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OPERATIONAL DECISIONS, CAPITAL STRUCTURE, AND MANAGERIAL COMPENSATION: A NEWS VENDOR PERSPECTIVE

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While firm growth critically depends on financing ability and access to external capital, the operations management and engineering economics literature seldom considers the effects of financial constraints on the firms' operational decisions. Another critical assumption in traditional operations models is that corporate managers always act in the firm owners' best interests. Managers are, however, agents of the owners of the company, whose interests are often not aligned with those of equity holders or debt holders; hence, managers may make major decisions that are suboptimal from the firm owners' point of view. This article builds on a news vendor model to make optimal production decisions in the presence of financial constraints and managerial incentives. We explore the relationship between operating conditions and financial leverage and observe that financial leverage can increase as margins reach either low or high extremes. We also provide some empirical support for this observation. We further extend our model to consider the effects of agency costs on the firm's production decision and debt choice by including performance-based bonuses in the manager's compensation. Our analyses show how managerial incentives may drive a manager to deviate from firm-optimal decisions and that low-margin producers face significant risk from this agency cost while high-margin producers face relatively low risk in using such compensation.

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INTRODUCTION

The operations management and engineering economics literature has largely ignored corporate financing decisions on the assumption that a firm's optimal inventory level or production decisions can be fully financed by internal capital or in the capital market without affecting the operational decision. In reality, firms face financial constraints; their development heavily depends on debt issues, bank loans, venture capital, or other external equity investments that may have a variety of costs due, for example, to direct sources such as fees and indirect costs such as financial distress. Another critical assumption in traditional models is that the firm's manager always acts in the shareholders's best interest. Corporate managers may, however, deviate from value-maximizing operational and financing decisions and pursue their own self-interests; hence, ignoring the effects of financial constraints and agency costs creates a gap between theoretical research and industrial reality.

In this article, we build on previous work (Xu and Birge 2004) that studied the interactive mechanism between a firm's production decision and its capital structure choice. We will review that analysis and consider the effect of different operating conditions on capital structure, including some empirical support of our predicted relationship between production margin and market leverage. We will then extend our model to incorporate the interest conflict between corporate managers and owners. Our results show the relevance of these agency effects for traditional engineering economic decisions, such as the scale of production operations. We believe that these results are significant and relative enough to warrant inclusion in industrial engineering curricula.

Although few researchers in the operations management community have incorporated financial considerations into inventory or production decisions, an extensive literature considers questions in inventory control, capacity expansion, and supply chain management. The vast majority of models for these decisions assume that the firm can always finance its optimal production or inventory level without considering financial constraints. In reality, many firms face financial constraints and critically depend on external capital. Debt, for example, is commonplace across all firms. According to data on all publicly held U.S. firms (Damodaran 2004), the average debt-to–market value leverage ratio is 27.28%, while the debt-to–book value leverage ratio is even higher at 52.53% of total company value. The Federal Reserve Bank (2004) also reports that the total amount of net bonds issued by domestic corporations was $608 billion in 2003, and the total amount of business loans of all commercial banks was $880 billion by June 2004.

While financial economists have long considered the effects of capital structure on firm valuation, they usually assume that investment or production decisions are exogenously determined. The seminal work by Modigliani and Miller (MM) (1958) provided some justification by showing that a firm's value is independent of its capital structure in a perfect capital market. MM theory directly leads to the separation between a firm's operational and financial decisions. Due to market imperfections, such as taxes, agency costs, and asymmetric information, however, the choice of a firm's capital structure may in fact be closely related to its production decisions.

Three major theories address market imperfections in the capital structure category. According to Modigliani and Miller's traditional *trade-off* model (1963), the chief benefit of debt is the tax advantage of interest deductibility, while the primary costs are those associated with financial distress and personal tax expenses. Jensen and Meckling (1976) initiated the *agency cost* approach and identified two types of conflicts: conflicts between shareholders and managers, because managers only hold part of the residual claim, and conflicts between debt holders and equity holders because the debt contract gives equity holders an incentive to invest suboptimally. Myers and Majluf (1984) also provide a *pecking order* theory of capital structure choice created by the presence of information asymmetries between the firm and its potential financiers. In this theory, external funds are less desirable because informational asymmetries imply that external funds are undervalued in relation to the degree of asymmetry. We refer to Harris and Raviv (1991) for a general review of these theories of capital structure.

More recently, several studies in the operations management community have addressed the interface between operations management and finance. Among these analyses, Lederer and Singhal (1994) consider joint financing and technology choices when making manufacturing investments and show that considerable value can be added to investments through financing decisions. Birge and Zhang (1999) seek to use option theory to introduce risk into inventory management. In another example, Birge (2000) adapts contingent claim pricing methods to incorporate risk into a capacity planning model. Other papers include Babich and Sobel (2004), which examines the relationship between operational decisions and the timing of an IPO for a startup firm, and Buzacott and Zhang (2004), which attempts to incorporate asset-based financing into production decisions. These studies do not, however, consider optimal capital structure or discuss the cost of debt.

In a previous paper (Xu and Birge 2004), we described a simplified model of production and financing decisions based on an extension of the news vendor model. This model incorporates the tax shield advantages of debt and the costs of bankruptcy in an integrated framework for decision-making. In this article, we explore additional characteristics of that model in response to changing parameters and show how capital structure can vary as a function of production margin. We also provide some empirical support for an observation that market leverage may have a U shape as a function of production margin, where leverage increases both as margins decline to zero and rise to one.

Many operations management and finance models, including our previous analysis, assume that corporate managers always act in the shareholders' best interest. For a given compensation contract, however, managers have incentive to take corporate actions that maximize their individual utility. These decisions may not be consistent with firm-value maximization. The second part of this article proceeds to consider the effects of agency costs, in particular, the interest misalignment between shareholders and managers, on the firm's optimal production and financial decisions.

The interest conflicts between principal and agent play an important role in corporate finance. Jensen and Meckling (JM) (1976) challenge the MM proposition that investment decisions are independent of capital structure. They use the agency theory framework to study the effect on investment and financing decisions of conflicts of interest among managers, bond holders, and stockholders. Many others in the finance literature have followed JM in investigating such effects of agency costs.

Recognizing operations management as a natural area for application of the principal-agent paradigm, agency models have emerged in the *marketing-operations interface* area. Assuming the marketing and manufacturing managers of the firm act in their self-interest, Porteus and Whang (1991) seek incentive structures that maximize the residual return to the owner of the firm. Plambeck and Zenios (2000) develop a dynamic principal-agent model and identify an incentive-payment scheme that aligns the objectives of the owner and manager. Chen (2000, 2005) considers the problem of sales force compensation by considering the impact of sales force behavior on a firm's production and inventory systems. Overall, this line of literature mainly focuses on the marketing-operations interface without considering the effects of managerial compensation on the firm's production and financial decisions.

