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The sensitivity of CEO wealth to equity risk: an analysis of the magnitude and determinants☆

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Abstract

To control risk-related incentive problems, equity holders are expected to manage both the convexity and slope of the relation between firm performance and managers' wealth. I find stock options, but not common stockholdings, significantly increase the sensitivity of CEOs' wealth to equity risk. Cross-sectionally, this sensitivity is positively related to firms' investment opportunities. This result is consistent with managers receiving incentives to invest in risky projects when the potential loss from underinvestment in valuable risk-increasing projects is greatest. Firms' stock-return volatility is positively related to the convexity provided to managers, suggesting convex incentive schemes influence investing and financing decisions. © 1999 Elsevier Science S.A. All rights reserved.

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1. Introduction

Jensen and Meckling (1976) illustrate that, to reduce agency conflicts with managers, shareholders are expected to tie managers' wealth to firm, or stock-price, performance. By using compensation policy to manage the slope of the relation between managers' wealth and stock price, shareholders can induce managers to take actions that increase equity value. Managing this slope, however, is not sufficient to control agency conflicts arising between stockholders and managers. As is well-recognized in studies by Jensen and Meckling (1976), Haugen and Senbet (1981), and Smith and Stulz (1985), the convexity of the relation between stock price and managers' wealth, in addition to the slope, must be managed to induce managers to make optimal investment and financing decisions.

The convexity, or curvature, of the wealth–performance relation refers to the sensitivity of managers' wealth to the volatility of equity value. To date, no empirical evidence exists on the importance of convexity in the design of executives' incentives. This study quantifies the impact of equity risk, or stock-return volatility, on the value of stock options and common stock held by corporate CEOs, and provides evidence on cross-sectional determinants of convexity in executives' incentive schemes.

Smith and Stulz (1985) show that when managers' wealth is dependent upon firm performance, risk-aversion can cause managers to pass up risk-increasing, positive net-present-value projects. They illustrate how shareholders can reduce this risk-related agency problem by using stock options or common stock to structure managers' wealth as a convex function of firm performance. Since risk-related investment problems are expected to be greatest for firms with substantial investment opportunities, the magnitude of convexity in executives' wealth–performance relation is predicted to be positively related to the proportion of assets that are growth options. Smith and Watts (1992) also hypothesize that growth options are a determinant of executives' incentives. However, their argument focuses primarily on the slope of the wealth–performance relation. Theory suggests that, in addition to influencing the slope, the investment opportunity set is also a determinant of the convexity in the wealth–performance relation.

To illustrate differences between the slope and convexity of the wealth–performance relation, consider the options and common stock held by the following two CEOs. As of December 31, 1993, the CEO of Conrail Inc. held 94,400 shares of stock, worth \$6.3 million, and 102,500 stock options, worth approximately \$3.9 million. At that time, the CEO of GTE Corp. held 61,100 shares of stock worth \$2.1 million and 539,900 stock options worth approximately \$4.3 million. Using a Black and Scholes (1973) option-pricing framework (its application in this study is discussed in Section 4), and parameter values as of December 31, 1993, the securities held by each of the CEOs would increase in value by about $600,000 for a 5% increase in their firm's stock price. That is, the slope of the wealth–performance relation is approximately the same for both CEOs on this date. However, the convexity in their wealth–performance relation differs considerably. The GTE CEO's securities would increase in value by about $505,000 for a 5 percentage point increase in the annualized standard deviation of GTE's stock returns. This figure compares to a $55,000 increase in the value of the Conrail CEO's securities for the same increase in stock-return volatility. Therefore, the GTE CEO appears to have significantly greater risk-taking incentives than the CEO of Conrail Inc.

Using compensation data for 278 corporate CEOs, I present evidence that stock options, but not common stockholdings, play an economically significant role in increasing the convexity of the relation between managers' wealth and stock price. I measure convexity as the change in the value of managers' stock options and stockholdings for a given change in stock-return volatility. The median change in the value of CEOs' option portfolios for a 10 percentage point change in the standard deviation of stock returns is approximately $300,000, with an interquartile range of $425,000.[1] Convexity provided by common stock, on the other hand, is several orders of magnitude lower than that of stock options, and is of little economic importance for most CEOs in the sample. The median change in the value of CEOs' common stockholdings for a 10 percentage point change in return volatility is only $22, with an interquartile range of $2400. Since most firms are financially healthy, common stock, when viewed as an option on the firm's asset value, is generally so deep 'in the money' that the payoff to shareholders is effectively a linear function of firm value.

I also find that the convexity in CEOs' incentive schemes is positively related to the proportion of a firm's assets that are growth options. Thus, firms appear to provide managers with incentives to invest in risky projects when the potential loss from forgoing valuable risk-increasing projects is greatest. Finally, equity risk is shown to be positively related to the convexity provided to CEOs, suggesting that managers' investment and financing decisions are influenced by their risk-taking incentives.

Section 2 briefly highlights the relation between convexity, managers' preferences toward firm risk, and risk-related agency costs. The data are summarized in Section 3. Section 4 describes the procedure used to estimate the slope and convexity of the wealth–performance relation, and provides descriptive findings. The cross-sectional relation between firms' investment opportunities and the convexity provided to managers is explored in Section 5. Section 6 examines whether firms' stock-return volatility is related to the convexity of managers' wealth–performance relation. I conclude with Section 7.

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[1] A 10 percentage point change represents the standard deviation of the sample firms' stock-return volatility, adjusted for industry and firm size. Stock-return volatility is measured as the annualized standard deviation of daily stock returns.

2. Managers' preferences toward firm risk and risk-related agency costs

The relation between firm risk and managers' incentives is well-developed in the literature. When a manager holds common stock and stock options, a dependence exists between his wealth and the firm's stock-price performance (see Jensen and Meckling, 1976; Jensen and Murphy, 1990). This dependence is commonly referred to as the wealth–performance relation. Since stock price varies over time, the payoffs to this incentive scheme are uncertain, and risk is imposed on the manager. In Pratt (1964), a risk-averse manager is shown to be indifferent between a risky payoff and the following payoff with certainty:

$$\text{Certainty equivalent} = \text{E(wealth)} - \text{risk premium}. \tag{1}$$

Differentiating this expression with respect to firm risk yields the following:

$$\partial \text{CE}/\partial\sigma = \partial \text{E(wealth)}/\partial\sigma - \partial(\text{risk premium})/\partial\sigma. \tag{2}$$

Smith and Stulz (1985) and Lambert et al. (1991) illustrate how this expression partitions the effect of firm risk on managers' preferences into two components. The first component, $\partial \text{E(wealth)}/\partial\sigma$, which I will refer to as the wealth effect, represents the change in expected wealth experienced by a manager when firm risk changes. When the payoffs of an incentive scheme are a linear function of firm performance, the wealth effect is zero, since changes in the distribution of firm performance do not affect managers' expected wealth. Expected wealth is an increasing function of risk when managers own securities with convex payoffs, such as stock options or common stock, that increase in value as firm risk increases. Bonus plans and other incentive schemes can also contribute to the wealth effect when their payoffs are concave or convex functions of firm performance (see Section 5.2 for further discussion).

The presence of convex, or option-like, payoffs in the structure of executives' incentives is well-recognized by both academics and practitioners. For example, Jensen and Meckling (1976) point out that equity holders in a levered firm essentially hold a European call option to buy the firm at an exercise price equal to the face value of debt. As such, the value of common stock increases with the volatility of the firm's cash flows. Haugen and Senbet (1981) analyze the incentive effects of convex payoffs from employee stock options. Several empirical studies, such as Agrawal and Mandelker (1987), DeFusco et al. (1990), and Tufano (1996), have also examined the convexity implications of managers' stock-based wealth. However, none of these studies has quantified the magnitude of this convexity for common stock or stock options, or explored its determinants. The following excerpt from the *Committee Report on Executive Compensation* in BellSouth's 1993 proxy statement (p. 11) illustrates that corporate compensation committees also recognize the need to structure compensation plans to give executives appropriate risk-taking incentives:

> BellSouth's long term [incentive] program is intended to focus the executive group on the achievement of corporate goals. … Recognizing the dynamic convergence of industries such as telecommunications, entertainment, and cable which will continue throughout the next decade, the Committee wants to motivate BellSouth executives to take the risks necessary to secure a strong foothold for BellSouth in this extremely competitive new marketplace.

