Can Employee Stock Options Contribute To Less Risk-taking?

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ABSTRACT

The executive compensation literature presumes that shareholders offer risk-averse managers stock options to entice them to take on more risk, resulting in riskier investment decisions and thus a greater return on investment. However, recent empirical work challenges this assumption, and theoretical research even argues that high levels of option-based compensation for generally under-diversified managers may actually lead to greater risk *aversion*. We evaluate the incentive structure of employee stock options by examining the level of R&D investment and the return on that investment conditional on the portfolio "vega", which captures the sensitivity of option value to stock price volatility. Our results suggest that both investment in R&D and the return on R&D, as measured by future earnings and patent awards, varies concavely with vega. That is, low to moderate levels of vega correspond to increasing investment in and returns on R&D, consistent with vega inducing more profitable investments, but marginal returns decline as vega increases. Collectively, these results, bolstered by several supplemental analyses, suggest that this surprising relation between vega and risky investment is driven by greater risk aversion at higher levels of vega. Overall, our results imply that employee stock options may not always align the incentives of manager and shareholders.

Keywords: Executive compensation; Managerial incentives; Risk-taking; Research and Development

1. Introduction

Conventional wisdom is that shareholders rely on employee stock options (ESOs) to incentivize risk-taking by managers. However, several analytical papers demonstrate that the accumulation of stock options over time can prove counterproductive (Carpenter 2000; Meulbroek 2001; Ross 2004). An increase in managers' exposure to idiosyncratic risk and the accumulation of managers' firm-specific wealth from additional ESOs can actually induce risk aversion rather than motivate risk-taking. Despite these provocative theoretical predictions, very little empirical research directly investigates how the accumulation of stock options corresponds to the riskiness of investment decisions. We address this issue by empirically examining the relations between the risk-taking incentives of the manager's stock option portfolio and both the level of R&D spending (a proxy for risky investment) and the related economic outcomes (profits and patents) of R&D spending, which reflect the underlying investment risk profile.

The asymmetric payoffs associated with ESOs reward managers for investing in risky but value-increasing projects. This presumably counteracts the risk-averse nature of managers and better aligns their interests with shareholders.[1] However, a stream of theoretical research suggests that the incentive effects of option awards are more complex and depend on the manager's utility function. Increasing manager wealth via ESOs, which cannot be sold or easily hedged, compounds managers' lack of diversification. This increases managers' exposure to idiosyncratic risk, which in turn decreases their appetite for volatility and risk-taking (Carpenter 2000; Meulbroek 2001; Lewellen 2003). Further, Ross (2004) proposes that the accumulation of

[1] In support of this view, a number of studies link managers' stock option portfolio vega (i.e., the sensitivity of manager wealth to stock price volatility) to greater risk-taking (Rajgopal and Shevlin 2002; Coles, Daniel and Naveen 2006; Rego and Wilson 2012). In particular, Coles et al. (2006) document a positive, monotonic relation between vega and the level of R&D spending.

option wealth may shift managers to a more risk-averse portion of their utility function. That is, managers must evaluate the incentive effects of ESOs in light of their relatively undiversified wealth. In spite of the convexity of the manager's payoff structure arising from option vega, greater levels of vega also imply that the manager's *wealth* is more susceptible to idiosyncratic volatility. This creates a disincentive for increasing firm risk that could dominate the incentives created by the ESO's convex payoff. Thus, we expect that managers attempting to protect their under-diversified, firm-specific wealth will exhibit greater risk avoidance as they accumulate option portfolios with higher levels of vega, manifesting as a concave relation between vega and risky investment.

While prior empirical studies focus on the convex payoff of options and document a positive relation between ESOs and risk-taking, the functional form of that relation has received little attention. Guay (1999) describes the tension between the wealth-performance effect of ESO convexity and a manager's natural aversion to risk but notes that the risk-aversion effect is very difficult to measure. Unlike the wealth-performance effect, which can be estimated using accepted option pricing models, the risk-aversion effect depends on a manager's diversification, total wealth and risk-aversion parameters that are inherently difficult to obtain.[2] Given the inability to directly observe many factors that determine a manager's risk aversion, we take the approach of examining investment outcomes to infer the extent of managerial risk-taking.