To analyze the effects of agency cost on the firm's decisions, we extend our model by considering the structure of managerial compensation. With the assumption that the manager acts on his own behalf given the compensation plan in place, we show that the manager prefers aggressive investment decisions and conservative debt policy. A manager's self-interest maximization causes his actions to deviate from firm-optimal decisions, lowering the value of the company. We demonstrate that a manager's production decisions are positively correlated with the weight of performance-based bonus compensation, while the debt usage increases as the share of managerial equity ownership increases. Our model also suggests that agency costs can be mitigated by aligning the interests between the manager and shareholders and that low-margin producers are most susceptible to value loss from misaligned managerial incentives.

The article is organized as follows. In the next section, we review our previous model to show the effects of financial constraints on firm production. We explore the effect of varying operating conditions on the production and financial decisions and provide some empirical results about the relationship between capital structure and operating margin. We then model the corporate manager's incentive plan as the sum of fixed basic salary, performance-based bonus, and equity ownership. The following section contains the results and analysis of a numerical example.

PRODUCTION UNDER FINANCIAL CONSTRAINTS AND DEBT FINANCING

The traditional production-related literature in operation management assumes that the firm faces no financial constraints and can secure funds to adopt an optimal production policy based exclusively on information related to the production system. As we have stated earlier, in practice, however, production decisions are constrained by financial situations.

We start with the simple model from Xu and Birge (2004), which is essentially a classical news vendor problem with financial constraints k. The assumptions of the model are as follows: the firm is in a quantity competitive industry, makes a single type of product, and only operates for one period within an equivalent risk-neutral world. The stochastic demand s, realized at the end of the operating period, has a risk-neutral equivalent cumulative distribution function F and density function f. We also assume that F is continuous, differentiable, and strictly increasing. At the beginning of the period, the company produces x units of product at a constant cost of c dollars per unit so that x is used as the capacity constraint on production. The firm then sells $\min(x, s)$ units of product at a fixed price $p \geq c(1 + r_f)$, where r_f is the risk-free interest rate, and then liquidates the remaining inventory. To simplify the problem, we assume the firm produces perishable or fashion goods with no salvage value.

The risk-neutral equivalence assumption represents a transformation from a nominal probability distribution that is usually considered in studies of the news vendor model and extensions. The risk-neutral transformation is equivalent to a capital-asset pricing model (CAPM) evaluation. We refer to Singhal (1988) for the news vendor solution using the CAPM framework and Birge and Zhang (1999) for the risk-neutral equivalent formulation. Both models, however, effectively assume unlimited, all-equity financing.

To find the optimal production decision, x^*, with financial constraints, we have

$$\begin{aligned} &\text{maximize } p\left[\int_0^x s\, dF(s) + x\int_x^\infty dF(s)\right] - cx(1+r_f) \\ &\text{subject to } 0 \le cx \le k. \end{aligned} \tag{1}$$

Let $\hat{x}$ be the solution to $F(x) = \frac{p-c(1+r_f)}{p}$, then the optimal production policy for the financially constrained company is $x^* = \min(k/c, \hat{x})$. This model illustrates that tight financial constraints may lead to suboptimal decisions.

In reality, many firms face financial constraints and raise funds from the financial market to support production. The next section describes our basic model to incorporate the financing decision into the news vendor model.

Optimal Investment Level and Capital Structure

We assume that corporate profits are taxed at a constant rate τ and debt payments are fully deductible in computing taxable corporate income. Given production and debt decisions, (x, D), the firm's taxable income is $max[0, ps - cx - rD]$, where s is the realization of the demand and r is the interest cost corresponding to debt level D. For simplicity, we assume that gains are taxed at a constant rate τ, while tax losses are not allowed for tax carry-backs or carry-forwards.

If operating income cannot repay the debt, we assume that debt holders take ownership of the firm after paying bankruptcy costs and acquire the residual value of the company. As noted in our previous paper, we use a proportional bankruptcy cost, $(1-\alpha)\,ps \;\; \forall\; s < s^b$, where $s^b = L/p$ is the bankruptcy point in terms of sales and $0 < \alpha < 1$ represents the asset recovery rate after bankruptcy. The result is that the payoff to debt holders with taxes and proportional bankruptcy cost is.

$$Y_D(x, D) = \begin{cases} D[1 + r(D)] & \text{if } s \ge s^b, \\ \alpha\, ps & \text{if } s^b > s, \end{cases}$$

where $r(D)$ is the nominal interest charged by debt holders for lending D. As noted earlier, we assume that debt holders are fairly compensated under the risk-neutral equivalent measure, so that $E(Y_D) = D(1 + r_f)$.

The flow to the equity holder is then

$$Y_E(x, D) = \begin{cases} px - \tau(px - cx - rD) - D(1+r) & \text{if } x \leq s, \\ ps - \tau(ps - cx - rD) - D(1+r) & \text{if } s^* \leq s < x, \\ ps - D(1+r) & \text{if } s^b \leq s < s^*, \end{cases}$$

where x is the production capacity, $s^* = \frac{cx+rD}{p}$, is the amount of demand for which revenues equal expenses.

The overall model from Xu and Birge (2004), which maximizes the equity holder's value, is then:

$$\begin{aligned} \text{maximize} \quad & V(x, D) = E(Y_E) - (cx - D)(1 + r_f) \\ \text{subject to } & D(1 + r_f) = D(1 + r)[1 - F(s^b)] + \alpha \int_0^{s^b} psf(s)ds, \\ & 0 \leq D \leq cx. \end{aligned} \tag{2}$$

The following two first-order conditions provide the optimal production and financial decisions:

$$p(1-\tau)\int_x^{\infty} f(s)ds + c\tau \int_{s^*}^{\infty} f(s)ds = c(1 + r_f), \tag{3}$$

$$\tau[1 - F(s^*)]\left(\frac{dL}{dD} - 1\right) = (1 - \alpha)s^b f(s^b)\frac{dL}{dD}, \tag{4}$$

where $L = D(1 + r)$ denotes face value of debt. In Xu and Birge (2004), we verify second-order conditions and give general conditions to guarantee satisfaction of (3) and (4). We also show the existence of a debt capacity, beyond which the firm can raise no additional capital.

Equations (3) and (4) indicate that the firm's production decision and capital structure policy must be made jointly since the break-even point s^*, which is a function of the investment decision, x, and the financing decision, D, appears in both equations. To characterize the relationship between the firm's production and financial decisions, in Xu and Birge (2004) we show that the optimal production decision is a decreasing function of financial leverage, indicating that the production decisions of an all equity financed firm are different from that of a leveraged firm and that making production decisions without considering financial choice incurs a loss for equity holders.