The second component in Eq. (2), $\partial(\text{risk premium})/\partial\sigma$, which I will refer to as the risk-aversion effect, captures the influence of risk-aversion on managers' utility. If managers are risk-averse and poorly diversified with respect to firm-specific wealth, an increase in firm risk decreases managers' expected utility. The magnitude of the risk-aversion effect is expected to depend upon the degree of diversification in a manager's portfolio of wealth, the level of a manager's wealth, and manager-specific risk-aversion parameters.

A manager's overall preference toward firm risk will depend upon the relative magnitudes of the wealth effect and the risk-aversion effect. If the risk-aversion effect dominates, the manager will prefer to decrease firm risk. This condition can give rise to risk-related agency problems. When shareholders hold well-diversified portfolios, they would like managers to invest in all positive net-present-value projects, irrespective of the risk associated with those projects. However, due to a lack of diversification, risk-averse managers may choose to forgo some positive net-present-value projects that would increase firm risk. Smith and Stulz (1985) and Milgrom and Roberts (1992) argue that by making adjustments to the slope and convexity of the wealth–performance relation, shareholders can reduce the likelihood that managers pass up valuable risky projects. Holding the slope constant, greater convexity in the wealth–performance relation is expected to shrink the gap between the risk-aversion effect and the wealth effect. Though, in principle, the wealth effect could dominate the risk-aversion effect, Lambert et al. (1991) find that, for most plausible incentive schemes, managers are likely to remain averse to firm risk.

Unlike the wealth effect, which can be estimated with option pricing techniques and readily available data about managers' stock options and common stockholdings, a measure of the risk-aversion effect requires manager-specific data that is much more difficult, if not impossible, to obtain. For example, the risk-aversion effect is expected to be a function of a manager's total wealth, the degree of diversification in a manager's portfolio of wealth, and a manager's utility function. Given these measurement problems, this study focuses primarily on developing a better understanding of the magnitude and cross-sectional variation in the wealth effect.[2] However, I do not ignore the risk-aversion effect in the empirical tests. Since securities that induce convexity in the wealth–performance relation, such as stock options and common stock, are also likely to influence managers' aversion toward firm risk, the wealth effect and risk-aversion effect are expected to be correlated. Section 5 addresses the implications of this correlation and how the research design is structured to control for these effects.

3. Data and descriptive statistics

I compile compensation and stock-based wealth data for 278 corporate CEOs as of December 31, 1993. To obtain the sample, I first rank the largest 1000 firms included in the Compustat database by market value as of December 31, 1988. By allowing a five-year period between the ranking date and the compensation measurement period, I reduce the potential bias of including only successful firms in the sample, and increase the probability of finding cross-sectional variation in the firms' financial characteristics. However, because firms are required to have survived from 1988 until 1993, a survival bias could be present, as some firms are likely to have been eliminated due to bankruptcy or being acquired. From this initial sample, 500 firms are chosen for inclusion in the final sample using a uniform selection method where every other firm is selected.

I delete firms without a December-end fiscal year from the sample. Firms are also removed if data are not available from the Center for Research in Security Prices (CRSP) or Compustat. These selection criteria result in a sample of 315 firms. For 20 of these firms, either the time series of proxy statements is incomplete, or sufficient proxy data are not available to construct the CEO's option portfolio. To check for errors in the procedure used to construct option portfolios, I compute the cash value each CEO would obtain if all options in the constructed portfolios were exercised on December 31, 1993, and compare this amount to the cash value of the CEOs' options if exercised immediately. This cash value disclosure is required for all named executive officers. CEOs are excluded from the sample if these two cash value measures differ by more than 25% and $200,000, resulting in the removal of 14 CEOs. Finally, CEOs are excluded if they own more than one-third of their corporation's common stock, since it is doubtful that these managers' compensation schemes are designed for

[2] Ofek and Yermack (1997) provide evidence that managers can influence the magnitude of their own stock-based wealth and degree of diversification. This suggests a less important role for the risk-aversion effect. However, to the extent that convexity in managers' incentive schemes comes largely from non-portable employee stock options, managers are less likely to be able to influence the wealth effect.

contracting purposes. This criteria reduces the sample by three CEOs. The results are not sensitive to using a lower ownership threshold, such as five or ten percent stockholdings. The final sample contains 278 CEOs.

3.1. Summary of compensation and stock-based wealth data

For each CEO, I compile data on common stock, restricted stock, and outstanding stock options held as of December 31, 1993, as well as salary and bonus received during 1993. With the exception of the composition of the CEOs' option portfolios, this data is readily available from the firms' 1993 proxy statements. To reduce the influence of a few CEOs that hold extremely large quantities of common stock, the upper-most percentile of aggregate stockholdings and sensitivities of these stockholdings to stock price and equity risk are set equal to the stockholdings and sensitivities of the CEOs at the 99th percentiles.

I construct the CEO's option portfolios using the past time-series of proxy statements. For each CEO, I collect data on the number of options granted in each fiscal period, the average exercise price per option granted, and the actual or maximum allowable time-to-maturity for the options granted. In approximately 5% of the fiscal periods, it was necessary to average option grants over a multi-year period. Beginning in 1992, proxy statements report the total number of stock options held by each named executive officer. I use the number of options held at the end of 1993, combined with the time series of options granted, to construct an estimate of the composition of each CEO's option portfolio as of December 31, 1993. Detailed information on option exercises is not readily available from proxy statements prior to 1992. I assume that, unless otherwise noted, options with the shortest remaining time-to-maturity are exercised first. Since this exercise strategy is expected to simulate the true exercise strategies with error, it is important to remove CEOs with constructed option portfolios that differ significantly from the option portfolio characteristics disclosed in the 1993 proxy statements, as described in Section 3.

Table 1 indicates that common stock and options are significant components of CEOs' incentive schemes. Using the Black and Scholes (1973) model, the median stock option portfolio has a value of $1.78 million. Furthermore, the substantial standard deviation and interquartile range (not reported) suggest there is considerable variation in the extent to which firms use options to provide managers with incentives. The median value of CEOs' common stockholdings is $2.74 million, which is about 50% larger than the median value of option holdings. Though restricted stock is held by less than half of the CEOs, nearly 25% of the CEOs hold restricted stock valued at $1 million or more. The median value of total stock-based wealth, including stock options, common stockholdings, and restricted stock, is $6.79 million, and several times larger than the median annual cash compensation of $866,700.

Table 1
Summary statistics for CEOs' stock option portfolios, common stockholdings, and cash compensation

The sample consists of 278 CEOs selected uniformly from the 1000 largest firms on Compustat, ranked by market value of equity on December 31, 1988. The CEOs' salary and bonus are for the fiscal year ending December 31, 1993. The number of options held by the CEOs and their stock-based wealth are as of December 31, 1993. Option values are based on the Black–Scholes formula for valuing European call options, as modified to account for dividend payouts by Merton (1973). Option value is calculated as $[S\mathrm{e}^{-dT}N(Z) - X\mathrm{e}^{-rT}N(Z - \sigma T^{(1/2)})]$, where Z is equal to $[\ln(S/X) + T(r - d + \sigma/2)]/\sigma T^{(1/2)}$. The parameters in the Black-Scholes model are set as follows: S = price of the underlying stock at December 31st, 1993, E = exercise price of the option, σ = annualized volatility, estimated as standard deviation of daily logarithmic stock returns over the last 120 trading days in 1993, multiplied by $252^{(1/2)}$, $r = \ln(1 +$ risk-free interest rate), where the risk-free interest rate is the yield, as of December 31, 1993, on a U.S. Treasury strip with the same time to maturity as the remaining life of the stock option, T = remaining time to maturity of the option in years, as of December 31, 1993, and $d = \ln(1 +$ expected dividend rate), where the expected dividend rate is set equal to the dividends paid during 1993 divided by the year-end stock price. Total stock-based wealth is the sum of the value of the CEO's options, stockholdings, and restricted stock.

