsilon$, which increases the manager's rents, and the second term represents the effect of the offsetting adjustment in a^{L^*} to maintain the optimality condition Equation (1). In contrast to firm value (which monotonically decreases in $\Delta\varepsilon$), the manager's rents are concave in $\Delta\varepsilon$ ($d^2\rho/d\Delta\varepsilon^2 = -3k$), reaching a maximum at $\Delta\varepsilon = 1/(3k)$. To maintain focus, we restrict attention to the case where the direct effect of the additional information asymmetry dominates, so that asset substitution increases the manager's rents (a sufficient condition is that $\Delta x + \Delta y \leq 1/(3k)$).[8]

This implies that, when F_2 is risk-less and the incentive contract is designed to maximize $t = 1$ shareholder wealth as in Equation (1), the manager pursues asset substitution. This result is stated formally as lemma 2.

Lemma 2. *When the debt level F_2 remains risk-less, the manager invests opportunistically (chooses asset substitution) in the first period, increasing $\Delta\varepsilon$ from Δx to $\Delta x + \Delta y$.*

Lemma 2 illustrates that a suboptimal first-period investment strategy results if second-period debt remains risk free.

Higher (potentially risky) debt levels, however, affect investment choices, because risky debt introduces the familiar agency conflicts between shareholders and bondholders. In our model, this affects the shareholders' $t = 1$ compensation design problem and therefore the manager's first-period investment incentives, as seen next.

1.3 Risky debt and under-investment

A risky second-period debt level affects the analysis above because risky debt levels leave no residual in the low state, so that shareholders are primarily concerned with the high state and shareholder–bondholder agency conflicts arise [Myers (1977), Jensen and Meckling (1976)]. Since the manager makes the operating decisions in our model, the shareholder–bondholder conflict affect the analysis through the managerial incentive contract—i.e., the opportunity to expropriate bondholder wealth distorts the shareholders' contract design problem at $t = 1$. Specifically, with risky debt, the incentive contract that maximizes shareholder wealth induces highly inefficient actions when low value is realized ($a^L = 0$) to increase the return when high value is realized. This expropriation incentive is similar to the under-investment incentive in Myers (1977) where shareholders forego profitable projects because part of the return would accrue to debt holders. Here, the shareholders forego a profitable *ex post*

[8] The restrictions above, i.e. $\varepsilon^H > \varepsilon^L \geq 0$ and $y^L = -y^H < 0$ so that Δy is mean preserving, require $x^L \geq -y^L = y^H$. The restriction that $0 < \Delta\varepsilon = \Delta x + \Delta y \leq 1/(3k)$ requires $x^L \geq x^H - 1/(3k) + \Delta y = x^H - 1/(3k) + 2y^H$. There are parameter values that satisfy these restrictions – e.g., $x^L = y^H$ and $x^H + y^H \leq 1/(3k)$.

"investment" of w^{L} since the benefit, an increase in a^{L}, accrues to the bondholders.

The effect of risky debt on the incentive contract offered by the shareholders is presented in lemma 3.

Lemma 3. *When the second-period debt payment F_2 is risky, the dynamically consistent compensation contract offered by the shareholders induces a highly inefficient level of a^L, i.e. $a^L = 0$. This reduces firm value despite reducing managerial rents to zero.*

The formal explanation (proof) of lemma 3 follows directly from the change in the shareholders' objective in the contract design problem, which becomes

$$\max_{<wi,ai>} L = .5\left(c_1 + \varepsilon^{\mathrm{H}} + a^{\mathrm{H}} - w^{\mathrm{H}} - F_2\right) + \theta^{\mathrm{L}}_{\mathrm{RU}}\left(w^{\mathrm{L}} - A(a^{\mathrm{L}}) - u\right)$$
$$+ \theta^{\mathrm{H}}_{\mathrm{IC}}\left(w^{\mathrm{H}} - A(a^{\mathrm{H}}) - w^{\mathrm{L}} + A\left(a^{\mathrm{L}} - \Delta\varepsilon\right)\right).$$

The first-order conditions for w^{i} and a^{H} now yield $\theta^{\mathrm{L}}_{\mathrm{RU}} = .5$ and $\theta^{\mathrm{H}}_{\mathrm{IC}} = .5$, $A'(a^H) = 1$, and

$$\frac{\partial L}{\partial a^{\mathrm{L}}} = -.5\left(A'\left(a^{\mathrm{L}}\right) - A'\left(a^{\mathrm{L}} - \Delta\varepsilon\right)\right) = 0 \Rightarrow a^{\mathrm{L}} = 0 \qquad (3)$$

The shareholders reduce a^{L} to zero to minimize the manager's rent in the high state, $\rho(a^{\mathrm{L}}, \Delta\varepsilon)$. They are no longer concerned with the cost of the corresponding inefficiency in the low state, because this cost is borne by the bondholders. As illustrated above, however, firm value (i.e., the value of equity plus debt) is maximized at a^{L^*} [i.e., $\kappa(a^{\mathrm{L}^*}, \Delta\varepsilon) < \kappa(0, \Delta\varepsilon)$ as in (1′)]. Thus, inducing $a^{\mathrm{L}} = 0$ expropriates bondholder wealth but reduces firm value.

Although the creditors bear the cost of under-investment in a^{L} at $t = 1$, they anticipate the possibility at $t = 0$ and price it into the initial debt contract. Thus, as in Jensen and Meckling (1976) and Myers (1977), the original owners ultimately bear the residual loss from the expropriation incentive. This implies that the initial owners issue risky debt at $t = 0$ only to the extent that there are offsetting benefits. In our model, the offsetting benefits stem from the interaction between the manager's first-period asset substitution incentive and the shareholders' second-period under-investment incentive.