We next analyze the properties of the firm's capital structure decisions as a function of profit margin. Although the trade-off theory predicts that the leverage ratio should be negatively related to its operating margin, we find, for our log-normal base case, that the firm's optimal book leverage ratio is convex in production cost and increases both as net margin approaches low and high values. For other distributions, such as uniform demand, we also observe increasing debt-to-market ratios as margins decrease and observe this behavior empirically as well.

Effects of Capital Structure Decisions on Firm Valuation

In Xu and Birge (2004), we considered varying parameter values in Model (2) and discovered that, to mitigate the effects of misidentifying optimal corporate decisions, a low-margin company should take a conservative output level and an aggressive financial decision, while a high-margin company should take aggressive production decisions and conservative debt policy. We also found that low-margin producers face the most significant risks in not coordinating financing and production decisions.

We continue that analysis in this article by varying values around a base case with selling price $p = 1$, production cost $c = 0.6p$, industrial average tax rate $\tau = 35\,\%$, and risk-free interest rate $r_f = 5\,\%$. In the base case, we also assume that the market demand for the product approximately follows a log-normal distribution, the current market demand is 1000 units, and the expected market growth rate and volatility are 10 and 40 % per operating period, respectively. The debt recovery rate equals 30 %.

Figure 1 demonstrates the effect of increasing production cost on firm valuation, where firm values are standardized by company value corresponding to production cost 0.4. Observe that as production cost increases, firm value decreases sharply. Because a higher production cost not only lowers the profit margin but also decreases the optimal output level of the company, both factors lead to lower firm valuation.

To facilitate our discussion, we define the normalized firm value, $I(x, l)/I(x^*, l^*)$, as the ratio between the value associated with a certain production and debt leverage decision pair (x, l) and that corresponding to the optimal decision pair (x^*, l^*). The normalized firm value ranges from 0 to 1 with maximize value achieved at the optimal decision point.

Figure 2 plots the normalized firm value as a function of production cost for two extreme cases, corresponding to all equity financing and all debt financing, respectively. Both cases show positive correlation between misidentification cost and profit margin. For a company with high margin, the effects of capital structure choice on firm valuation are small, because the contribution of debt tax shield and the financial distress cost become smaller as the firm's profitability increases. Figure 3 shows that deviating from optimal capital structure or production decision for a low-margin company may result in large losses, suggesting that low-margin firms should abide more strictly by optimal production and debt policies. Another

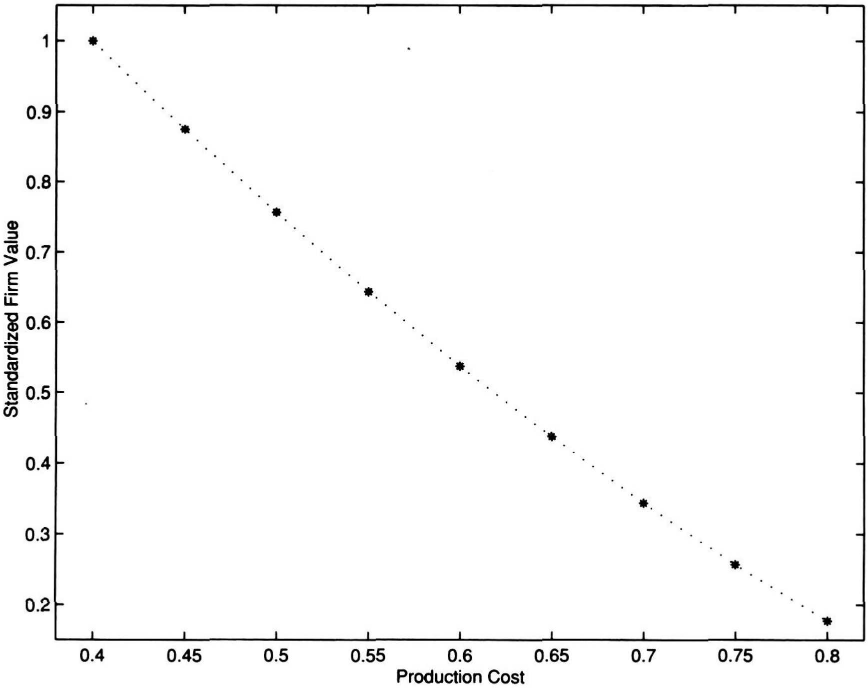


Figure 1. The firm value as a function of production cost.

observation is that the effect of over-leverage is more significant than under-leverage. Although an under-leveraged firm does not fully take advantage of potential debt service deductibility, the over-leveraged company faces more severe financial distress losses.

To show the effect of production margin on optimal capital structure, we consider the log-normal base and the case of a uniform demand distribution. Figure 4 compares the market leverage ratio and book leverage ratio as a function of production cost for both log-normal (left panel) and uniform (right panel) market demand distributions. Notice that, in general, the book leverage ratio is higher than the market leverage ratio. We also find that, for a low-margin company, an increase in production cost pushes the firm to a higher leverage ratio. This result is consistent with the empirical observation (supporting the pecking order model) that lower profit margins have higher leverage ratios (see Fama and French 2002). Fama and French (1998) also argue that as profit margins increase, the firm tends to invest more; the high investment is in part financed with more debt, but, because