We provide initial evidence regarding these countervailing effects by re-examining how the level of risky investment varies with option compensation. Building on Coles et al. (2006), we first replicate their main finding of a positive, monotonic relation between R&D spending and portfolio vega. We then re-estimate the relation using a quadratic model that allows for non-

[2] The net preference towards additional risk depends on which of these effects dominates.

linearity (i.e., a model that includes a vega squared term).[3] Controlling for firm fixed effects, we find a significant concave relation indicating declining R&D investment as vega increases, though this effect diminishes when including CEO-firm fixed effects.[4] This result conforms with compensation theory suggesting that the accumulation of ESOs can diminish managers' willingness to take on additional risk.

Curtailing the level of R&D investment is but one way managers might limit their exposure to risk. Managers can also limit their exposure by selecting investments with a lower risk profile, arguably a strategy that is less transparent and less likely to trigger a negative market reaction than lowering R&D spending. Although we cannot directly observe the riskiness of investment projects, we can observe certain firm-level economic outcomes, such as future earnings and patent awards, which should reflect the risk underlying R&D. Relying on the classic risk-return relation that less risky investment should yield lower returns, we examine how two distinct measures of return on R&D, future earnings and patent awards, vary with a manager's portfolio vega. We fail to find a significant linear relation between vega and either return-on-R&D measure. However, after modeling each return measure as a quadratic function of vega, results reveal that higher levels of vega lead to diminishing returns on R&D, suggesting unresolved incentive alignment problems related to managers who presumably are being highly incentivized to engage in risky investment.

We supplement these findings by evaluating how R&D, conditional on vega, relates to total firm risk, measured as stock return volatility, and how the concentration of managers' firm-

[3] We model the relation as a quadratic function of vega because it allows for, but does not impose, a concave relation (a second derivative less than zero). This specification is quite common for modeling non-linearity. For example, in a related study, Hanlon, Rajgopal, and Shevlin (2003) utilize a quadratic function to examine non-linear effects of levels of stock options on performance.

[4] As we discuss later, the average number of observations per CEO-firm combination (4.4) is quite small in our sample, indicating that power may be an issue in specifications using these fixed effects.

related wealth affects these relations. If managers limit their exposure to idiosyncratic risk by curtailing investment in risky R&D, we should observe a second order effect on firm-level risk. Indeed, we find a concave association between R&D and future return volatility, consistent with diminished risk-taking for higher levels of vega. Further, according to the option compensation theory that supports our expectations, the concentration of managers' firm-related wealth contributes to increased risk aversion, which may more than offset their risk-taking incentives (Carpenter 2000; Meulbroek 2001; Lewellen 2003; Ross 2004). Therefore, we test and find that concavity for R&D level and both earnings- and patent-based returns is generally concentrated in managers with higher firm-related stock and option wealth. This is consistent with greater firm-specific wealth accentuating the sensitivity to firm-specific risk, leading managers to engage in less risk-taking in spite of a convex payoff structure.[5]

Additionally, we find weak evidence consistent with investors' discounting expectations of future cash flows related to R&D investment when vega is relatively high. We also conduct a placebo test, replacing R&D with less-risky capital expenditures in our regressions and fail to observe a concave relation, confirming that the non-linearity relates to more risk-sensitive investing decisions (Coles et al. 2006). Finally, we conduct a battery of other sensitivity tests and find that the tenor of our results is largely similar to our main specifications.