1.4 The interaction between the asset substitution and under-investment incentives

The analysis above illustrates that the firm's capital structure affects the dynamically consistent compensation contract in our model and therefore the manager's first-period investment incentive. In particular, lemma 2 illustrates that when the second-period debt payment F_2 remains risk-less, asset substitution will increase the manager's rents under the dynamically consistent compensation contract. Lemma 3, however, illustrates that the manager will refrain from asset substitution that makes F_2 risky, because risky debt induces the shareholders to offer the under-investment contract that minimizes managerial rents. The manager's first-period asset substitution choice therefore depends on the risk of making the second-period debt payment. Since the risk of making the second-period debt payment depends on the value of F_2 chosen at $t = 0$ and the realized cash flow c_1, the asset substitution choice depends on F_2 and c_1. In this subsection, we develop the effects of c_1 on the asset substitution choice, still taking F_2 as given. The optimal choice of F_2 is presented in the next section.

The first-period cash flow c_1 affects the asset substitution choice because, *ceteris paribus*, a lower realization reduces the funds available to make the second-period debt payment. Sufficiently low realizations make F_2 risky, such that the shareholders prefer the under-investment compensation contract. Since c_1 affects the compensation design incentive, it affects the manager's investment incentive.

To formally illustrate the effect of c_1 on the investment choice, we identify the realization of c_1 for which the shareholders are indifferent between the efficient and under-investment compensation contracts. This realization, denoted $\hat{c}$, is found by equating the shareholders' expected wealth in each case. Since the under-investment contract in lemma 3 induces $a^{\mathrm{L}} = 0$ and allows no managerial rents in the high state (so that $w^{\mathrm{H}} = A(a^{\mathrm{FB}})$), expected shareholder wealth is given by

$$.5[c_1 + \varepsilon^{\mathrm{H}} + a^{\mathrm{FB}} - A(a^{\mathrm{FB}}) - F_2] + .5[0]$$

In contrast, the efficient (value-maximizing) contract of Equation (1) yields a residual in the low state and allows managerial rents in the high state, yielding expected shareholder wealth of

$$\begin{aligned} &.5[c_1 + \varepsilon^{\mathrm{H}} + a^{\mathrm{FB}} - A(a^{\mathrm{FB}}) - \rho(a^{\mathrm{L}^*}(\Delta\varepsilon), \Delta\varepsilon) - F2] \\ &\quad + .5[c_1 + \varepsilon^{\mathrm{L}} + a^{\mathrm{L}^*} - A(a^{\mathrm{L}^*}) - F_2]. \end{aligned}$$

The value of c_1 at which the shareholders are indifferent, denoted $\hat{c}$, equates these two expressions,

$$\begin{aligned} \hat{c}(F_2, \Delta\varepsilon) &= F_2 - \varepsilon^{\mathrm{L}} + \rho\big(a^{\mathrm{L}^*}(\Delta\varepsilon), \Delta\varepsilon\big) - \big(a^{\mathrm{L}^*}(\Delta\varepsilon) - A\big(a^{\mathrm{L}^*}(\Delta\varepsilon)\big)\big) \\ &= F_2 - \varepsilon^{\mathrm{L}} - a^{\mathrm{FB}} + A\big(a^{\mathrm{FB}}\big) + 2\kappa\big(a^{\mathrm{L}^*}(\Delta\varepsilon), \Delta\varepsilon\big), \end{aligned} \tag{4}$$

where again $\kappa\left(a^{L^*}(\Delta\varepsilon),\Delta\varepsilon\right) \equiv .5\left[\rho\left(a^{L^*}(\Delta\varepsilon),\Delta\varepsilon\right)\right] + .5\left[a^{FB} - A\left(a^{FB}\right) - \left(a^{L^*}(\Delta\varepsilon) - A\left(a^{L^*}(\Delta\varepsilon)\right)\right)\right]$ is the contracting cost under the efficient compensation contract (i.e., the expected cost to the firm of the rent in the high state or the low action in the low state).

As seen in Equation (4), the set of realizations for which the shareholders offer the under-investment contract, i.e. $c_1 < \hat{c}(F_2, \Delta\varepsilon)$, is contingent on the manager's asset substitution choice, $\Delta\varepsilon$. A mean preserving increase in $\Delta\varepsilon$, from Δx to $\Delta x + \Delta y$, increases this set (increases $\hat{c}$) for two reasons. First, since Δy is mean preserving, $y^L < 0$ and $y^H > 0$, so that ε^L decreases from x^L to $x^L + y^L$. This reduces the shareholders' residual in the low state if they offer the efficient contract, making the under-investment contract relatively more attractive. To restore indifference, c_1 must increase to restore the shareholders' residual under the efficient contract. Second, adding Δy increases contracting costs as in lemma 1, reflecting the increase in managerial rents and the offsetting reduction in a^{L^*}, both of which reduce expected shareholder wealth under the efficient contract. The increase in $\hat{c}$ due to asset substitution is represented by ϕ, i.e.

$$\begin{aligned}\phi &\equiv \hat{c}(F_2, \Delta x + \Delta y) - \hat{c}(F_2, \Delta x) \\ &= 2(\kappa(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y) - \kappa(a^{L^*}(\Delta x), \Delta x)) - y^L > 0.\end{aligned} \tag{5}$$

The increase in $\hat{c}$ due to asset substitution implies that there are realizations of c_1 for which the shareholders will offer the under-investment contract if the manager pursues asset substitution, but not otherwise. Specifically, equation (5) implies that, upon observing

$$\hat{c}(F_2, \Delta x) \le c_1 \le \hat{c}(F_2, \Delta x + \Delta y),$$

the manager refrains from asset substitution to ensure the efficient contract, and the associated rents $\rho(a^{L^*}(\Delta x), \Delta x) > 0$; otherwise the shareholders will choose the under-investment contract and reduce the manager's rents to zero. For these values of c_1, therefore, the second-period debt payment induces efficient investment and compensation decisions. This result is stated formally as Proposition 1.