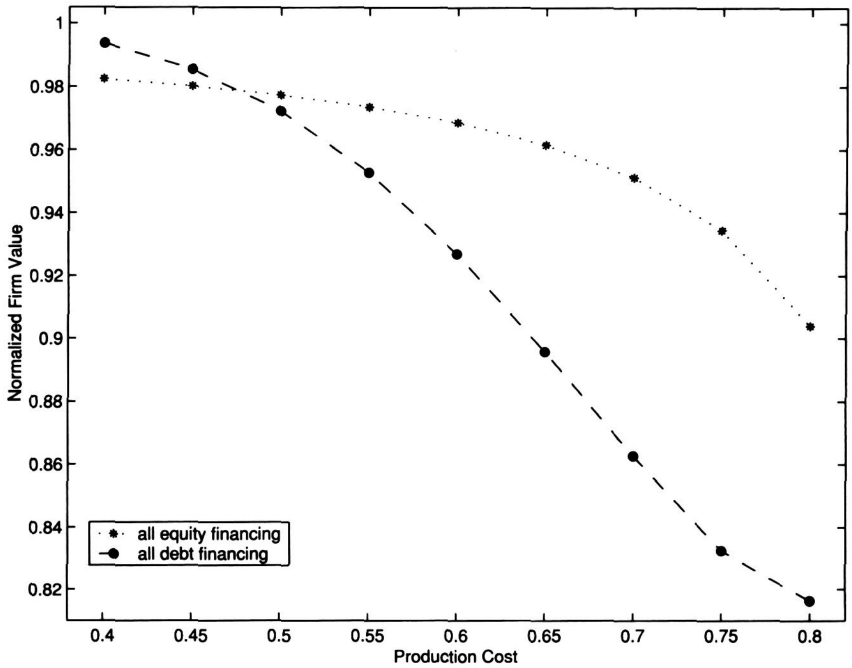
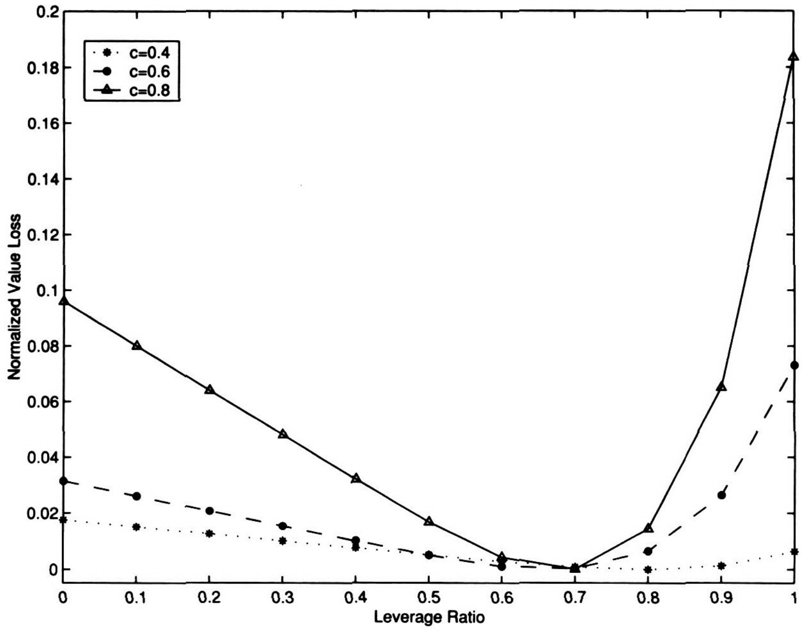


Figure 2. The effect of production cost on standardized firm valuation.

production cost decreases and firm value increases, the market leverage does not grow.

An interesting observation from Figure 4 is that the book leverage ratio is convex and U-shaped in production cost; specifically, for a high-margin company, rising operating margins may also increase the book leverage ratio as in the traditional trade-off model. While this observation may contradict the pecking order theory prediction that decreasing production cost (i.e., increasing profitability) leads to lower debt usage, the positive profitability-to-leverage relationship only holds here for high operating margins, where it has an intuitive explanation: an increase in profitability lowers the risk of future cash flow and decreases the cost of debt; hence, lower production cost results in a higher output level and larger debt usage; therefore, for a company with high operating margin, a decrease in production cost may lead to high leverage ratios. The opposite relationship holds for low-margin firms in this model since increasing margins cause firms to increase production, which then increases risk and the cost of debt. The addition of the production decision in this model then provides



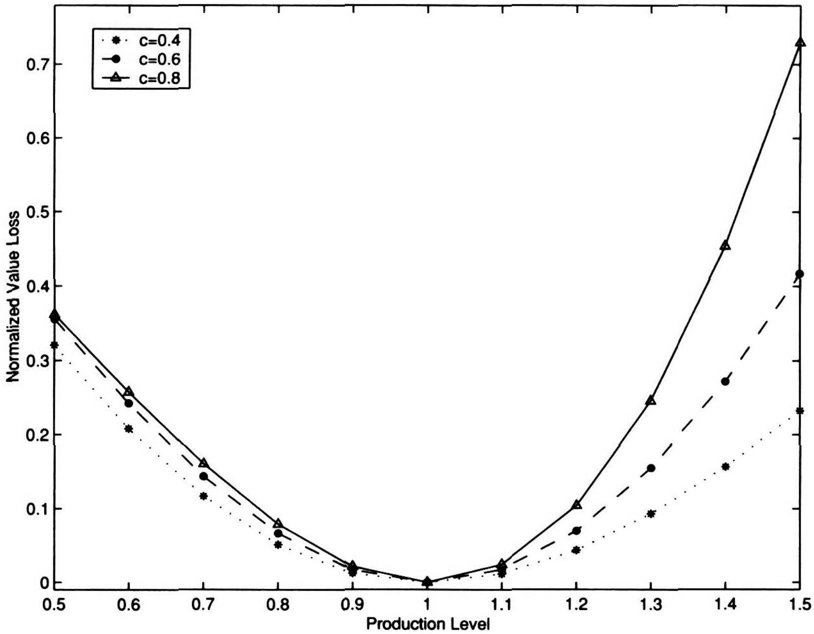


Figure 3. Production and financial decision mis-specifying effects for different profit margin.