Overall, our results challenge the prevailing assumption that ESOs universally encourage risk-taking and provide support for previously untested theory on how accumulation of option-related wealth can alter managers' appetites for risk. Our study contributes to the executive

[5] As an alternative measure of risk aversion related to manager wealth, we partition the sample on the average length of time to expiration for the managers' portfolio of exercisable options. A longer average time suggests that the manager exercises his or her options more quickly, consistent with greater risk aversion. As with wealth effects, concavity is concentrated where greater risk aversion is expected.

compensation literature, which generally links managers' stock option portfolio vega to greater risk-taking (Rajgopal and Shevlin 2002; Coles et al. 2006; Rego and Wilson 2012). We extend Coles et al. (2006) by showing that the positive effect of vega on R&D investing diminishes rapidly at higher levels of vega. More importantly, we are among the first to study how vega affects the profitability of firms' portfolios. Results suggest that vega contributes to a diminishing rate of return on R&D, particularly for managers accumulating relatively higher levels of firm-related wealth. Our evidence highlights a potential unintended consequence of ESOs; that is, the accumulation of stock and ESO wealth may counteract presumed incentives from higher vega and contribute to greater risk aversion and less risky investment.[6] However, since we cannot observe all factors contributing to compensation contract design, we stop short of suggesting investment decisions are suboptimal or that compensation contracts are inefficient.

Our paper also contributes to the debate about the appropriateness and efficacy of option-based compensation contracts. Our results cast doubt on the assumption that large ESO awards always align manager and shareholder incentives. Our evidence that vega does not appear to uniformly mitigate risk aversion extends the evidence in other studies suggesting that boards do not necessarily award options for incentive alignment reasons (Dittmann and Maug 2007; Larcker and Tayan 2012; Shue and Townsend 2017; Hayes, Lemmon, and Qiu 2012).[7]

[6] These findings contrast with recent concern that excessive levels of ESOs contribute to excessive risk-taking (PWC 2009; Dong, Wang, and Xie 2010; Shen and Zhang 2013).

[7] Dittmann and Maug (2007) conclude that models of efficient contracting cannot explain the extent of ESO compensation commonly observed. Larcker and Tayan (2012) infer that boards simply renew contracts each year and do not anticipate how the accumulation of stock option wealth over time may shift the incentive structure away from its original intent. Similarly, Shue and Townsend (2017) document the tendency for firms to grant the same number of options from year to year and conclude that this arises from a lack of sophistication about option valuation. Hayes et al. (2012) find that ESO awards declined sharply following implementation of SFAS 123R, which required expensing the fair value of stock options, suggesting that firms favored ESOs to minimize expenses and report higher income. Further, they observe that the decline is unrelated to risk-taking behavior.

Finally, our study provides empirical evidence consistent with the theoretical arguments in studies like Ross (2004), Meulbroek (2001), Lewellen (2006) and Carpenter (2000). Specifically, our results suggest that managers' risk aversion may increase as they accumulate firm-specific wealth and become less diversified, resulting in less effective, or even counterproductive, stock option compensation.

2. Background and hypothesis development

ESO compensation and risk-taking

Traditional agency theory suggests that the convex payoff from ESO-based compensation reduces agency conflicts by better aligning managers' interests with those of shareholders (Jensen and Meckling 1976; Haugen and Senbet 1981; Smith and Stulz 1985; Lambert 1986). While share-based compensation can motivate managers to behave more like investors, a concentration of own-firm wealth may result in managers having a lower appetite for risk than the firm's investors. The convex nature of ESO-based compensation, which asymmetrically rewards risk-taking, is typically viewed as a means to counteract this risk-aversion. However, compensation features that affect ESO convexity (vega) could also affect a manager's risk aversion (Guay 1999).

Empirically, prior studies support the premise that ESO-incentivized managers take on greater risk. Coles et al. (2006) examine specific incentives derived from ESOs and find that higher vega leads to greater R&D spending and lower investment in property, plant, and equipment. Other studies link higher vega to riskier oil and gas exploration (Rajgopal and Shevlin 2002), higher leverage (Chava and Purnanandam 2010; Coles et al. 2006), and more aggressive tax avoidance strategies (Rego and Wilson 2012).[8] Panousi and Papanikolaou (2012) document that, as idiosyncratic risk increases, capital expenditures decline, but option compensation mitigates this negative relation.