Proposition 1. *For first-period cash flow realizations satisfying $\hat{c}(F_2, \Delta x) \le c_1 \le \hat{c}(F_2, \Delta x + \Delta y)$, the second-period debt level F_2 deters asset substitution in the first period and produces the value-maximizing incentive contract in the second period. For lower realizations, $c_1 < \hat{c}(F_2, \Delta x)$, the shareholders pursue under-investment, a^L=0, and for higher realizations, $c_1 > \hat{c}\ (F_2, \Delta x + \Delta y)$, the manager pursues asset substitution, Δy.*

Proposition 1 illustrates that, for a particular range of first-period cash flows, the second-period debt payment F_2 can control asset substitution without causing under-investment. The optimal capital structure exploits this benefit, while accounting for the incentives associated with the remaining realizations of c_1, as seen next.

2. Optimal Capital Structure

The optimal capital structure in our model minimizes the expected cost of the asset substitution and under-investment problems developed above. As seen in Proposition 1, there is a set of cash flows for which the second-period debt payment can deter both asset substitution and under-investment at no cost, i.e., $\hat{c}(F_2, \Delta x) \leq c_1 \leq \hat{c}(F_2, \Delta x + \Delta y)$. Since $\hat{c}$ depends on F_2 as in Equation (4), the $t = 0$ debt choice determines which realizations fall within this set. The optimal debt choice depends on the size of this set relative to the set of possible realizations, i.e., on the size of $\phi \equiv \hat{c}(F_2, \Delta x + \Delta y) - \hat{c}(F_2, \Delta x)$ relative to $\bar{c} - \underline{c}$ (the boundaries of the uniform distribution $c_1 \sim \text{unif}[\underline{c}, \bar{c}]$). We focus on the case where $\bar{c} - \underline{c} > \phi$, so that it is not possible to satisfy the condition in Proposition 1 for all realizations of c_1—i.e., the case where asset substitution induces under-investment only for a subset of first-period performance levels.[9]

With $\bar{c} - \underline{c} > \phi$, the debt payment F_2 cannot induce value-maximizing investment and compensation decisions for all realizations of c_1 because, if the firm sets F_2 sufficiently low to ensure the efficient incentive contract for all possible realizations of c_1, such that $\hat{c}(F_2, \Delta x) = \underline{c}$, the manager will invest opportunistically when the highest realizations obtain, i.e., when $c_1 > \underline{c} + \phi$, as in Proposition 1. Alternatively, if the firm sets F_2 sufficiently high to avoid asset substitution for all c_1, i.e., $\hat{c}(F_2, \Delta x + \Delta y) = \bar{c}$, the shareholders will offer the under-investment contract when the lowest realizations obtain, i.e., when $c_1 < \bar{c} - \phi$. The optimal choice of F_2 therefore depends on the relative costs of asset substitution and under-investment.

The cost of asset substitution in our model is given by the increase in contracting costs under the efficient compensation contract due to the greater information asymmetry as in lemma 1, i.e., by

$$\kappa(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y) - \kappa(a^{L^*}(\Delta x), \Delta x).$$

Similarly, the cost of under-investment is the increase in contracting costs that results when the shareholders offer the inefficient compensation contract of lemma 3 rather than the efficient contract characterized by (1), i.e. by

$$\kappa(0, \Delta x) - \kappa(a^{L^*}(\Delta x), \Delta x).$$

[9] If $\bar{c} - \underline{c} \leq \phi$, an F2 satisfying $\underline{c} + x^L + y^L + a^{FB} - A(a^{FB}) - 2K(\Delta x + \Delta y) \leq F2 \leq \underline{c} + x^L + y^L + a^{FB} - A(a^{FB}) - 2K(\Delta x)$ produces efficient incentives for all realizations of c1. Note that the optimal F2 below satisfies this condition (i.e. the optimal choice of F2 when $\bar{c} - \underline{c} > \phi$ is also an optimal choice of F2 when $\bar{c} - \underline{c} \leq \phi$).

As in lemma 3, the under-investment contract allows the shareholders to induce the first best action when the high state is realized without paying managerial rents, for either $\Delta\varepsilon = \Delta x$ or $\Delta\varepsilon = \Delta x + \Delta y$. Thus, $\kappa(0, \Delta x) = \kappa(0, \Delta x + \Delta y)$, and since

$$\kappa(0, \Delta x) = \kappa(0, \Delta x + \Delta y) > \kappa(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y),$$

asset substitution is less costly than under-investment in our model. That is, the distortion in managerial actions due to the additional information advantage Δy is less costly than the distortion in the shareholders' compensation design problem due to the complete disregard for managerial actions in the low state, making the opportunistic managerial investment choice less costly than bondholder wealth expropriation in our model.

Owing to the relatively high cost of under-investment, the optimal capital structure specifies a relatively low debt payment that avoids under-investment despite opportunistic asset substitution for the highest realizations of c_1. This result is presented formally as Proposition 2 (proof in the appendix).

Proposition 2. *The optimal debt level allows either under-investment for the lowest realizations of c_1, or asset substitution for the highest realizations. Since asset substitution is less costly, the optimal debt level is set sufficiently low to avoid under-investment. Specifically, the optimal debt level is chosen such that* $\hat{c}(F_2, \Delta x) = \underline{c}$ *, which yields* $F_2 = \underline{c} + x^L + a^{FB} - A(a^{FB}) - 2\kappa (a^{L^*}(\Delta x), \Delta x)$.