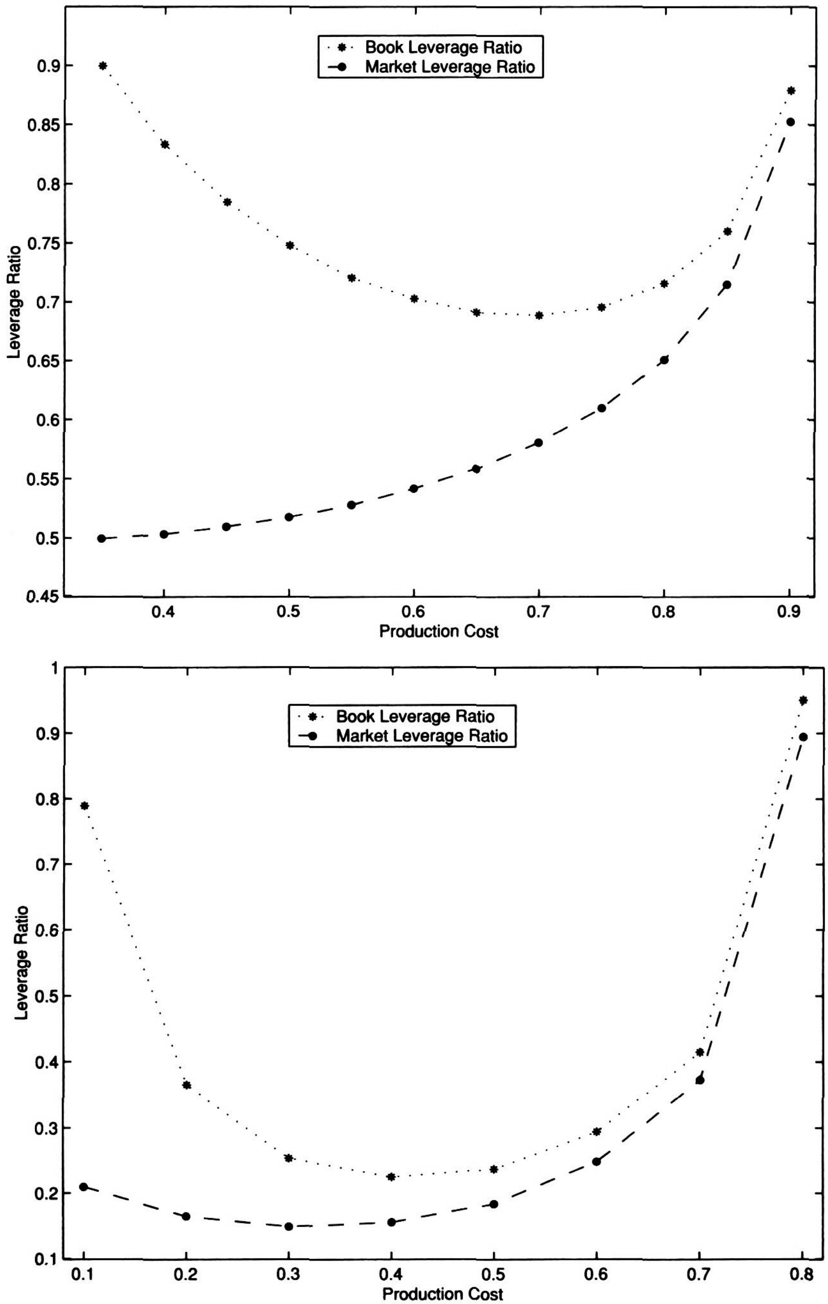


Figure 4. The market and book leverage ratio as a function of production cost.

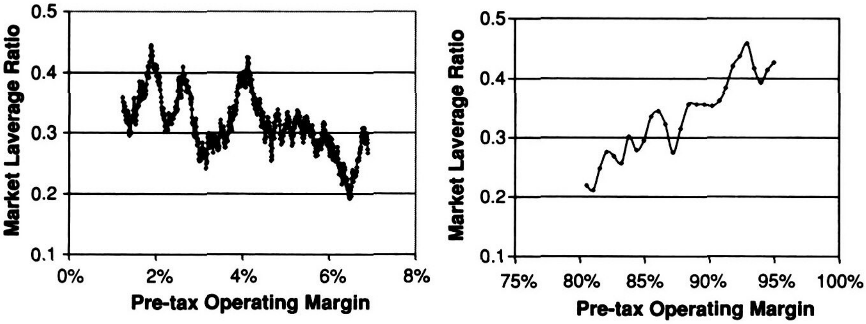


Figure 5. Empirical debt-to-market-value ratio as a function of pre-tax operating margin.

a possible explanation for empirical observations of decreasing leverage with profitability.

For other distributions, we also find that the market leverage is convex in net margin and may even increase as the margin increases. As shown in the right panel of Figure 4 where the underlying market demand follows a uniform distribution, $S \sim U(0, 1000)$, debt-to-market ratios increase as the operating margin increases (or production cost decreases). We can observe this behavior empirically as well. Our analysis of individual company data from Value Line and provided by Damodaran (2004) indicates that for very high margins, the leverage ratio appears (weakly) to increase. For example, the right graph of Figure 5 shows average market leverage ratio for firms with average pretax operating margins increasing from 80 to 96%. Each data point corresponds to the average leverage ratio of ten firms. For these high-margin firms, linear regression yields a slope coefficient of 0.91 with a standard error of 0.69 and P-value for non-positive slope of 0.098; thus, we can reject a non-positive slope at a 10% level (although we cannot reject at a 5% level).

The left graph of Figure 5 gives the market leverage ratios of the average of 100 firms with pretax operating margins from 1 to 7%. The density of the points in the left graph is much higher than of those in the right side due to the much greater number of firms reporting low operating margins than those reporting very high operating margins. In this case, our prediction would be a negative slope for leverage against operating margin. Linear regression produces a slope coefficient of -1.84 with a standard error of 0.58. With significantly more total observations of 901 low-margin firms compared to 46 high-margin firms, we have stronger confidence with a P-value for nonnegative slope of 0.00084, thus leading to rejection of nonnegative slope at even the 0.1% level. This is then consistent with the observations in Fama and French (2002) over a broad cross section of firms.

Comparing our numerical results for leverage ratios overall with empirical data, we find that the actual leverage ratios are lower than those from our simplified model, but our model does not include fixed costs or long-term debt that would generally lead to more conservative debt policy. Forms of financial distress costs other than bankruptcy costs may also reduce debt levels. Our findings are consistent with the empirical analysis by Graham (2000), who finds that debt conservatism is persistent. On average, for example, he finds that a firm can use 2.36 times its current debt and that nearly half of the sample companies could double their interest deductions before the marginal benefits begin to decline. He also finds that firms with intangible assets, growth options, or in sensitive industries, such as computer or chemical, are more conservative in their debt usage.

EFFECTS OF MANAGERIAL COMPENSATION

Our prior analyses assume that the firm manager always acts in the shareholders' best interests. Such an assumption may not hold in practice. Jensen and Meckling (1976), for example, identify conflicts between shareholders and managers due to the incomplete alignment of their interests. A manager may pursue her own interest and deviate from value maximizing decisions. The manager's self-interested decisions reduce the equity holders' wealth and result in agency cost. We present a model to capture the agency relationships between shareholders and managers. We find that compensation plans can induce managers to take overinvestment actions and conservative debt policies. We show that the managerial production decision increases with the reduction in managerial ownership, whereas debt usage is positively correlated with managerial ownership.

In our model, the manager maximizes her benefits given the compensation contracts in place, while equity holders claim the residual wealth. We assume that the manager uses the same risk-neutral equivalent valuation as in the firm model (i.e., that the manager is only concerned with market risk). In previous work, Mehran (1992) investigates the relationship between executive incentive plans and a firm's capital structure. He finds that nearly 90% of top executives' total compensation is in the form of salary, bonus, and equity-based compensation, while salary and bonus account for 67% of total compensation. For simplicity, we assume that management compensation consists of three parts, corresponding to fixed salary, performance-based bonus, and equity ownership. Since the fixed salary does not depend on the decisions taken by the manager, we ignore it in the following discussion. We assume the performance-based bonus is proportional to the expected profit above the break-even level, representing a call option on the firm's market-value above expected market return. We also assume that the manager's compensation does not affect firm value.