Some studies suggest that the convex nature of ESO payoffs could encourage excessive risk taking, though the arguments are less compelling and evidence is mixed.[9] Closely related to our study, Shen and Zhang (2013) examine a small sample of firms exhibiting substantial increases in R&D spending and find that firms with relatively higher vega report lower future profitability and generate lower future stock returns. They conclude that self-interested managers overinvest in R&D.[10] Unlike Shen and Zhang (2013), who examine transient R&D expenditures, we examine the overall R&D investment profile and assess non-linearity in the relation between vega and the return on R&D, including future patents, arguably a more direct measure of R&D success or failure. We also differ from their study by linking the non-linearity to proxies for CEO risk aversion (i.e., firm-related wealth and length of time to expiration of exercisable options).

ESO compensation and heightened risk aversion

While option-pricing theory maintains that the *fair market value* of a stock option increases with volatility, risk-averse and under-diversified managers view ESOs through a

[8] Chava and Purnanandam (2010) also find that CEO vega is associated with lower cash balances, but Liu and Mauer (2011) find the opposite relation. To our knowledge, the reason for this discrepancy has not been investigated. One possibility is that Liu and Mauer (2011) scale vega by total compensation whereas most studies do not employ this scalar.

[9] For example, Dong, Wang, and Xie (2010) conclude that greater levels of option compensation can lead managers to make overly risky financing decisions, resulting in a sub-optimal capital structure (i.e., over-levered). Bhagat and Bolton (2014) attribute the 2007-2008 banking crisis to excessive levels of ESOs, which motivated executives to engage in overly risky behavior, though Fahlenbrach and Stulz (2011) reach the opposite conclusion.

[10] Other studies suggest an indirect link between ESOs and excessive risk-taking whereby overconfident and overly optimistic managers self-select into highly convex payoff schemes that expose them to greater risk (Gervais et al. 2011). This overconfidence can also result in managers overestimating the expected returns on potential investment opportunities and contribute to riskier or overly aggressive corporate decisions (Roll 1986; Malmendier and Tate 2005; Ben-David, Graham and Harvey 2013). This line of research suggests that high vega compensation packages can attract managers with certain characteristics that contribute to excessive risk-taking.

different lens. The implications of price volatility for managers' personal welfare likely lead them to value ESOs quite differently than suggested by the Black-Scholes model. Several analytical studies take distinct but overall congruent approaches to collectively conclude that the accumulation of firm-specific wealth in the form of ESOs and lack of diversification can magnify managers' risk aversion and discourage risk-taking behavior. Ross (2004) demonstrates that the accumulation of additional wealth from stock option awards could move managers to a different portion of their utility function where risk aversion may be greater. In spite of the options' convex payoff schedule encouraging risk-taking, managers may be more concerned with protecting their current wealth from future uncertainty and the potential for substantial loss from higher risk ventures. We expect this concern is most pronounced for relatively higher levels of vega since it directly captures the sensitivity of managers' wealth to volatility.

In addition to shifting managers along their utility function, the accumulation of options can exacerbate managers' lack of diversification. Lewellen (2006) suggests that evaluating managerial preferences for risk using the Black-Scholes model can be misleading when managers are risk averse and under-diversified. She further notes (p. 552) that "in-the-money options make the manager's portfolio more sensitive to changes in stock price, so they make the manager more averse to stock price volatility."[11] Meulbroek (2001) investigates the tension between incentive alignment and the manager's lack of diversification, noting that the manager is exposed to total firm risk while diversified investors are exposed only to systematic firm risk. Related to arguments in Ross (2004), she shows this dual risk-exposure leads managers to value their options at less than fair market value. Thus, as vega increases, the gap between managers'