The optimal debt level in Proposition 2 is designed to make the shareholders indifferent between the efficient and the under-investment compensation contracts when the lowest value of c_1 is realized and the manager makes the efficient investment choice. At the optimum, therefore, the debt level is risk-less (made with certainty). The debt level optimally increases with the lower bound of the cash flow distribution $\underline{c}$ and with the low investment payoff x^L, since both increase the shareholders' residual in the low state and therefore the incentive to offer the efficient compensation contract. The debt level is particularly (twice as) sensitive to the contracting costs, $\kappa(a^{L^*}(\Delta x), \Delta x)$, because each component reduces the shareholders' residual under the efficient contract—a lower value of a^{L^*} reduces efficiency and therefore the residual in the low state, and a higher managerial rent reduces the residual in the high state.

The results in Proposition 2 illustrate that capital structure can increase value in our model. If the firm issues no debt, the manager pursues asset substitution for *all* realizations of c_1, as in lemma 2. In contrast, the optimal debt level in Proposition 2 deters asset substitution for $\underline{c} \leq c_1 \leq +\phi$. Higher debt levels are suboptimal because they substitute under-investment for asset substitution, and under-investment is more detrimental to firm value. In short, the optimal capital structure trades off the manager–owner and shareholder–bondholder agency conflicts to maximize firm value.

We relate the analysis to the empirical literature and discuss some interesting extensions, in the next section.

3. Empirical Implications and Extensions

This section presents the empirical implications of our analysis and discusses extensions relating to contractible variables and security design. The empirical implications address the relationships between leverage, investment opportunities, compensation, and the firm's cash flow position.

Investment opportunities are a major determinant of the firm's optimal leverage (defined as the market value of debt divided by the market value of the firm). As discussed above, investment opportunities are characterized by the mean and dispersion of their payoffs. A higher mean corresponds to a higher value of Ex (since, by definition, $Ey = 0$). Holding dispersion constant, a higher Ex implies a higher payoff x^i in each state, so that greater leverage is needed to deter opportunistic asset substitution. In contrast, a mean preserving increase in dispersion $\Delta x = x^H - x^L$ implies a higher payoff in the high state and a *lower* payoff in the low state. This decreases the debt/value ratio for two reasons. First, the debt level decreases with the payoff in the low state but is insensitive to the payoff in the high state, whereas firm value incorporates the change in both payoffs. Second, dispersion increases the manager's information advantage and therefore his rents under the efficient compensation scheme. This exacerbates the shareholders' incentive to offer the expropriating scheme and avoid the rents at the bondholders' expense. To offset this incentive, the firm further reduces its leverage. These results are presented formally in Proposition 3 (proven in the appendix).

Proposition 3. *The firm's $t = 0$ leverage increases with the expected payoff of the investment opportunity, Ex, and decreases with the dispersion in payoffs, Δx.*

Empirical proxies for investment opportunities do not distinguish the mean and dispersion of investment payoffs. The most common empirical proxy is market-to-book, which incorporates simultaneous variation in Ex and Δx. To illustrate the relationship between leverage and market-to-book, therefore, we consider a simultaneous increase in mean and dispersion—specifically, we consider increasing the scale of the investment opportunity, which increases the mean and dispersion in proportion. As suggested by Proposition 3, the effects on leverage and market-to-book depend on the increase in the mean relative to the increase in dispersion and therefore on the magnitude of Ex relative to Δx. Increasing the scale of the worst opportunities (i.e., those with the smallest Ex relative to Δx) decreases firm value, because the additional contracting costs arising from the increase in dispersion outweigh the increase in the expected payoff. Similarly, leverage decreases because the dispersion effect in Proposition 3 dominates. This produces a positive relationship between leverage and market-to-book for firms with the worst (value-decreasing) investment opportunities. For firms with value-increasing opportunities (i.e., those with higher values of Ex relative to Δx), market-to-book increases with the scale of the investment. The effect on leverage, however, depends further on the relative value of Ex. In particular, for values of Ex where the investment opportunity moderately increases value ("normal" investment opportunities), increasing the investment scale decreases leverage because the debt level is highly sensitive to the additional contracting costs. This produces a negative correlation between leverage and market-to-book. For the highest values of Ex relative to Δx (i.e., exceptional opportunities that are highly successful even in the low state), the mean effect in Proposition 3 dominates, so that leverage increases, producing a positive correlation between leverage and market-to-book. The model therefore implies a non-monotonic relationship between leverage and market-to-book, as presented formally in Proposition 4.

Proposition 4. *Increasing the scale of the investment opportunity x produces a negative relationship between leverage and market-to-book for firms with normal investment opportunities, and a positive relation between leverage and market-to-book for firms with exceptionally bad (value-decreasing) or exceptionally good (certain success) opportunities.*

The negative relationship for "normal" opportunities—i.e., opportunities that neither decrease value nor are certain to be highly successful—is consistent with the negative relationship between leverage and market-to-book found by Titman and Wessels (1988), Barclay, Smith, and Watts (1995), and Rajan and Zingales (1995). In addition, since exceptionally good (bad) opportunities are associated with exceptionally high (low) market-to-book ratios, Proposition 4 suggests that a closer examination may reveal non-monotonicity in the tails of the market-to-book distribution, such as that detected in the lower tail by Rajan and Zingales (1995, note 32).