Compensation component (in $ millions)	Mean	Standard deviation	Minimum	Median	Maximum
Salary + bonus	1.10	0.93	0.00	0.87	8.87
Number of options held (000s)	257.89	329.69	0.00	170.55	2500.00
Value of option portfolio	4.23	6.83	0.00	1.78	42.53
Value of common stockholdings	24.23	88.75	0.00	2.74	600.90
Value of restricted stock	0.97	2.46	0.00	0.00	25.17
Total stock-based wealth	29.43	89.80	0.04	6.79	600.90

4. Estimating convexity in the wealth–performance relation

As discussed above, the focus of this study is not on the slope of CEOs' wealth–performance relation, but instead on the convexity of this relation. I measure the convexity contributed by a stock option or share of common stock as the change in the security's value for a 0.01 change in the annualized standard deviation of stock returns. The contribution of stock options and common stock to the convexity in the wealth–performance relation can vary widely across CEOs, and is a function of firms' financial characteristics, the quantities of each security held, and the specific parameters that underlie the stock-based components, such as the exercise prices and times to maturity of the options in a manager's portfolio.

I estimate the incentive effects of employee stock options using the Black–Scholes formula for valuing European call options, as modified to account for dividend payouts by Merton (1973). The details of this procedure are presented in Section A.1. of the appendix. Huddart (1994) and Cuny and Jorion (1995) point out that the optimal exercise policy is likely to deviate from the assumptions underlying the Black–Scholes framework, due to managers' risk-aversion and the non-transferability of employee stock options.[3] However, adjusting the Black–Scholes model to accommodate these differences is not straightforward. First, there is no clear method of determining the value of an employee stock option from the employee's perspective, as opposed to the firm's perspective. Second, since there is considerable variation in the remaining time-to-maturity for the options held by the CEOs, it is difficult to estimate the expected time until these options will be exercised.

I estimate the sensitivity of an option portfolio's value to equity risk as follows. First, for each option in a CEO's portfolio, I compute the Black–Scholes partial derivative of option value with respect to a 0.01 change in the annualized standard deviation of stock returns. Next, the partial derivatives are weighted by the number of options in the portfolio. The procedure and parameters used to compute the Black–Scholes partial derivatives are described in Section A.1. of the appendix.

To check the sensitivity of the reported results to alternative option valuation techniques, all tests are reproduced using the methods suggested in Hemmer et al. (1994) and in Statement of Financial Accounting Standards No. 123, 'Accounting for stock-based compensation' (FASB, 1995). To implement the Hemmer et al. and FASB techniques, I assume that the expected time to exercise for all options held is equal to 60% of the remaining time-to-maturity, though the cross-sectional results are not sensitive to varying this percentage. With respect to the Hemmer et al. method, I also assume that all options have a three-year vesting period at the grant date. The option values and convexity measures using these procedures are generally about 10–25% lower than those using the Black–Scholes formula. However, all cross-sectional results are qualitatively unchanged.

As illustrated by Black and Scholes (1973) and Smith (1976), the payoff to a share of common stock in a levered firm can also be viewed as a call option, where the option's underlying asset is the value of the firm and the exercise price is the face value of the firm's liabilities. Unlike stock options, the Black–Scholes parameters for common stock are not all readily available. However, an

[3] Cuny and Jorion (1995) and Statement of Financial Accounting Standards No. 123, 'Accounting for stock-based compensation', address valuation issues resulting from vesting and portability restrictions. The difference between Cuny and Jorion's 'corrected' option value and Black/Scholes' value is smallest when options do not have vesting restrictions. Since most of the options valued in this study are not newly granted options, measurement error due to vesting issues is not likely to be a serious problem. Failure to consider portability restrictions is likely to lead to upward biased estimates of option values and convexity. However, it is much more difficult to determine how portability restrictions affect cross-sectional variation in option values and convexity.

estimate of the value of the option component is readily observable in the stock price. Knowledge of this option value reduces, by one, the number of Black–Scholes parameters that must be estimated. I estimate parameters for the exercise price, time to maturity, interest rate, dividend yield, and volatility of firm value as described in Section A.2. of the appendix. Firm value, the sum of market value of equity and market value of debt, and the underlying asset in this option pricing application, is left as the free parameter. Using the Black–Scholes model, I compute the implied per-share value of each sample firm. As reported in Table A1 of the appendix, the implied per-share firm values are slightly smaller than the sum of per-share book value of debt plus stock price for nearly all firms. This relation is not surprising given that the value of an option is strictly greater than the price of the underlying asset less the exercise price. The correlation between the implied firm value and the sum of book debt plus market value of equity is 0.99.

Together with the other parameters, I use the implied firm value to estimate the Black–Scholes partial derivative of each firm's stock price with respect to volatility. Note that because common stock is an option on firm value, its value is sensitive to the volatility of firm value. In contrast, a stock option's value is sensitive to stock-return volatility. To make the two convexity measures comparable, I compute the change in common stock value with respect to a 0.01 change in the annualized standard deviation of stock-returns. Since firm value is the sum of debt value plus equity value, portfolio theory suggests that the volatility of firm value can be estimated using measures of debt volatility and equity volatility, and an assumption about the correlation between debt value and equity value. For simplicity, I set this correlation equal to one, though the results are not sensitive to this assumption. The sensitivity of common stock value to equity volatility is then estimated, at the margin, by holding debt volatility constant while stock-return volatility is allowed to vary by 0.01 (see Section A.2. for further details). Finally, I estimate the aggregate sensitivity of a CEO's common stock to equity risk as the partial derivative of stock price with respect to stock-return volatility, multiplied by the number of shares of stock held by the CEO.

To gain some insight for the source of convexity inherent in common stock, consider how the value of common stock varies as a function of firm value. In an unlevered firm, the payoff to common stock is a linear function of firm value, and the value of common stock increases by $1 for every $1 increase in firm value. For a levered firm, an increase in firm value will not accrue entirely to common stockholders, but will instead be shared between the debtholders and shareholders, assuming the probability of financial distress is greater than zero. Confirming this notion, a $1 change in firm value translates into a median change in common stock value of only $0.97, with $0.03 accruing to the firms' debtholders (see Table A1 in the appendix).

4.1. Descriptive statistics on convexity in the wealth–performance relation

Table 2 presents the characteristics of the stock option portfolios held by the CEOs in the sample. Panel A indicates that the characteristics of the CEOs' options vary considerably. For each CEO, I compute the mean price-to-strike ratio and mean time-to-maturity of the options in their portfolio. The price-to-strike ratio is the stock price divided by the option's exercise price. The mean price-to-strike ratio indicates, on average, the extent to which the CEO's options are in the money. The value of an option with a price-to-strike ratio much greater than one increases almost linearly with stock price, and as such, will be quite insensitive to changes in stock-return volatility. By comparison, an "at the money" option has a price-to-strike ratio of one, and will be more sensitive to equity risk. The mean price-to-strike ratio has a median value of 1.3, and ranges from about 0.4 to 9.0. The mean time-to-maturity is the number of years remaining to expiration, on average, for a CEO's options. The mean time-to-maturity has a median value of 7.2 years, and ranges from 1.5 to 16.5 years. This variation suggests that per-option incentive effects are expected to vary widely across CEOs.

Estimates of the sensitivity of CEOs' options and stock to equity risk are presented in Panel B of Table 2. In the first row, the sensitivity of option value to equity risk is averaged over the options in each CEO's portfolio. For the 228 CEOs with options, the median change in value, per option, for a 0.01 change in the standard deviation of stock returns is \$0.156, and ranges from \$0.001 to \$0.748. The considerable variation in these per-share statistics indicates that the incentive effects of stock options are heavily dependent on security-specific parameters. Measures that ignore this variation are likely to estimate the incentive effects of these instruments with considerable error. The median aggregate sensitivity of CEOs' wealth to equity risk due to options is \$29,893. These sensitivities range from a minimum of \$0 for the 50 CEOs that do not hold options, up to a maximum of \$347,256 for the CEO holding the option portfolio most sensitive to equity risk.