Before including the equity payoff into managerial compensation, we first define the bonus payoff model. If the realized demand s is above the break-even point s^*, the manager gains a reward as follows:

$$Y_B(x, D) = \begin{cases} (1-\tau)(px - cx - rD) & \text{if } x \leq s, \\ (1-\tau)(ps - cx - rD) & \text{if } s^* \leq s < x. \end{cases}$$

We denote the expected bonus compensation as $U(x, D)$. The model maximizing the manager's bonus payoff is then:

$$\begin{aligned} \text{maximize} \quad & U(x, D) = (1-\tau)(px - cx - rD)\int_x^{\infty} f(s)\,ds \\ & \qquad + \int_{s^*}^{x} (1-\tau)(ps - cx - rD) f(s)\,ds \\ \text{subject to } & D(1+r_f) = D(1+r)[1 - F(s^b)] + \alpha \int_0^{s^b} psf(s)ds, \\ & 0 \leq D \leq cx \end{aligned} \tag{5}$$

To focus on the effects of misalignment between the manager's and the equity holders' interests, we use the relative weight between bonus compensation and equity payoff. Let $0 \leq \lambda \leq 1$ and $0 \leq 1 - \lambda \leq 1$ be the relative weights of the manager's compensation associated with the firm's net operating income, $U(x, D)$, and the company value, $V(x, D)$, respectively. Let $M(x, D)$ be the expected managerial compensation. The model maximizing the manager's payoff is then:

$$\text{maximize } M(x, D) = (1-\lambda)V(x, D) + \lambda U(x, D). \tag{6}$$

To facilitate our discussion, we define an executive with compensation structure (in addition to a fixed salary) that consists solely of equity ownership as an "inside manager"; we denote a manager with no direct ownership stake and only bonus compensation as an "outside manager."

We assume that the manager is compensated enough under any choice of α to remain with the firm (i.e., the manager is "individually rational"). We only allow a single choice of α (i.e., the owners do not offer a schedule of possible compensation but only one at a time) and, therefore, do not need to consider the "incentive compatibility" of the compensation plan. We are not measuring the potential benefit of different α choices on the manager's effort but, instead, focus on the potential cost. Future studies might consider both benefits and costs and would then need to consider issues of incentive compatibility.

Based on the value of λ, the managerial optimization problem can be divided into three cases. A weight of $\lambda = 0$ corresponds to the case where managerial incentives are perfectly aligned with shareholders interest. Under such a situation, Model (6) reduces to Model (2), so that Equations (3) and (4) give the optimal investment level and debt choice. The manager's optimal decisions in this case also maximize the benefit of shareholders.

Another extreme case is $\lambda = 1$, where the outside manager gains a certain percentage of the firm's above break-even profit but owns none of the firm's equity. This case is equivalent to maximizing $U(x, D)$. Taking derivatives of U with respect to x and D, we obtain

$$\frac{\partial U}{\partial x} = p(1-\tau)\int_x^{\infty} f(s)ds - c(1-\tau)\int_{s^*}^{\infty} f(s)ds, \text{ and} \tag{7}$$

$$\frac{\partial U}{\partial D} = -(1-\tau)\left(r + D\frac{dr}{dD}\right)\int_{s^*}^{\infty} f(s)ds < 0. \tag{8}$$

Equation (8) indicates that the marginal contribution of debt to the benefit of the manager is negative. For an additional unit of debt, the marginal tax shield benefit, $\tau(r + D\frac{dr}{dD})\int_{s^*}^{\infty} f(s)ds$, is less than the marginal loss, $-(r + D\frac{dr}{dD})\int_{s^*}^{\infty} f(s)ds$. An intuitive explanation is that higher debt usage increases the break-even point, which decreases net operating profit; therefore, for an outside manager, the optimal capital structure is all equity. Comparing Equation (7) with (3), also notice that $p(1-\tau)\int_x^{\infty} f(s)ds + c\tau\int_{s^*}^{\infty} f(s)ds$ is a monotonically decreasing function in x; the manager's optimal production choice is clearly higher than that of the case with $\lambda = 0$. The outside manager's incentive to maximize his own benefit induces an aggressive production decision, deviating from the shareholders' optimal investment level.

The third case is $0 < \lambda < 1$, corresponding to the most common compensation structure in reality. The following computation gives the optimal production and financial decisions for the manager with equity fraction, λ. The derivatives of $M(x, D)$ with respect to x and D are

$$\frac{\partial M}{\partial x} = p(1-\tau)\int_x^{\infty} f(s)ds + c(\tau-\lambda)\int_{s^*}^{\infty} f(s)ds - c(1-\lambda)(1+r_f), \text{ and} \tag{9}$$

$$\frac{\partial M}{\partial (D)} = \left(r + D\frac{dr}{dD}\right)\left[(\tau-\lambda)\int_{s^*}^{\infty} f(s)ds - \gamma(1-\lambda)(1-\alpha)s^b f(s^b)\right], \tag{10}$$

where $\gamma = 1 + 1/\left(r + D\frac{dr}{dD}\right) > 0$, and $\frac{dr}{dD} > 0$.

Proposition 0.1. *With managerial compensation structured as in Model (6) with $0 < \lambda < 1$, the manager implements an aggressive production decision and a conservative debt financing policy; i.e., $x^m > x^*$ and $D^m \leq D^*$, where (x^m, D^m) corresponds to the decision maximizing the manager's compensation while (x^*, D^*) is the optimal policy maximizing the equity holders' wealth.*

Proof. To show $D^m \leq D^*$, consider the case where $\lambda > \tau$. From Equation (10), we know $\frac{\partial M}{\partial D} < 0$ if $\tau < \lambda$, which indicates the marginal contribution of debt financing to the manager's wealth is negative; therefore, the optimal capital structure that maximizes managerial compensation is zero debt financing; i.e., $D^m = 0 \leq D^*$. For $\tau \geq \lambda$, we know the optimal debt policy satisfies the first order condition; i.e.,

$$\frac{\tau - \lambda}{1 - \lambda} \int_{s^*}^{\infty} f(s)ds - \gamma(1-\alpha)s^b f(s^b) = 0. \tag{11}$$

Comparing Equation (11) with (4), $D^m \leq D^*$ since $\frac{\tau-\lambda}{1-\lambda} \leq \tau$; therefore, the optimal policy for the manager includes less debt than that of the optimal equity-holder policy.

From Equation (9), we know the optimal production decisions for the manager satisfy

$$\frac{p(1-\tau)}{c} \int_{x}^{\infty} f(s)ds + \tau \int_{s^*}^{\infty} f(s)ds = (1-\lambda)(1+r_f) + \lambda \int_{s^*}^{\infty} f(s)ds. \tag{12}$$

Note that the left-hand side of (12) corresponds to the first two terms of $\frac{\partial V}{\partial x}$ in (3) after division by c. From (3), $\frac{\partial V}{\partial x} = 0$ when the term on the right-hand side of (12) equals $1 + r_f$. Comparing Equation (12) with a solution to (3), we have $(1-\lambda)(1+r_f) + \lambda \int_{s^*}^{\infty} f(s)ds < 1 + r_f$ and note that $\frac{p(1-\tau)}{c} \int_{x}^{\infty} f(s)ds + \tau \int_{s^*}^{\infty} f(s)ds$ is a decreasing function of x; the manager's optimal production decision is then greater than that for maximizing firm equity-holders' wealth; i.e., $x^m > x^*$.