[11] In-the-money options make the CEO's portfolio more levered in the stock such that changes in stock price have a greater impact on the portfolio's value. As a result, options magnify risk, increasing the CEO's aversion to stock volatility (Lewellen 2006).

and investors' expected returns widens. At some point, managers' expected returns fail to compensate them for their risk exposure (which is greater than an investor's risk exposure), leading to risk averse behavior.[12] Finally, Carpenter (2000) demonstrates that increasing the proportion of options in a manager's total portfolio value can increase the manager's exposure to the underlying assets' risk. This exposure, in turn, incentivizes the manager to decrease the volatility of the underlying assets. In other words, increasing a manager's sensitivity to asset risk can make him or her seek less risk. While taking different approaches, these theoretical studies are consistent in suggesting an inverse relation between stock option compensation and risk-taking behavior by managers at higher levels of vega, implying a concave association.

Challenges to ESO compensation as a means to align incentives

A concave relation between vega and actual risk-taking by the CEO implies some inefficiencies may exist in the incentive-alignment role of ESOs. Extant research supports the possibility of ESO-related inefficiencies. Dittmann and Maug's (2007) analysis of contracting models indicates that options are rarely predicted as an efficient component of compensation. They conclude that either currently employed contracting models are flawed or observed compensation practice suffers from significant deficiencies.[13] Hayes et al. (2012) find that ESO awards declined sharply following implementation of SFAS 123R, suggesting that firms favored ESO compensation to minimize expenses and report higher income.[14] Further, they observe that

[12] As Meulbroek (2001, p. 7) points out, if stock-based compensation were purely designed to align incentives, there would be no natural "stopping point", and managers' compensation would be 100 percent equity-based.
[13] Bebchuk and Fried (2003) claim that ESOs represent a form of hidden compensation rather than a tool to align incentives. Consistent with this, stock option plans substantially increased as stock values grew in the 1990s but declined over the 2000s as stock prices reversed.
[14] Prior to the passage of SFAS 123R (codified in ASC 718), which requires firms to expense the fair value of stock options granted over the service period, firms largely recorded no (or minimal) compensation expense using the then-acceptable intrinsic value method. Under this method, if options were granted with an exercise price equal to market price (i.e., no intrinsic value), no compensation expense was recorded.

the decline is unrelated to risk-taking behavior. More recently, Shue and Townsend (2017) document the tendency for firms to grant the same number of options from year to year. They observe that this number-rigidity arises from a lack of sophistication about option valuation. Likewise, Larcker and Tayan (2012) suggest that the accumulation of stock option wealth over time could result in a manager holding a portfolio with an incentive structure that is much different from what was originally intended. In summary, these studies imply the extent of ESO compensation observed in practice does not necessarily correspond to an efficient alignment of incentives for risk-taking.

Predictions

While the empirical literature to date documents a monotonic relation between a CEO's portfolio vega and risky investment, we build on theory arguing that a non-monotonic (concave) relation exists as greater stock option awards fail to incentivize the extent of risk-taking that shareholders desire. Consistent with prior studies, we focus our analysis on risky investment in R&D. Coles et al. (2006) document a positive relation between R&D and vega under the assumption that higher levels of R&D spending imply greater risk-taking.[15] They interpret their evidence as consistent with incentive alignment. However, the theoretical arguments discussed above maintain that an accumulation of stock option awards concentrates manager wealth in the firm, which increases their exposure to idiosyncratic risk and potentially increases their risk aversion. Although we cannot directly observe a CEO's risk aversion, vega directly measures his or her exposure to firm volatility. Thus, if CEOs with relatively higher levels of vega seek to mitigate their risk exposure, they could choose to scale back the investment in risky R&D. If so,

[15] Other studies viewing R&D as a measure of risky investment include Chambers et al. (2002), Kothari, Laguerre, and Leone (2002), Ho, Xu, and Yap (2004), and Ciftci and Cready (2011).

we should observe a *concave* relation between vega and the level of R&D spending. We express this expectation in the following hypothesis (stated in the alternative form):

H1: The relation between vega and the level of R&D investment is a concave function of vega.