The sensitivity of common stock to equity risk is much smaller than that of options. The median change in per-share stock price for a 0.01 change in stock-return volatility is \$0.00005, compared to \$0.156 per option. This result is not surprising, given that the median price-to-strike ratio for a share of common stock is 1.9, which is much larger than the price-to-strike ratio of most CEOs' stock options (see Table 6 of the appendix). Even when multiplied by the quantity of stock held, the total sensitivity of common stock value to equity risk is very small for most CEOs, with a median sensitivity of \$2. As a result, for most firms, the aggregate sensitivity of CEOs' stock-based wealth to equity risk due to options plus stock is driven primarily by stock options. However, the sensitivity of stock value to equity risk is significant for a small number of CEOs. For approximately 3% of the CEOs, the change in stock value for a 0.01 change in

Table 2
The sensitivity of CEOs' wealth to equity risk and stock price

The data consist of option portfolios and common stockholdings for 278 CEOs selected uniformly from the 1000 largest firms on Compustat, ranked by market value of equity on December 31, 1988. Price-to-strike ratio is the December 1993 stock price divided by the exercise price of an option. The mean price-to-strike ratio is the simple average of the price-to-strike ratios for all options in a CEO's option portfolio. Time-to-maturity is the remaining time to expiration for an option as of December 31, 1993. The mean time-to-maturity is the simple average of the time-to-maturity for all options in a CEO's option portfolio. Sensitivity of wealth to equity risk due to options and stock is the change in the dividend-adjusted Black–Scholes value of a CEO's stock option portfolio and common stockholdings for a 0.01 change in the annualized standard deviation of the firm's stock returns (see the appendix). The average sensitivity of an option's value to equity risk is the sensitivity of wealth to equity risk averaged over all options in a CEO's option portfolio. Total sensitivity of wealth to equity risk aggregates the per option and per-share sensitivities weighted by the number of securities held. Sensitivity of wealth to a 1% change in stock price is the change in the dividend-adjusted Black–Scholes value of stock options or common stockholdings for a 1% change in the value of the firm's stock price (see the appendix). The average sensitivity of an option's value for a 1% change in stock price is the sensitivity of wealth to stock price averaged over all options in a CEO's option portfolio.

Option portfolio characteristic	Mean	Standard deviation	Minimum	Q1	Median	Q3	Maximum
Panel A:							
Mean price-to-strike ratio[a]	1.50	0.86	0.38	1.07	1.30	1.67	9.00
Mean time-to-maturity per option[a]	7.18	1.68	1.50	6.25	7.23	8.17	16.53
Panel B:							
Average sensitivity of an option's value to equity risk ($)[a]	0.167	0.105	0.001	0.097	0.156	0.212	0.748
Total sensitivity of wealth to equity risk: options ($)[a]	45,967	51,641	82	14,108	29,893	56,590	347,256
Total sensitivity of wealth to equity risk: options – all CEOs ($)	37,700	49,982	0	4614	20,915	48,164	347,256
Per-share sensitivity of stock price to equity risk: ($)	0.005	0.016	0.000	0.000	0.000	0.002	0.225
Total sensitivity of wealth to equity risk: stock ($)	2857	12,654	0	0	2	240	98,232
Total sensitivity of wealth to equity risk: stock + options ($)	40,557	50,777	0	6489	22,664	55,770	347,292

Panel C:

Average sensitivity of an option's value to a 1% change in stock price ($)[a]	0.272	0.173	0.006	0.147	0.231	0.366	1.160
Per-share sensitivity of stock price to a 1% change in stock price ($)	0.393	0.247	0.029	0.248	0.336	0.490	2.548
Total sensitivity of wealth to a 1% change in stock price: options ($)	72,169	104,844	0	3997	36,407	96,250	687,350
Total sensitivity of wealth to a 1% change in stock price: stock ($)	251,995	886,860	0	10,571	37,307	108,341	6,008,957
Total sensitivity of wealth to a 1% change in stock price: stock + options ($)	324,164	904,534	353	38,784	90,685	222,387	6,300,594

[a]Excludes 50 CEOs that do not hold stock options.

stock-return volatility exceeds \$25,000. Thus, while the sensitivity of stock value to equity risk can potentially provide managers with incentives to shift wealth from bondholders, this effect is expected to be extremely isolated, and relevant only for firms experiencing severe financial distress.

To interpret the economic significance of these sensitivities, one must consider both the sensitivity of a CEO's wealth to equity risk and his ability to alter the risk of the firm. I estimate the latter component for each sample firm by first computing the difference between 1993 stock-return volatility and the 1993 volatility of a control sample obtained from the CRSP tapes, and matched on two-digit SIC code and market value of equity. Each sample firm is then assumed to experience a change in equity volatility that brings it in line with its industry and size-matched control portfolio. The mean change in CEOs' stock-based wealth from this change in volatility would be \$324,000, with a standard deviation of \$562,000. This mean change in wealth is about 20% larger, at \$391,000, when considering only CEOs with option portfolios. The magnitude of these wealth effects suggests that the convexity generated by stock options is potentially large enough to influence managers' behavior.

The maintained hypothesis in this paper is that firms add convexity to a manager's incentive scheme to encourage investment in valuable risk-increasing projects, that is, to help overcome the risk-aversion effect. However, note that even in the absence of convexity in the wealth–performance relation, managers have incentives to undertake positive NPV projects when the slope of the wealth–performance relation is greater than zero. Therefore, it is difficult to precisely determine how much convexity, at the margin, is necessary to induce managers to invest in risk-increasing, positive NPV projects.

To illustrate the differences between the slope and convexity of the wealth–performance relation, Panel C of Table 2 reports descriptive statistics on the sensitivity of CEOs' wealth to stock price. On average, a stock option changes in value by \$0.27 for a 1% change in stock price, compared to \$0.39 for a share of common stock. Thus, in contrast to the convexity induced by each of these securities, a share of stock increases the slope of the wealth–performance relation by about 40% more than a stock option does, on average. On an aggregate basis, both stock options and common stock make a substantial contribution to the wealth–performance slope. The median change in option portfolio value for a 1% change in stock price is \$36,400, compared to a median change of \$37,300 for common stockholdings.

5. Convexity and the investment opportunity set

As illustrated in Section 2, risk-related agency problems can cause managers to pass up risky, positive NPV projects. This problem is likely to be most severe in firms with substantial investment opportunities (see Milgrom and Roberts, 1992, Chapter 13, for a discussion of potential risk-related agency costs in firms with valuable growth opportunities).[4] As such, the expected loss from valuable projects bypassed by managers is hypothesized to be positively related to the proportion of assets that represent growth options. By providing managers with incentive schemes that have convex payoffs, equity holders can reduce these risk-related agency costs. The following hypothesis follows directly: Convexity in the relation between managers' wealth and stock price is positively related to the proportion of assets that are growth options.

I use three proxies to capture variation in firms' investment opportunities. These are: (i) the book-to-market ratio, (ii) expenditures on research and development, scaled by market value of assets, and (iii) a measure of investment expenditures defined as the sum of capital expenditures plus acquisitions over the most recent three years, divided by market value of assets. Though these variables are expected to contain information about investment opportunities, each has unique limitations as a measure of this unobservable underlying construct. Therefore, as in Baber et al. (1996) and Gaver and Gaver (1993), I employ common factor analysis to construct a single variable that captures variation common to these observable proxies. Separate results are presented using the common factor as an alternative to the above three proxies.

Table 3 summarizes the proxies for investment opportunities and the financial characteristics of the 278 sample firms. In general, the sample firms are large, with median market value of assets equal to $5.4 billion. The range in values for book-to-market, R&D, and investment expenditures is quite large, suggesting that there is considerable variation in investment opportunities across the sample firms. The factor score for investment opportunities has a mean of zero, by construction, and varies from -0.85 to 2.27.

5.1. Empirical results: convexity and the investment opportunity set

To explore the relation between convexity and the investment opportunity set, I regress the sensitivity of CEOs' wealth to equity risk on the proxies for growth options described in the previous section. I use two alternative measures of the sensitivity of CEOs' wealth to equity risk: (i) the sensitivity of CEOs' option portfolios to equity risk, and (ii) the combined sensitivity of stock options and common stockholdings to equity risk.