The above proposition indicates that companies with interest conflicts between shareholders and managers take suboptimal decisions. To maximize his benefits, the manager is motivated to take advantage of the call option character of the bonus payment and to produce aggressively. On the other hand, the manager takes a conservative debt financing policy to lower the break-even point, hence, increasing the chance and amount of the bonus gained. The manager's overinvestment behavior increases the risk of the company and the conservative debt policy loses the tax shield provided by debt financing, decreasing the wealth of equity holders.

Proposition 0.2. *If $\lambda \leq \tau$, the optimal production decision that maximizes managerial compensation, x^m, is an increasing function of λ, while the corresponding optimal debt choice, D^m, is negatively correlated with λ.*

Proof. To show x^m and $-D^m$ are increasing functions of λ, it is enough to show that $M(x, D)$ is supermodular in $(x, -D)$. Notice that the effective constraints on production and debt decisions, x, D, are $cx \geq D$ and $0 \leq D \leq \bar{D}$, where $\bar{D}$ is the debt capacity (see Xu and Birge 2004); hence, the feasible region is a sublattice of R^2.

The cross-derivative of M with respect to x and $-D$ is

$$\frac{\partial M^2}{\partial x \partial(-D)} = \frac{c(\tau - \lambda)}{p}\left(r + D\frac{dr}{dD}\right) f(s^*). \tag{13}$$

Since $\lambda \leq \tau$, $\frac{\partial M^2}{\partial x \partial(-D)} \geq 0$. Taking derivatives of M with respect to x, λ, and $-D$, λ yields

$$\frac{\partial M^2}{\partial x \partial \lambda} = c(1 + r_f) - c\int_{s^*}^{\infty} f(s)ds > 0, \text{ and} \tag{14}$$

$$\frac{\partial M^2}{\partial(-D)\partial \lambda} = \left(r - D\frac{dr}{dD}\right)\left[\int_{s^*}^{\infty} f(s)ds - \gamma(1-\alpha)s^b f(s^b)\right]. \tag{15}$$

From Equation (10), we know the optimal production and financial decisions, (x^m, D^m), corresponding to a given λ satisfy

$$\gamma(1-\alpha)s^b f(s^b) = \frac{\tau - \lambda}{1 - \lambda}\int_{s^*}^{\infty} f(s)ds. \tag{16}$$

Substituting (16) into (15), we have $\frac{\partial M^2}{\partial(-D)\partial\lambda} \geq 0$ since $0 \leq \tau \leq 1$. Hence, M is supermodular in $[(x, -D), t]$; therefore, x^m is an increasing function of λ and D^m and is negatively correlated with λ.

Proposition 0.2 characterizes the sensitivity of the managerial optimal production and debt decisions with respect to λ. As λ increases, the optimal investment level increases. An intuitive explanation here is that, if investment yields larger profit, bonus compensation achieves a higher gain. If investment fails, net operating profit is negative, but the equity holders bear the loss. For the effect of λ on debt policy, the explanation is still straightforward. The manager's trade-off is between losing the debt tax shield, leading to a lower level of equity value, and gaining more bonus due to a lower break-even level. With declining managerial ownership, the manager's best policy is to take less debt.

NUMERICAL EXAMPLE FOR AGENCY COSTS

This section examines the effects of agency costs on the firm's optimal production decision and financial policy. We follow the same numerical base case as earlier. To facilitate our comparison, we define the zero agency cost case as when the firm is operated by a manager whose compensation plan only contains equity ownership; i.e., $\lambda = 0$. In this case, managerial interests are perfectly aligned with those of the stockholders. In the following discussion, this case serves as a reference point for comparison; i.e., the values for all other management compensation structures are normalized by that of the zero agency cost case.

The main observations from our numerical example are as follows:

1. **Agency costs are positively correlated with the weight of performance-based bonus in the total managerial compensation plan, λ; the deviation of managerial action from firm-optimal decisions decreases as managerial equity ownership increases.**
2. **The managerial production decision increases, while debt usage decreases, as managerial equity ownership declines; compared with decisions that maximize the value of the equity holders, the manager's incentive favors aggressive production decisions and conservative debt policy.**
3. **Agency costs rise as the firm's profit margin decreases; moreover, managerial production and financial decisions become more sensitive to λ as the firm's operating margin decreases.**

Figure 6 shows the normalized agency costs, $[V(x^*, D^*) - V(x^m, D^m)]/V(x^*, D^*)$, as a function of the weight on performance-based bonus compensation, λ, where (x^*, D^*) gives the optimal production and debt decisions for the zero agency cost case, (x^m, D^m), are the best individual choices of the manager with compensation structure corresponding to $\lambda > 0$, and $V(x, D)$ is the value of the company with decision (x, D). We observe that in all three cases, agency cost is an increasing function of the weight on managerial bonus compensation. This can be explained by noting that, as managerial equity ownership declines, the conflict between managerial incentives and equity holders' interests can become intense,

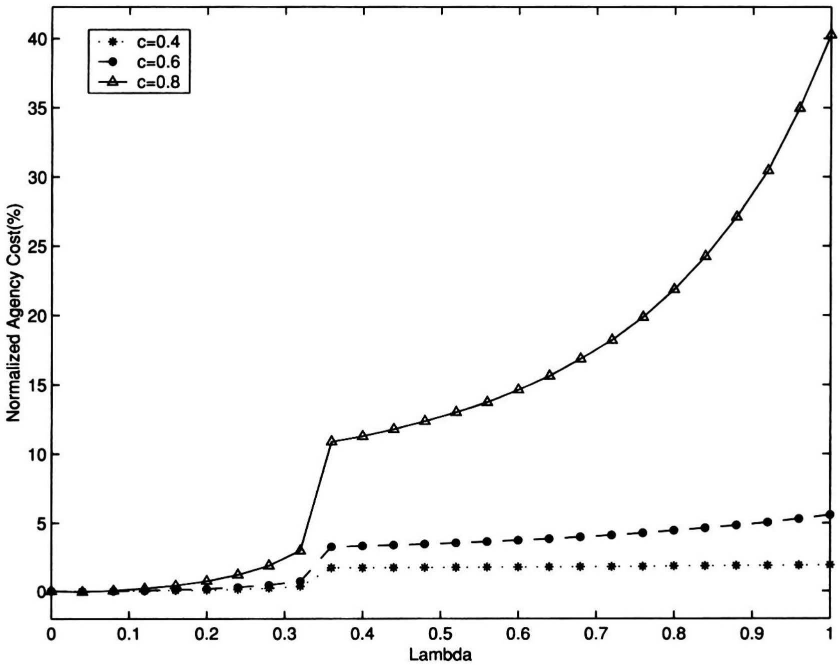


Figure 6. Relative agency cost as a function of the weight on performance-based bonus.

leading to higher agency costs. These numerical observations from our model are consistent with the empirical work by Ang et al. (2000). They document that agency costs are inversely related to the manager's ownership share and are significant for an outside manager compared to an inside manager.