Next, consider the effect of investment opportunities on pay-for-performance, defined here as the difference between the optimal compensation in the high and low states, $w^{\mathrm{H}} - w^{\mathrm{L}}$. The effect is seen from the optimal compensation levels implied by Equation (1),

$$w^{\mathrm{H}} = A(a^{\mathrm{FB}}) + \rho(a^{\mathrm{L}^*}(\Delta x))$$
$$= A(a^{\mathrm{FB}}) + A(a^{\mathrm{L}^*}(\Delta x)) - A(a^{\mathrm{L}^*}(\Delta x) - \Delta x) \text{ and } w^{\mathrm{L}} = A(a^{\mathrm{L}^*}(\Delta x)),$$

which yield pay-for-performance of $w^{\mathrm{H}} - w^{\mathrm{L}} = A(a^{\mathrm{FB}}) - A(a^{\mathrm{L}^*}(\Delta x) - \Delta x)$. Additional investment opportunities increase Δx and therefore pay-for-performance, since

$$\frac{d(w^{\mathrm{H}} - w^{\mathrm{L}})}{d\Delta x} = -A'\left(\frac{\partial a^{\mathrm{L}^*}}{\partial \Delta x} - 1\right) > 0,$$

where the sign follows because the optimal value of a^L decreases in Δx as above. Intuitively, investment opportunities increase the manager's information advantage, so that higher compensation must be offered to deter mimicry in the high state (i.e., greater high state compensation is required to satisfy the incentive compatibility constraint). The increase in pay-for-performance is driven solely by the increase in dispersion and therefore results for all opportunities. For value-increasing opportunities, therefore, the model predicts a positive relationship between pay-for-performance and market-to-book, consistent with Smith and Watts (1992), Gaver and Gaver (1993), Kole (1997), and Bryan, Hwang, and Lilien (2000). In addition, when combined with the relationship between market-to-book and leverage, pay-for-performance decreases with leverage for all but very high market-to-book ratios, consistent with the negative relationship found on average by Ortiz-Molina (2004).

Our analysis also predicts that leverage is related to the firm's cash flow position, as defined by both the $t = 0$ distribution and the $t = 1$ realization of the cash flows from assets in place, c_1. The mean and variance of the uniform distribution for c_1 both affect the debt level chosen at $t = 0$, since both affect the lower bound $\underline{c}$, which appears directly in the expression for the debt level in Proposition 2. An increase in the mean shifts the cash flow distribution right, increasing $\underline{c}$. This increases the potential for opportunistic asset substitution, so that the debt (and leverage) level optimally increases with expected cash flow.[10] In contrast, a mean preserving spread decreases $\underline{c}$, increasing the potential for under-investment, so that leverage decreases with cash flow volatility (these results are shown formally in the appendix). The negative relationship between

[10] To our knowledge, the positive relationship between leverage and mean cash flows has not been directly tested. To the extent that price proxies for expected cash flows, however, the relationship is consistent with the positive announcement effects of leverage increasing transactions [Smith (1986)]. Similarly, to the extent that industry classification proxies for expected cash flow, it is consistent with the finding of Long and Malitz (1985) that firms in mature industries (cash cows) use more debt. A more direct examination requires a mean cash flow variable, perhaps similar to the volatility variable in Bradley, Jarrell, and Kim (1984).

leverage and volatility is consistent with Bradley, Jarrell, and Kim's (1984) finding that cash flow volatility (measured by the standard deviation of differenced earnings before interest, taxes, depreciation, and amortization, EBITDA) reduces leverage.

The $t = 1$ realization of cash flows also affects the firm's leverage, because higher realizations of c_1 increase firm value without changing the debt level. The debt level is insensitive to c_1 for two reasons. First, as in Proposition 1, the pre-set debt level dissuades asset substitution for all realizations satisfying $\underline{c} \leq c_1 < \underline{c} + \phi$, because the discrete increase in variance would make the debt payment risky (causing the shareholders to offer the rent-minimizing compensation contract). Second, debt adjustment is costly, reflecting our underlying assumption that debt contracts are more costly to renegotiate than compensation contracts, so that debt is not adjusted to dissuade opportunistic investment when $\underline{c} + \phi < c_1 \leq \bar{c}$. The constant $t = 1$ debt level implies that higher realizations of c_1 increase firm value without affecting the value of debt, decreasing the $t = 1$ debt/value ratio.[11]

The negative effect of realized cash flow on leverage is consistent with the negative relationship between leverage and profitability (EBITDA) found by Barclay, Smith, and Watts (1995), Rajan and Zingales (1995), Fama and French (2002), and Johnson (2003). These studies, however, interpret this finding as evidence against free cash flow (or static trade-off) theories of capital structure, in favor of the pecking order hypothesis. Our analysis is more consistent with the free cash flow theories [Jensen (1986), Zwiebel (1996)], in that *ex ante* debt commitments deter managerial opportunism. While the optimal commitment is based on expected cash flows, periods of non-adjustment produce the negative relationship found in the data.[12] Moreover, this relationship arises from the positive effect of profitability on firm value, rather than the negative effect of profitability on debt financing predicted by the pecking order hypothesis. Together, therefore, our analysis helps reconcile the negative leverage–profitability relationship, with the finding of Welch (2004) that this relationship is driven by changes in firm value rather than debt, and the recent finding of Leary and Roberts (2004) that specific financing choices deviate from the pecking order.

Finally, our analysis can be directly extended to examine the effects of contractible proxies for the firm's cash flows and the firm's optimal

[11] There is a discontinuity in the relationship between firm value and realized cash flow in our model at $c_1 = \hat{c}(F_2, \Delta x + \Delta y) = \underline{c} + \phi$, where an increase in c_1 induces asset substitution and decreases value by ϕ. Overall, value is positively related to c_1 since c_1 increases value one-for-one ($dv_1/dc_1 = 1$) at all other c_1 and $\bar{c} - \underline{c} > \phi$.