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[4] Note that this risk-related agency problem is somewhat different than the well-known underinvestment problem described by Myers (1977). He demonstrates that when fixed claims are present in the capital structure, equity holders may forgo positive net-present-value projects if the gains accrue primarily to fixed claim holders. The risk-related agency problem described here does not require debt in the capital structure, but instead derives from risk-averse managers that are poorly diversified with respect to their firm-specific wealth.

Table 3
Summary firm characteristics

The sample consists of 278 CEOs selected uniformly from the 1000 largest firms on Compustat, ranked by market value of equity on December 31, 1988. All financial variables are computed for fiscal year ending December 31, 1993. Book-to-market ratio is the book value of assets divided by the sum of book value of liabilities and market value of equity. R&D expenditures is R&D expense divided by the market value of assets (in %). Investment expenditures is the sum of capital expenditures plus acquisitions over the period 1991 through 1993, divided by market value of assets. Factor score is obtained using common factor analysis on the variables Book-to-market, R&D expenditures, and Investment expenditures. Market value of assets is book value of debt plus market value of equity. Leverage is calculated as [(book value of assets − book value of equity)/market value of equity].

Firm characteristics	Mean	Standard deviation	Minimum	Median	Maximum
Book-to-market ratio	0.74	0.21	0.24	0.78	1.20
R&D expenditures	0.80	1.78	0.00	0.00	13.80
Investment expenditures	0.13	0.10	− 0.01	0.12	0.71
Factor score (investment opportunities)	0.00	0.54	− 0.85	− 0.05	2.27
Market value of assets ($billion)	16.59	34.15	0.20	5.42	315.21
Leverage	2.74	4.13	0.06	1.10	34.28

Though stock options and common stockholdings add convexity to the relation between managers' wealth and stock price, both securities also increase the slope of this relation. Smith and Watts (1992) argue that because the management of investment opportunities is difficult to monitor, firms with greater investment opportunities are expected to tie managers' wealth more closely to firm performance.[5] To control for a relation between the wealth–performance slope and investment opportunities, the sensitivity of CEOs' wealth to stock price is included in all regressions. The market value of assets is also included in the regressions to control for a relation between firm size and both the probability of having a formal incentive compensation plan, such as a stock option plan, and the level of compensation (see Smith and Watts, 1992; Gaver and Gaver, 1993). All t-statistics are calculated using heteroskedasticity-consistent standard errors.

The regression results are reported in Table 4. The negative coefficient on book-to-market and positive coefficients on R&D and investment expenditures are consistent with the hypothesis that the investment opportunity set is

[5] Gaver and Gaver (1993) and Baber et al. (1996) provide further empirical support for this hypothesis. Yermack (1995) finds that the investment opportunity set does not help in explaining the wealth–performance slope when examining new grants of stock options.

positively related to convexity in the relation between CEOs' wealth and stock price. In Columns (2) and (5), book-to-market ratio, R&D expenditures, and investment expenditures are replaced with the factor variable that captures variation common to these observable proxies for investment opportunities. In both columns, the coefficient on this factor is positive and significant at the 1% level.

To interpret the magnitude of the factor score coefficient, consider two CEOs with factor scores that differ by the standard deviation of the sample firms' factor scores. The coefficient on the factor score in Column (5) implies that the compensation schemes for these two CEOs are expected to be set so that a ten percentage point rise in stock-return volatility increases the stock-based wealth of the CEO managing the high growth options firm by about $143,000 more than the CEO managing the low growth option firm.

As noted in Section 2, the sensitivity of CEOs' wealth to equity risk, or the wealth effect, is expected to measure the impact of risk on managers' utility with error. Missing from this estimate is the risk-aversion effect, or the reduction in utility that risk-averse, poorly diversified managers experience when the volatility of their wealth increases. To examine whether this omitted variable is influencing the results, I include proxies for the risk-aversion effect in the regressions.

The dollar value of 1993 cash compensation, salary plus bonus, is included to control for the level of CEOs' outside wealth. The greater the cash compensation that can be invested outside the firm, the better diversified the CEO is likely to be, and the lower the expected risk-aversion effect. CEO age is included to control for manager-specific variation in diversification of wealth and degree of risk-aversion. The results are robust to the following alternative treatments of the age variable: (i) including dummy variables for various age categories, (ii) interacting age with the other independent variables, and (iii) re-estimating the regressions on subsamples of the CEOs formed by age. The signs of the coefficients on cash compensation and age are difficult to predict since it is unclear how the wealth and risk-aversion effects are likely to be correlated for these variables. The log of the sensitivity of CEOs' wealth to stock price is also added as a proxy for the CEOs' degree of diversification. The more sensitive the CEO's wealth is to firm performance, the less well-diversified the CEO is likely to be, and the greater the expected risk-aversion effect. Though logarithm is the reported functional form of this variable, the regressions are not sensitive to using other concave functional forms, such as the square root. Since the same stock-based securities drive both the sensitivity of CEOs' wealth to equity risk and to equity value, a positive coefficient is predicted.

When these variables are included, as shown in Columns (3) and (6), the coefficient on log[sensitivity of wealth to stock price] is significantly positive, indicating that securities that increase the risk-aversion effect also increase the wealth effect. However, the coefficient on the investment opportunities factor

Table 4
The relation between investment opportunities and the sensitivity of CEOs' wealth to equity risk

$$\text{Sensitivity of wealth to equity risk} = a + b_1(\text{Book-to-market}) + b_2(\text{R\&D}) + b_3(\text{Investment expenditures}) + c_1 \text{ Log(market value of assets)} + c_2(\text{Sensitivity of wealth to stock price}) + c_3(\text{Cash compensation}) + c_4 \text{ Log(sensitivity of wealth to stock price)} + c_5 \text{ Age} + \text{error.}$$

All variables are measured as of December 31, 1993. Sensitivity of wealth to equity risk from options is the change in the dividend-adjusted Black–Scholes value of a CEO's stock option portfolio for a 0.01 change in the annualized standard deviation of the firm's stock returns (in $ thousands). Sensitivity of wealth to equity risk from options and stock is the change in the dividend-adjusted Black–Scholes value of a CEO's stock option portfolio and common stockholdings for a 0.01 change in the annualized standard deviation of the firm's stock returns (in $ thousands). Book-to-market ratio is (book value of assets/market vlaue of assets). R&D expenditures is R&D expense divided by market value of assets (in %). Investment expenditures is the sum of capital expenditures plus acquisitions over the period 1991 through 1993, divided by the market value of assets at December 31, 1993. Factor score is obtained using common factor analysis on the variables Book-to-market ratio, R&D expenditures, and Investment expenditures. Log[market value of assets] is the natural logarithm of [book value of liabilities + market value of equity]. Sensitivity of wealth to stock price is the change in the dividend-adjusted Black-Scholes value of a CEO's stock option portfolio and common stockholdings for a 1% change in the value of the firm's stock price (in $ thousands). Cash compensation is the sum of salary plus cash bonus for 1993 (in $ millions). Age is the CEO's age in years. T-statistics in parentheses are computed using White's heteroskedasticity-consistent standard errors.

	Predicted sign	Sensitivity of wealth to equity risk: options (000's)			Sensitivity of wealth to equity risk: options & stock (000's)		
		(1)	(2)	(3)	(4)	(5)	(6)
Intercept	(?)	– 82.62 (– 3.67)	– 112.37[a] (– 5.18)	– 71.05[a] (– 2.03)	– 77.29[a] (– 3.40)	– 103.04[a] (– 4.64)	– 80.80[a] (– 2.28)
Book-to-market ratio	(–)	– 63.72[a] (– 4.61)			– 55.79[a] (– 3.76)		

R&D expenditures	(+)	3.10[a]			3.29[a]		
		(2.44)			(2.51)		
Investment expenditures	(+)	48.29			46.81		
		(1.63)			(1.54)		
Factor score (investment opportunities)	(+)		27.76[a]	19.46[a]		26.44[a]	17.12[a]
			(5.32)	(3.96)		(4.92)	(3.44)
log(market value of assets)	(+)	18.19[a]	17.13[a]	11.00[a]	17.10[a]	16.26[a]	9.61[a]
		(6.59)	(6.44)	(3.54)	(6.01)	(6.01)	(3.08)
Sensitivity of wealth to stock price	(+)	− 0.00	0.00	− 0.01[a]	0.00	0.00	− 0.01[b]
		(− 0.02)	(0.18)	(− 2.08)	(0.74)	(0.85)	(− 1.70)
Cash compensation	(±)			7.06			6.71
				(1.48)			(1.44)
Log (sensitivity of wealth to stock price)	(+)			10.96[a]			12.79[a]
				(6.11)			(6.84)
Age	(±)			− 0.70			− 0.41
				(− 1.57)			(− 0.87)
Adjusted R^2		22.47	20.76	31.77	20.12	19.25	32.59

[a]Statistical significance at the 5% level.
[b]Statistical significance at the 10% level.

remains significantly positive in both columns, providing further support for the hypothesis that firms provide managers with incentives to invest in risky projects when the potential loss from underinvestment in valuable risk-increasing projects is greatest.