We also notice that, for given values of λ, agency costs increase as the production cost decreases. This observation suggests that agency cost is a function of firm operating margin; agency costs are much smaller for a high-margin company in comparison to a low-margin firm. For example, the maximum cost corresponding to 60% operating margin (i.e., $c = 0.4$) is only 2 % of the zero agency cost case, while agency cost increases to 40 % with 20% operating margin ($c = 0.8$). For a low-margin company, firm value depends more crucially on operational decision-making; equivalent deviations from optimal decisions incur higher losses for the low-margin compared to the high-margin producer. Another observation from Figure 6 is the non-smooth behavior of agency cost at $\lambda = \tau$. This occurs because the optimal debt policy for the company becomes zero at that point.

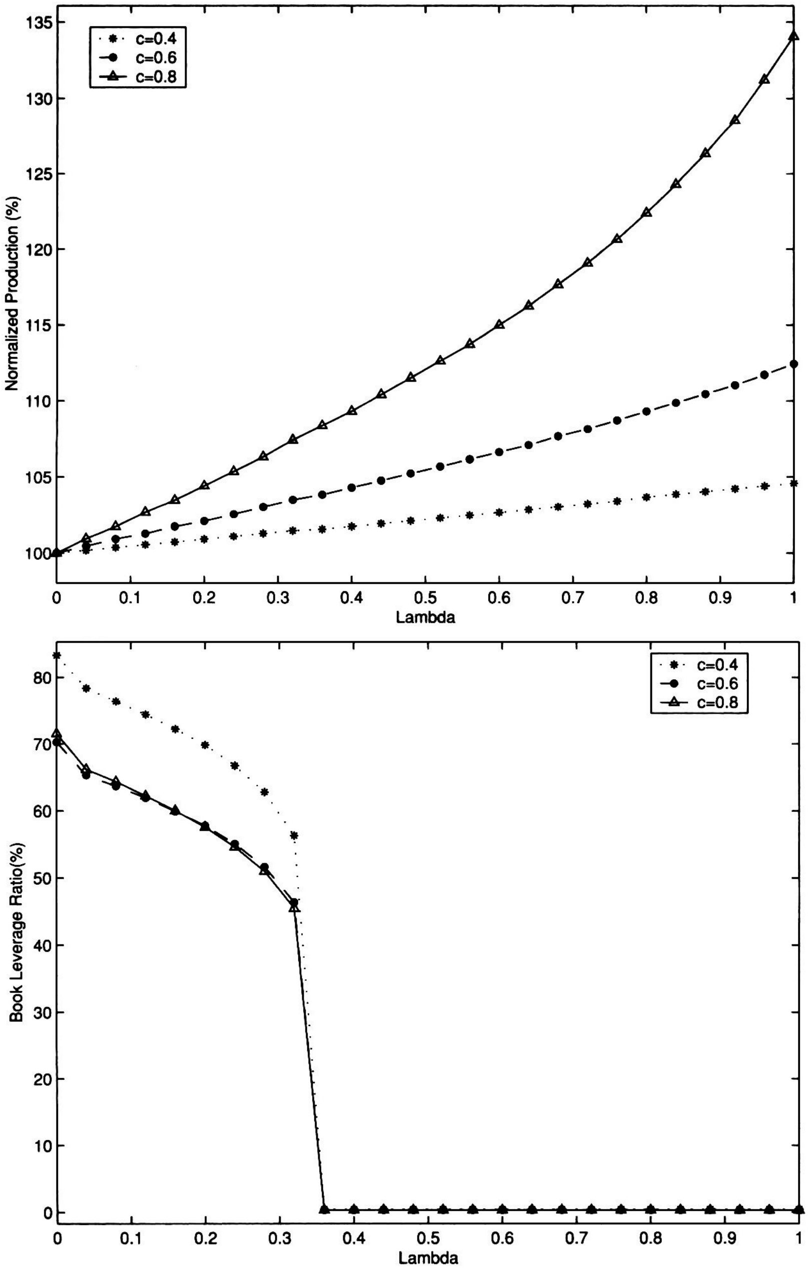


Figure 7. Production and leverage ratio as a function of the weight on performance-based bonus.

The top panel of Figure 7 illustrates the relationship between the managerial production decisions, x^m, and the compensation coefficient, λ. The lines plot normalized production, x^m/x^*, for three different production cost levels. We find that the manager takes aggressive investment decisions in all cases. If the realized market demand is high, the manager captures a large bonus; on the other hand, if demand is low, the loss for the manager only comes from equity ownership. As managerial equity ownership declines, the benefit of an additional unit of output exceeds the loss from equity ownership.

To consider the effects of different compensation plans on the firm's capital structure, the bottom panel of Figure 7 plots the book leverage ratio, $\frac{D^m}{cx^m}$, as a function of λ for different production cost c. From the figure, equity ownership is positively correlated with book leverage ratio. When the equity ownership, $1-\lambda$, falls below the corporate tax rate, the optimal capital structure is again a zero debt-financing policy. An explanation for this behavior is that, when the performance-based bonus share in managerial total compensation increases, the manager focuses more on the bonus payment, which is positively correlated with the chances of being above the break-even demand point. Lower debt levels lead to higher bonus payments, causing the manager to prefer conservative debt policy.

Another observation from Figure 7 is that both the firm's production decisions and debt policies become more sensitive to agency effects as operating margins decrease. The underlying explanation is that the optimal output decision depends on the balance of marginal production cost and marginal profit; this balance structure becomes more delicate as a firm's profitability decreases. The effect of changing λ is more significant for lower margin companies. The same explanation holds regarding debt policy. An implication from the above discussion is that the weight of performance-based bonus in the total compensation of the firm's manager should be small for a low-margin company to avoid misaligned managerial incentives. For a high-margin company, however, bonus compensation might be useful to provide possible additional managerial incentive without significant agency costs.

CONCLUSIONS

This article examines production, capital structure, and managerial compensation in a unified framework to reflect and explore the interactions among a firm's financial choice, compensation policy, and production decisions. Both our analytical and numerical results demonstrate the value of coordinating operational and financial decisions with consistent managerial incentives. Our results provide motivation for incorporating the consideration of these incentives into discussions of such engineering economic decisions as capacity expansion, production sourcing, and equipment replacement. In our view, these considerations warrant inclusion in the basic curriculum on these topics.

Our model includes multiple simplifications of reality such as a single period and product. The model's implications on the operating margin–leverage relationship, however, appear consistent with empirical observations. Further empirical study, such as examination of performance-based bonus compensation usage across firms with varying operating margins, could also be useful in supporting the conclusions on agency-cost effects. Other areas for further research include model enhancements such as the effects of multiple products, multiple periods, and competitive decisions.

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