[12] The negative relationship here is consistent with the simulation results of Strebulaev (2004), which illustrate that even relatively small adjustment costs can produce leverage–profitability relationship observed in the data.

securities. If cash flows are directly contractible in our model, the firm can design its capital structure to control both the under-investment and asset substitution problems without cost (i.e., so that total contracting costs remain $\kappa(a^{L^*}(\Delta x), \Delta x)$ for all c_1). In particular, the debt contract can specify a cash flow-contingent repayment, $F_2(c_1)$, where

$$F_2(c_1) - x^L - a^{FB} + A(a^{FB}) + 2\kappa(a^{L^*}(\Delta x), \Delta x) \leq c_1 \leq F_2(c_1) - x^L - y^L - a^{FB} + A(a^{FB}) + 2\kappa(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y).$$

This contingent repayment deters asset substitution and induces the value-maximizing compensation contract for all realizations of c_1, just as in Proposition 1. Since the best that can be done in our model is to ensure the low contracting cost $\kappa(a^{L^*}(\Delta x), \Delta x)$, this debt contract would be an optimal security.

In practice, however, it is prohibitively costly to contract on actual cash flows, and contractible proxies for c_1, such as accounting reports, are employed. The effects of including such proxies in our analysis depend on their reliability. For example, if accounting reports are perfect and costless proxies for c_1, the optimal security specifies a debt payment contingent on accounting reports as in the preceding paragraph (since c_1 effectively becomes contractible). Alternatively, if accounting reports are imperfect but still informative, accounting covenants can be employed to reduce the cost of the incentive problems that remain in Proposition 2. For example, an accounting covenant that is violated in the first period can provide bondholders with the power to deter expropriation. The benefit of accounting covenants can then be balanced against the costs of unreliability, such as the unnecessary violations that result from accounting imperfections. Finally, if accounting values are completely unreliable (so that c_1 is effectively non-contractible as above), the standard debt contract considered above is an optimal security.

4. Conclusions

The literature studying corporate incentive conflicts has typically focused on shareholder–bondholder or manager–owner conflicts, paying relatively little attention to the interactions between the two.[13] Our article presents a theory of capital structure based on these interactions, which are derived from the primitive objectives of managers, shareholders, and bondholders. In particular, we show that, when debt contracts are more costly to renegotiate than managerial compensation contracts, the agency conflict between shareholders and bondholders affects the shareholders'

[13] See, for example, the conclusions of Allen and Winton (1995).

compensation design problem and the ability to discipline managerial opportunism.

Our analysis yields many interesting predictions, including that the shareholder–bondholder conflict is the main concern when the firm is performing poorly and the manager–owner conflict is the main concern when the firm is doing well and that relatively low debt levels minimize the costs of the potential agency conflicts. The value-maximizing debt and compensation contracts provide additional insight into the empirical literature studying the interactions between capital structure, managerial compensation, investment opportunities and cash flows.

There remain significant directions for future research. For example, we focus on optimal capital structure in a setting where compensation is designed to maximize shareholder wealth, implicitly assuming a well functioning board. Another possibility is that managers influence the board (and therefore capital structure and compensation decisions). With moderate managerial influence, the primitive objectives and information structure here should produce similar interactions between capital structure and compensation design. In the more extreme case, however, where the manager effectively controls the board (including the compensation committee), debt and compensation contracts would be designed to maximize managerial rents subject to the possibility of external discipline (e.g. a hostile takeover or bankruptcy). This should produce results closer to those relying on debt to discipline managers while abstracting from the role of compensation contracts, such as Grossman and Hart (1982), Jensen (1986) and Zweibel (1996).

Appendix

Proof of Proposition 2. Define $c^x \equiv \hat{c}(F_2, \Delta x)$ and $c^y \equiv \hat{c}(F_2, \Delta x + \Delta y)$. When $\bar{c} - \underline{c} > c^y - c^x \equiv \phi$, there are realizations of c_1 that are less than c^x or greater than c^y. From Proposition 1, the former leads to under-investment at additional cost of $\mathrm{UI} \equiv \kappa(0, \Delta x) - \kappa(a^{\mathrm{L}^*}(\Delta x), \Delta x)$, and the latter leads to asset substitution at additional cost of $\mathrm{AS} \equiv \kappa(a^{\mathrm{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y) - \kappa(a^{\mathrm{L}^*}(\Delta x), \Delta x)$. Letting $g(c_1)$ represent the density function for the uniform distribution of c_1, the expected cost of the under-investment and asset substitution problems when $\bar{c} - \underline{c} > \phi$ is therefore

$$\mathrm{EC}(F_2) = \int_{\underline{c}}^{c^x} \mathrm{UI}g(c_1)dc_1 + \int_{c^x}^{c^y} 0g(c_1)dc_1 + \int_{c^y}^{\bar{c}} \mathrm{AS}g(c_1)dc_1.$$

Since $\partial c^x/\partial F_2 = \partial c^y/\partial F_2 = 1$ as in (4), $\partial \mathrm{EC}/\partial F_2 = \mathrm{UI}g(c^x) - \mathrm{AS}g(c^y)$. Since $\kappa(0, \Delta x) = \kappa(0, \Delta x + \Delta y)$,

$$\mathrm{UI} - \mathrm{AS} = \kappa(0, \Delta x + \Delta y) - \kappa(a^{\mathrm{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y) > 0.$$