Yermack (1995) concludes that investment opportunities are not an important determinant for grants of CEO stock options. However, the sensitivity of wealth to stock price is used as the dependent variable in his tests. The results in Table 4 suggest that firms are expected to consider the sensitivity of wealth to equity risk, in addition to sensitivity of wealth to stock price, when granting stock options.

5.2. Specification checks

Corporate hedging theory identifies circumstances where firm value can be increased through reductions in risk (e.g., Myers, 1977; Smith and Stulz, 1985; Smith and Mayers, 1987, 1990; Froot et al., 1993). All else being equal, firms with strong incentives to hedge are expected to provide managers with weaker incentives to increase firm risk. To examine the sensitivity of the reported results to these factors, I include measures of financial leverage, operating performance, cash flow volatility, and tax-loss-carryforwards in the Table 4 regressions as proxies for firms' incentives to hedge. The coefficients and significance levels on the growth option variables (not reported) are qualitatively similar to those reported previously. The coefficient on leverage is in the predicted direction, negative, and is significantly different from zero. The coefficients on the other hedging variables are not significantly different from zero.[6]

Yermack (1995) and Dechow et al. (1996) hypothesize that liquidity constraints can induce firms to use stock options in lieu of cash compensation. If firms with substantial growth options tend to be cash constrained, the inferences drawn in this section could be spurious. The results reported in Table 4 are robust to including free cash flow, measured as cash flow from operations less capital expenditures, and financial leverage, as proxies for cash constraints.

The preceding analysis focuses exclusively on the convexity of payoffs in CEOs' stock-based wealth. However, it is possible that firms make adjustments to other forms of compensation, such as salary and bonuses, to offset changes in

[6] In addition to the determinants posited here, Jensen and Meckling (1976) explain how fixed claims in the capital structure can create incentives for equity holders to transfer wealth from bondholders by increasing the firm's risk. This incentive to shift wealth from bondholders may increase the desire of equity holders to motivate managers to invest in risky projects. However, this argument is only relevant ex-post with respect to the issuance of debt. Prior to issuing debt, equity holders, as the residual claimants, are expected to structure incentive schemes that discourage wealth transfer from fixed claim holders.

stock-based wealth that CEOs' experience when equity risk changes. To explore this possibility, I examine the relation between changes in the CEOs' salary and bonuses from 1993 to 1994, and both changes in firms' stock-return volatility and estimates of realized changes in CEOs' stock-based wealth due to changes in equity risk. To estimate the CEOs' realized change in stock-based wealth due to equity risk, the sensitivity of the CEOs' wealth to equity risk at December 31, 1993, is multiplied by the change in stock-return volatility from 1993 to 1994. The change in stock-return volatility is computed as the standard deviation of daily stock returns over the last 120 trading days in 1994 minus the standard deviation of stock returns over the last 120 trading days in 1993. Note that this method measures the true changes in wealth during 1994 with error due to new grants/exercises of options, changes in stockholdings, and changes in the Black/Scholes parameters used to estimate the 1993 sensitivities. I find no significant correlations between these variables.

6. The relation between stock-return volatility and the sensitivity of CEOs' wealth to equity risk

The analysis in Section 2 suggests that managers are more willing to invest in risk-increasing projects as the convexity of payoffs in the relation between their wealth and stock price increases. This relation between convexity and investment choice also underlies the hypothesis tested in Section 5, that the sensitivity of CEOs' wealth to equity risk is directly related to firms' investment opportunities. Therefore, it is of interest to examine whether firms' stock-return volatility, as a measure of the riskiness of a firm's projects, is positively related to the sensitivity of managers' wealth to equity risk.

To explore the relation between equity risk and the convexity of payoffs to managers, I regress contemporaneous stock-return volatility on the sensitivity of CEOs' wealth to equity risk.[7] The dependent variable, stock-return volatility, is computed over 240 trading days, from 120 days before through 120 days after the compensation measurement date of December 31, 1993. The results are not sensitive to alternatively measuring volatility over 120 or 240-day periods

[7] Theories of risk management hypothesize that the benefits from hedging are increasing in cashflow volatility. Therefore, other things equal, managers of firms with highly volatile cashflows are expected to be provided with weaker incentives to increase equity risk than managers' of firms with steady cashflows. Since cashflow volatility and stock-return volatility are positively correlated, the alignment of managers' incentives with optimal hedging strategies can induce a bias against finding the positive relation hypothesized between equity risk and the sensitivity of managers' wealth to equity risk. Though this issue clouds the interpretation of the results if the null hypothesis cannot be rejected, it does not create interpretive difficulties when the null hypothesis can be rejected.

Table 5
The relation between stock-return volatility and the sensitivity of CEOs' wealth to equity risk

$$\text{Stock-return volatility} = a + b_1(\text{Sensitivity of wealth to equity risk}) + c_1(\text{market value of assets}) + c_2(\text{Leverage}) + c_3(\text{Factor score for investment opportunities}) + \text{error}.$$

Stock-return volatility is the annualized standard deviation of daily logarithmic stock returns (in %) over 240 trading days, starting with the last 120 trading days in 1993 and ending with the first 120 trading days in 1994, multiplied by $252^{(1/2)}$. Sensitivity of wealth to equity risk from options and stock is the change in the dividend-adjusted Black–Scholes value of a CEO's stock option portfolio and common stockholdings (in $ thousands) for a 0.01 change in the annualized standard deviation of the firm's stock returns. Adjusted sensitivity of wealth to equity risk due to options and stock removes the influence of firm-specific stock-return volatility by using the sample mean standard deviation of stock returns in all Black–Scholes computations, instead of using the equity risk specific to each firm. Log[market value of assets] is the natural logarithm of [book value of liabilities + market value of equity] at December-end 1993. Leverage is [(Book value of assets − book value of equity)/market value of equity]. Factor score is obtained using common factor analysis on the variables Book-to-market ratio, R&D expenditures, and Investment expenditures as described in Section 5.

	Annualized standard deviation of stock returns (%)			
	(1)	(2)	(3)	(4)
Intercept	55.37[a]	51.84[a]	53.91[a]	50.07[a]
	(10.47)	(10.97)	(9.68)	(10.21)
Sensitivity of wealth to equity risk: options + stock	0.047[a]	0.035[a]		
	(4.69)	(3.90)		
Adjusted sensitivity of wealth to equity risk: options + stock			0.026[a]	0.016[b]
			(2.97)	(1.88)
Control variables:				
log(market value of assets)	− 3.85[a]	− 3.51[a]	− 3.57[a]	− 3.21[a]
	(− 6.03)	(− 6.20)	(− 5.33)	(− 5.41)
Leverage	0.67[a]	1.04[a]	0.62[a]	1.02[a]
	(3.83)	(4.53)	(3.44)	(4.31)
Factor score: investment opportunities		6.20[a]		6.63[a]
		(5.12)		(5.28)
Adjusted R^2	19.63	27.88	15.91	25.48

T-statistics are in parentheses and are computed using White's heteroskedasticity-consistent standard errors.
[a]Statistical significance at the 5% level.
[b]Statistical significance at the 10% level.

starting at the compensation measurement date. To control for other determinants of equity risk, the log of market value of assets and financial leverage are included in all regressions. All t-statistics are calculated using heteroskedasticity-consistent standard errors.