Thus, the expected cost increases in F_2 for $g(c^x) > 0$, and F_2 is optimally reduced until $g(c^x) = \underline{c}$, or $c^x = F_2 - x^{\mathrm{L}} - a^{\mathrm{FB}} + A(a^{\mathrm{FB}}) + 2\kappa(a^{\mathrm{L}^*}(\Delta x), \Delta x) = \underline{c}$ and $F_2 = \underline{c} + x^{\mathrm{L}} + a^{\mathrm{FB}} - A(a^{\mathrm{FB}}) - 2\kappa(a^{\mathrm{L}^*}(\Delta x), \Delta x)$. ■

Proof of Proposition 3. Optimal leverage is given by the $t = 0$ debt/value ratio, $L_0 = F_0/v_0$. The $t = 0$ value of debt is simply F_2, since the interest rate is zero and, at the optimum, F_2 is risk-less. The $t = 0$ market value is the expectation of $t = 1$ value in (2), which is conditional on c_1. Since $c_1 \sim \text{unif}[\underline{c}, \bar{c}]$ and asset substitution occurs for $\underline{c} + \phi < c_1 \leq \bar{c}$, market value is

$$\begin{aligned} v_0(\cdot) &= \int_{\underline{c}}^{\underline{c}+\varphi} [(c_1 + Ex + a^{\text{FB}} - A(a^{\text{FB}}) - \kappa(a^{\text{L}^*}(\Delta x), \Delta x))/\Delta c] dc_1 \\ &\quad + \int_{\underline{c}+\phi}^{\bar{c}} [(c_1 + Ex + a^{\text{FB}} - A(a^{\text{FB}}) - \kappa(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y))/\Delta c] dc_1 \\ &= Ec_1 + Ex + a^{\text{FB}} - A(a^{\text{FB}}) - E\kappa(\cdot), \end{aligned}$$

where $\Delta c \equiv \bar{c} - \underline{c}$ and

$$E\kappa(\cdot) \equiv (\phi/\Delta c)\kappa(a^{\text{L}^*}(\Delta x), \Delta x) + (1 - \phi/\Delta c)\kappa(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y)$$

is the expected contracting cost at $t = 0$.

(i) A *ceteris paribus* increase in Ex implies $dEx = dx^{\text{L}}$ so that $dF_0 = dv_0 = dEx$. Since $F_0 < v_0$, this implies $dL_0/dEx > 0$.

(ii) A *ceteris paribus* increase in Δx yields

$$\frac{dF_0}{d\Delta x} = \frac{dx^{\text{L}}}{d\Delta x} - \frac{2d\kappa(a^{\text{L}^*}(\Delta x), \Delta x)}{d\Delta x} < \frac{-2d\kappa(a^{\text{L}^*}(\Delta x), \Delta x)}{d\Delta x}$$

and

$$\begin{aligned} \frac{dv_0}{d\Delta x} &= -\left(\frac{\varphi}{\Delta c}\right)\frac{d\kappa(a^{\text{L}^*}(\Delta x), \Delta x}{d\Delta x} - \left(1 - \frac{\varphi}{\Delta c}\right)\frac{d\kappa(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y)}{d\Delta x} \\ &\quad + \left(\frac{d\phi}{d\Delta x}\right)\frac{(\kappa(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y) - \kappa(a^{\text{L}^*}(\Delta x), \Delta x))}{\Delta c} \end{aligned}$$

Now $0 < \varphi/\Delta c$ and $d\kappa\left(a^{\text{L}*}(\Delta x + \Delta y), \Delta x + \Delta y\right)/d\Delta y < d\kappa(a^{\text{L}^*}(\Delta x), \Delta x)/d\Delta x$ imply $-(\phi/\Delta c)d\kappa(a^{\text{L}^*}(\Delta x), \Delta x)/d\Delta x - (1 - \phi/\Delta c)d\kappa(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y/d\Delta x > -d\kappa(a^{\text{L}^*}(\Delta x),$ $\Delta x/d\Delta x$.

In addition,

$$\left(\frac{d\phi}{d\Delta x}\right)\frac{\left(\kappa\left(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y\right) - \kappa\left(a^{\text{L}^*}(\Delta x), \Delta x\right)\right)}{\Delta c} > \frac{-d\kappa(a^{\text{L}^*}(\Delta x), \Delta x}{d\Delta x}$$

since

$$A'(a^{\text{L}^*}(\Delta x + \Delta y) - \Delta x + \Delta y) = .5k(1/k - 2\Delta x - 2\Delta y) = .5(1 - 2k\Delta x + d\phi/d\Delta x) > 0$$

implies

$$\frac{d\phi}{d\Delta x} > -(1 - 2k\Delta x) = -2\left(d\kappa\left(a^{\text{L}^*}(\Delta x), \Delta x\right)/d\Delta x\right) \tag{A1}$$

and

$$\begin{aligned} &\left(\kappa\left(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y\right) - \kappa\left(a^{\text{L}^*}(\Delta x), \Delta x\right)\right)/\Delta c \\ &\quad < .5\left(2\left(\kappa\left(a^{\text{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y\right) - \kappa\left(a^{\text{L}^*}(\Delta x), \Delta x\right)\right)\right)/\Delta c < .5 \end{aligned}$$

(since $y^{\mathrm{L}} < 0$). Thus, $dv_0/d\Delta x > -2d\kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right)/d\Delta x > dF/d\Delta x$ and, since $v_0 > F_0$, L_0 decreases with Δx (the absolute value of the percentage change in F_2 exceeds that in v_0). ■