Column (1) of Table 5 indicates that firms' stock-return volatility is positively related to the sensitivity of CEOs' wealth to equity risk. However, given the findings in Table 4, and the likelihood of a positive correlation between investment opportunities and equity risk, there is a concern that these inferences are spurious. When the factor score for investment opportunities is added to the regression, the coefficient on the sensitivity of wealth to equity risk is about 25% lower, but remains significantly positive. The regression results are robust to including the book-to-market ratio, R&D expenditures, and investment expenditures in place of the factor score as proxies for investment opportunities.

Since the standard deviation of stock returns is an input in the Black–Scholes model, it is possible that the regression coefficients are influenced by a mechanical relation between stock-return volatility and the Black–Scholes partial derivatives used to estimate the sensitivity of CEOs' wealth to equity risk. To address this concern, I recompute all Black–Scholes partial derivatives using the sample mean standard deviation of stock returns, instead of the volatility specific to each firm. Though this adjusted measure of sensitivity of wealth to equity risk is not expected to fully reflect the incentive effects of managers' compensation schemes, it is free from a mechanical relation with firm-specific stock-return volatility. As indicated in Columns (3) and (4) of Table 5, the coefficients on this adjusted measure of convexity are about 50% smaller than in the previous regressions. However, they remain significantly positive.

These findings support the hypothesis that firms' stock-return volatility is positively related to the convexity of payoffs in managers' incentive schemes. The coefficient on the sensitivity of CEOs' wealth to equity risk in Column (2) of Table 5 indicates that a difference of one sample standard deviation in the sensitivities of two CEOs' wealth to equity risk is expected to be associated with a two percentage point difference in the annualized standard deviation of their firms' stock returns. For a firm with the sample median standard deviation of stock returns, this difference amounts to nearly 10% of the firm's equity risk.

7. Conclusion

The determinants of executive compensation practices, and in particular the relation between managers' wealth and firm performance, is a topic of importance to both academics and practitioners. Though the slope of this relation has been examined in considerable detail, no study has quantified or explored the determinants of curvature, or convexity, in this relation. I argue that to effectively control agency conflicts between stockholders and managers, shareholders are expected to manage the convexity, in addition to the slope, of the relation between firm performance and managers' wealth. Since convexity in an incentive scheme generates a positive relation between a manager's wealth and firm risk, compensation components with convex payoffs, such as stock options and common stock, can induce risk-averse managers to invest in valuable risk-increasing projects that they may otherwise forgo.

My evidence indicates that the convexity of payoffs in managers' stock-based wealth is potentially large enough to influence investing behavior. In a sample of 278 corporate CEOs, I find stock options play an economically significant role in increasing the convexity of the relation between managers' wealth and stock price. The magnitude of the convexity provided by common stock is much lower than that of stock options, and of little economic importance for most CEOs in the sample.

In cross-sectional tests, after controlling for the slope of the wealth–performance relation, convexity is positively related to proxies for the importance of growth options in firms' assets. This finding supports the hypothesis that firms provide managers with incentives to invest in risky projects when the potential loss from underinvestment in valuable risk-increasing projects is greatest. Finally, consistent with managers making investment and financing decisions in accordance with their risk-taking incentives, I find that firms' equity risk is positively related to the convexity provided to CEOs.

This study makes two important contributions to the literature. First, I emphasize that the incentive effects of stock-based compensation encompass more than simply encouraging managers to increase stock price. Specifically, I consider firms' use of stock-based compensation to manage the sensitivity of managers' wealth to firm risk, and find evidence consistent with firms using stock options to control risk-related agency problems. Second, I stress the importance of considering an executive's complete portfolio of stock options and common stock when analyzing firms' compensation practices. Yermack (1995) observes that the absence of complete data on managers' option portfolios can hinder researchers' ability to find a strong link between extant agency and financial contracting theory, and firms' use of stock options. Since managers' incentives derive from both newly awarded and previously issued options and stock, firms are expected to consider the incentive effects of outstanding options and stock when choosing the size and characteristics of the current year's options grant.

Appendix A

A.1. Estimating the sensitivity of stock option portfolios to stock-return volatility

Estimates of the sensitivity of stock options and common stock to equity risk at December 31, 1993, are based on the Black–Scholes formula for valuing

European call options, as modified to account for dividend payouts by Merton (1973), as follows:

$$\text{Option value} = [S e^{-dT} N(Z) - X e^{-rT} N(Z - \sigma T^{(1/2)})],$$

where

Z is the $[\ln(S/X) + T(r - d + \sigma^2/2)]/\sigma T^{(1/2)}$, N the cumulative probability function for the normal distribution, S the price of the underlying stock, X the exercise price of the option, σ the expected stock-return volatility over the life of the option, r the risk-free interest rate, T the time to maturity of the option in years, and d the expected dividend rate over the life of the option.

The partial derivative with respect to stock-return volatility is defined as

$$\partial(\text{option value})/\partial(\text{stock volatility}) = e^{-dT} N'(Z) S T^{(1/2)},$$

where N' is the normal density function.

The parameters of the Black–Scholes model are estimated for stock options as follows:

S = price of the underlying stock on December 31, 1993.

X = exercise price of the option. The exercise price could not be obtained for approximately 2% of the options. For these options, the exercise price is set equal to the simple average of the stock prices prevailing at the beginning and end of the year in which the option was granted.

σ = annualized volatility, estimated as the standard deviation of daily logarithmic stock returns over the last 120 trading days in 1993, multiplied by $252^{(1/2)}$. There were 252 trading days in 1993.

r = ln(1 + risk-free interest rate), where the risk-free interest rate is the yield, on December 31, 1993, on a U.S. Treasury strip with the same time to maturity as the remaining life of the stock option.

T = remaining time to maturity of the option, in years, as of December 31, 1993. I use the grant date and duration of the option when granted to compute the remaining time to maturity. If the grant date is unavailable, I set it equal to July 1st in the year the option is issued. If the duration of the option is not specified, I set it equal to ten years at the grant date, since over 90% of newly issued options in the sample have a ten-year duration.

d = ln(1 + expected dividend rate), where the expected dividend rate is the per-share dividends paid during 1993 divided by the year-end stock price.

A.2. Estimating the sensitivity of common stock value to stock-return volatility

I estimate the per-share sensitivity of common stock value to equity risk at December 31, 1993, in two steps: i) Compute the implied, per-share firm value using the Black–Scholes model. ii) Use the implied firm value to estimate the

Black–Scholes partial derivative of stock price with respect to a 0.01 change in the annualized standard deviation of stock returns.[8]

Descriptive statistics for the parameters used to estimate the sensitivity of common stock to stock-return volatility appear in Table 6. These parameters are defined as follows:

Option value = per-share price of common stock

X = the per-share book value of debt, estimated as the book value of total liabilities divided by common shares outstanding.

σ = annualized volatility of firm value, estimated as the annualized standard deviation of the rate of return on a portfolio that includes the firm's debt and equity. Portfolio theory implies that the variance of firm value is equal to $X^2_{\text{debt}}\,\sigma^2_{\text{debt}} + X^2_{\text{equity}}\,\sigma^2_{\text{equity}} + 2X_{\text{debt}}X_{\text{equity}}$ $\text{Cov}\,(\sigma_{\text{debt}}\sigma_{\text{equity}})$. X_{debt} and X_{equity} are the weights on equity and debt in the firm's capital structure. σ_{equity} is estimated as the standard deviation of daily logarithmic stock returns over the last 120 trading days in 1993, multiplied by $252^{(1/2)}$. σ_{debt} is estimated as the standard deviation of monthly logarithmic returns on the Merrill Lynch corporate bond index that matches the firm's S&P senior debt rating, multiplied by $12^{(1/2)}$. The standard deviation of bond index returns is estimated over the five-year period ending December 1993. The correlation between equity and debt returns is set equal to one, which assumes that shocks to firm value affect equity and debt values similarly. Though this assumption is not expected to hold empirically (e.g., the value of debt may be much more dependent upon interest rates than the value of equity), the results are not sensitive to varying this correlation.