Proof of Proposition 4. Increasing the scale of the investment by $\lambda > 1$ yields $\lambda x \in \left\{\lambda x^{\mathrm{L}}, \lambda x^{\mathrm{H}}\right\}$, increasing the mean to $E[\lambda x] = .5\lambda x^{\mathrm{L}} + .5\lambda x^{\mathrm{H}} = \lambda Ex$, and the dispersion to $\lambda\Delta x \equiv \lambda x^{\mathrm{H}} - \lambda x^{\mathrm{L}}$. The optimal debt level from Proposition 2 becomes

$$F_0 = F_2(\lambda x, \cdot) = \underline{c} + \lambda x^{\mathrm{L}} + a^{\mathrm{FB}} - A\left(a^{\mathrm{FB}}\right) - 2\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right),$$

so that

$$\Delta F_0 = (\lambda - 1)x^{\mathrm{L}} - 2\left(\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right) - \kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right)\right).$$

Similarly, firm value becomes

$$v_0(2x,\cdot) = Ec + \lambda Ex + a^{\mathrm{FB}} - A\left(a^{\mathrm{FB}}\right) - E\kappa(\lambda\Delta x, \cdot)$$

so that

$$\Delta \nu_0 = (\lambda - 1)Ex - (E\kappa(\lambda\Delta x, \cdot) - E\kappa(\Delta x, \cdot)),$$

where

$$E\kappa(\lambda x, \cdot) \equiv (\phi(\lambda x)/\Delta c)\kappa(a^{\mathrm{L}^*}(\lambda\Delta x), 2\Delta x) + (1 - \phi(\lambda x)/\Delta c)\kappa(a^{\mathrm{L}^*}(\lambda\Delta x + \Delta y), \lambda\Delta x + \Delta y)$$

Now $\Delta F_0 < \Delta v_0$, since $x^{\mathrm{L}} < Ex$ and

$$\begin{aligned} &E\kappa(\lambda\Delta x, \cdot) - E\kappa(\Delta x, \cdot) - \left(\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right) - \kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right)\right) \\ &\quad = (1 - \phi(\lambda x)/\Delta c)\left(\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x + \Delta y), \lambda\Delta x + \Delta y\right) - \kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right)\right) \\ &\quad -(1 - \phi(x)/\Delta c)\left(\kappa\left(a^{\mathrm{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y\right) - \kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right)\right) < 0 \end{aligned}$$

which follows because κ is concave in Δx (i.e. $d^2\kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right)/d\Delta x^2 = -.5A'' < 0$), so that

$$\begin{aligned} &\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x + \Delta y), \lambda\Delta x + \Delta y\right) - \kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right) \\ &< \kappa\left(a^{\mathrm{L}^*}(\Delta x + \Delta y), \Delta x + \Delta y\right) - \kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right) \end{aligned},$$

and because ϕ is decreasing in Δx as in (A1), so that $\phi(\lambda x) < \phi(x)$.

Thus, for $0 < Ex < (E\kappa(\lambda\Delta x, \cdot) - E\kappa(\Delta x, \cdot))/(\lambda - 1)$, we have $\Delta F_0 < \Delta v_0 < 0$ which implies that both leverage and market-to-book decrease.

For $E\kappa(\lambda\Delta x, \cdot) - E\kappa(\Delta x, \cdot)(\lambda - 1) < Ex < \left(\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right) - \kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right) + .5x^{\mathrm{H}}\right)/(\lambda - 1)$, we have $\Delta F_0 < 0 < \Delta v_0$ so leverage decreases while market-to-book increases.

For $Ex > \left(\kappa\left(a^{\mathrm{L}^*}(\lambda\Delta x), \lambda\Delta x\right) - \kappa\left(a^{\mathrm{L}^*}(\Delta x), \Delta x\right) + .5x^{\mathrm{H}}\right)/(\lambda - 1)$, we have $\Delta v_0 > \Delta F_0 > 0$ so that the effect on leverage depends on the percentage changes. For the smallest Ex in this range, ΔF_0 is very small so that the percentage change in value dominates and leverage decreases. For larger Ex, the mean effect in Proposition 3 dominates, so that leverage increases with market-to-book. ■

Proof that a *ceteris paribus* increase in the mean $\mathbf{Ec_1}$ increases leverage. An increase in Ec_1 holding Δc constant increases c by the same amount, so that F_2 and v_0 increase by the same amount. Since $v_0 > F_2$, the percentage change in F_2 is greater so that L_0 increases. ■

Proof that a *ceteris paribus* increase in $\boldsymbol{\Delta c \equiv c - \underline{c}}$ decreases leverage. A mean preserving increase in Δc implies $d\overline{c}/d\Delta c = -d\underline{c}/d\Delta c = .5$, so that

$$dF/d\Delta c = (dF/d\underline{c})(d\underline{c}/d\Delta c) = 1(-.5) = -.5.$$

Substituting $\phi = 2\big(\kappa\big(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y\big) - \kappa\big(a^{L^*}(\Delta x), \Delta x\big)\big) - y^{\mathrm{L}}$ into v_0 yields

$$v_0(\cdot) = Ex + a^{\mathrm{FB}} - A\big(a^{\mathrm{FB}}\big) + Ec - \kappa\big(a^{L^*}(\Delta x + \Delta y), \Delta x + \Delta y\big) + (\phi/\Delta c)\big(\phi + y^{\mathrm{L}}\big)/2$$

so that

$$dv_0/d\Delta c = -\big(\phi/\Delta c^2\big)\big(\phi + y^L\big)/2 = -.5\big(\phi^2 + \phi y^{\mathrm{L}}\big)/\Delta c^2 > -.5$$

since $\phi < \Delta c$ and $y^{\mathrm{L}} < 0$. Thus, the absolute value of the percentage change in F_2 exceeds that in v_0, and leverage increases. ■

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