T = the weighted average maturity of the firm's liabilities estimated using Compustat data on corporate liabilities maturing in less than 1 year, 2 years, 3 years, 4 years, 5 years, and more than five years. When the firm has outstanding debt with different times to maturity, common stock is technically a compound option. That is, when a portion of the debt matures, the stockholders have the option to pay off that portion

[8] In contrast to stock options, where the price of the underlying asset is allowed to vary freely above or below the exercise price during the option's life, the option value of common stock may be reduced by the existence of bond covenants that generally do not allow the value of the firm to drop below a certain point without triggering technical default and forced renegotiation. To incorporate this feature into the Black–Scholes computations requires detailed assumptions about the constraints placed upon equity holders by firms' creditors. Since there is no theoretical or empirical guidance in making these assumptions, I use the standard Black–Scholes model to compute the sensitivity of common stock value to firm risk. Failure to incorporate this feature results in an upward-biased estimate of the option component and convexity contributed by common stock (see Core and Schrand (1998) for a detailed discussion of the impact of covenants on the option component of common stock).

Table 6
Description of parameters used in Black–Scholes computations for common stock

The sample consists of 278 CEOs selected uniformly from the 1000 largest firms on Compustat, ranked by market value of equity on December 31, 1988. All data are for 1993. Per-share stock price is the stock price on December 31, 1993. Per-share book value of debt is the book value of liabilities as of December 31, 1993. Per-share market value of assets is per-share stock price plus per-share book value of debt. Implied per-share market value of assets is computed using the Black–Scholes model (see Section A.2 of the appendix). The standard deviation of equity returns is the standard deviation of daily logarithmic stock returns over the last 120 trading days in 1993, multiplied by $252^{(1/2)}$. The standard deviation of debt is the standard deviation of monthly logarithmic returns on the Merrill Lynch corporate bond index that matches the firm's S&P senior debt rating, multiplied by $12^{(1/2)}$. The standard deviation of bond index returns is estimated over the five-year period ending December 1993. The standard deviation of equity and debt returns are used to compute the estimated standard deviation of returns on firm value (σ) (see Section A.2 of the appendix). The risk-free interest rate is the yield, as of December 31st, 1993, on a U.S. Treasury strip with the same time to maturity as the weighted average maturity of the firm's liabilities. The weighted average maturity of liabilities is estimated as described in Section A.2 of the appendix. Dividend yield is dividends per share paid during 1993, divided by the implied per-share market value of assets. Price-to-strike ratio is the implied per-share market value/per-share book value of debt. Sensitivity of stock price to a \$1 change in firm value is the change in the dividend-adjusted Black-Scholes value of common stock for a \$1 change in the value of the firm (see Section A.2 of the appendix).

Firm characteristics	Minimum	Median	Maximum
Per-share stock price (\$)	2.88	33.56	254.75
Per-share book value of debt (\$)	0.84	38.90	1632.73
Per-share market value of assets (\$)	9.78	76.75	1680.35
Implied per-share market value of assets (\$)	9.51	75.04	1617.96
Standard deviation of equity returns (%)	11.82	22.22	62.06
Standard deviation of debt returns (%)	3.48	4.15	12.24
Est. std. dev. of returns on firm value (%)	3.89	10.70	52.20
Risk-free interest rate (%)	3.22	4.33	5.57
Weighted average maturity of liabilities (yrs.)	0.50	2.57	7.60
Dividend yield (%)	0.00	1.11	5.06
Price-to-strike ratio	0.82	1.88	18.56
Sensitivity of stock price to a \$1 change in firm value (\$)	0.68	0.97	1.00

of debt and purchase an option to buy the firm for the remaining book value of debt. To approximate the sensitivity of wealth to firm risk for this compound option, I make the simplifying assumption that the firm has a single debt obligation with time to maturity equal to the weighted average time to maturity of the firm's debt. I assume a maturity of ten years for the portion of debt maturing in more than five years. For most banks, utilities, and insurance firms, maturity data for years two and over is unavailable. I assume these firms have an average maturity on long-term debt of 7.5 years, though the results are not sensitive to alternative maturity assumptions.

r = ln(1 + risk-free interest rate), where the risk-free interest rate is the yield, as of December 31, 1993, on a U.S. Treasury strip with the same time to maturity as the weighted average maturity of the firm's liabilities.

d = ln(1 + expected dividend rate on firm value), where the expected dividend rate is set equal to dividends paid during 1993 divided by the implied market value of the firm. Note that the dividend rate on firm value is not known ex ante. It is obtained in step (i) when the implied total market value of the firm is computed.

References

Agrawal, A., Mandelker, G., 1987. Managerial incentives and corporate investment and financing decisions. Journal of Finance 42, 823–837.

Baber, W., Janakiraman, S., Kang, S., 1996. Investment opportunities and the structure of executive compensation. Journal of Accounting and Economics 21, 297–318.

Black, F., Scholes, M., 1973. The pricing of options and corporate liabilities. Journal of Political Economy 81, 637–659.

Core, J., Schrand, C., 1998. The effect of accounting–based debt covenants on equity valuation. Journal of Accounting and Economics, forthcoming.

Cuny, C., Jorion, P., 1995. Valuing executive stock options with a departure decision. Journal of Accounting and Economics 20, 193–205.

Dechow, P., Hutton, A., Sloan, R., 1996. Economic consequences of accounting for stock-based compensation. Journal of Accounting Research 34 (Suppl.), 1–20.

DeFusco, R., Johnson, R., Zorn, T., 1990. The effect of executive stock option plans on stockholders and bondholders. Journal of Finance 45, 617–627.

Financial Accounting Standards Board, 1995. Accounting for stock-based compensation. SFAS No. 123, Norwalk, CT.

Froot, K., Scharfstein, D., Stein, J., 1993. Risk management: coordinating corporate investment and financing policies. Journal of Finance 48, 1629–1648.

Gaver, J., Gaver, K., 1993. Additional evidence on the association between the investment opportunity set and corporate financing, dividend, and compensation policies. Journal of Accounting and Economics 16, 125–160.

Haugen, R., Senbet, L., 1981. Resolving the agency problems of external capital through options. Journal of Finance 36, 629–648.

Hemmer, T., Matsunaga, S., Shevlin, T., 1994. Estimating the "fair value" of employee stock options with expected early exercise. Accounting Horizons 8, 23–42.

Huddart, S., 1994. Employee stock options. Journal of Accounting and Economics 18, 207–231.

Jensen, M., Meckling, W., 1976. Theory of the firm: managerial behavior, agency costs, and ownership structure. Journal of Financial Economics 3, 305–360.

Jensen, M., Murphy, K., 1990. Performance pay and top-management incentives. Journal of Political Economy 98, 225–264.

Lambert, R., Larcker, D., Verrecchia, R., 1991. Portfolio considerations in valuing executive compensation. Journal of Accounting Research 29, 129–149.

Mayers, D., Smith, C., 1987. Corporate insurance and the underinvestment problem. Journal of Risk and Insurance 54, 45–54.

Mayers, D., Smith, C., 1990. On the corporate demand for insurance: evidence from the reinsurance market. Journal of Business 63, 19–40.

Merton, R., 1973. Theory of rational option pricing. Bell Journal of Economics and Management Science 4, 141–183.
Milgrom, P., Roberts, J., 1992. Economics, Organization, and Management. Prentice-Hall Inc., Englewood Cliffs, NJ.
Myers, S., 1977. The determinants of corporate borrowing. Journal of Financial Economics 5, 147–175.
Ofek, E., Yermack, D., 1997. Taking stock: does equity-based compensation increase managers' ownership. Unpublished working paper. New York University.
Pratt, J., 1964. Risk aversion in the small and in the large. Econometrica (January), 122–136.
Smith, C., 1976. Option pricing. Journal of Financial Economics 3, 3–51.
Smith, C., Stulz, R., 1985. The determinants of firm's hedging policies. Journal of Financial and Quantitative Analysis 20, 391–405.
Smith, C., Watts, R., 1992. The investment opportunity set and corporate financing, dividends, and compensation policies. Journal of Financial Economics 32, 263–292.
Tufano, P., 1996. Who manages risk? An empirical examination of risk management practices in the gold mining industry. Journal of Finance 51, 1097–1137.
Yermack, D., 1995. Do corporations award CEO stock options effectively? Journal of Financial Economics 39, 237–269.