R&D investment levels are reasonably transparent and capitalized by investors (Lev and Sougiannis 1996). As a result, managers may be reluctant to curtail R&D spending even with personal incentives to do so. As an alternative or complement to lowering R&D spending, managers could alter the risk profile of their investments, which is less transparent to investors. We envision a scenario in which managers consider a variety of R&D projects and must allocate investment dollars. Based on the option compensation theory discussed above, we expect that managers with relatively higher levels of vega are more inclined, consciously or subconsciously, to choose less risky projects. Since we cannot directly observe the inherent riskiness of R&D projects, we instead rely on the classic risk-return relation where higher-risk investments are expected to yield commensurately higher returns. We use ex post returns on R&D as an indicator of the underlying risk associated with those investments. In fact, we propose that higher return on R&D represents a sounder measure of investment riskiness than the number of dollars invested in R&D projects, as it is more consistent with shareholders' objective to stimulate investment in risky but positive NPV projects.

Our primary proxies for the return on R&D investments are the extent to which R&D expenditures correspond to greater future earnings and patent awards. While both proxies capture a common factor of return on R&D investment, each does so in a somewhat unique fashion. Future earnings reflect realized profits from R&D investment, arguably yielding the ultimate measure of R&D success or failure. Greater risk aversion implies a lower dollar-for-dollar mapping of R&D into future earnings. On the other hand, patent awards are a more immediate measure of success, representing a firm's ability to protect future returns on R&D investment from competition. Thus, we also expect that the frequency of patent awards is adversely affected by greater risk aversion, resulting in less innovation.

On average, we expect that vega incentivizes managers to invest in riskier R&D with higher expected returns, resulting in a positive relation between vega and future return on R&D. However, if increasing levels of vega at some point lead to overly conservative investment, as discussed above, then we expect to observe diminishing returns on R&D as vega increases. We express this expectation in the following hypothesis (stated in the alternative form):

H2: The relation between vega and return on R&D investment is a concave function of vega.

3. Research design and primary results

Sample, data, and variable measurement

Our sample begins with estimates of vega and delta for individual CEOs, which we obtain from Dr. Lalitha Naveen.[16] Vega (Delta) measures the sensitivity of a CEO's equity-holdings to a one-percent change in stock volatility (price). These estimates, derived from Execucomp, are available for S&P 1500 firms beginning in 1992. For patent awards, we use patent data from Kogan, Papanikolaou, Seru, and Stoffman (2012).[17] We collect the remaining variables from commonly used sources. Specifically, we obtain required annual financial statement information from the Compustat Annual Fundamentals file and stock return data from the Center for Research in Security Prices (CRSP) monthly and daily files. Because we use

[16] We graciously thank Dr. Naveen for providing vega and delta estimates and explanations on her website (http://sites.temple.edu/lnaveen/data/). Details of these calculations can be found in Coles, Daniel, and Naveen (2013). Detailed variable definitions are also available in our Appendix.
[17] We graciously thank Dr. Noah Stoffman for making the patent data from Kogan et al. (2012) publicly available on his website (https://iu.app.box.com/patents).

lagged values of vega throughout the analysis, our sample period begins in 1993. The latest year our patent data is available is 2010, so our sample period ends in 2009 (since we require current and one-year ahead patent awards, as discussed later). This yields a sample of 18,329 observations for our test of H1 related to the level of R&D investment. For our tests of H2 related to returns on R&D investment, we restrict our sample to firms with positive, non-missing values for R&D (Compustat data item *XRD*).[18] As mentioned, we use two different dependent variables to test H2, future earnings and patent awards. For earnings, we require three years of future, non-missing earnings data, which reduces the sample to 7,657 observations. Our patent sample totals 9,313 observations.

Table 1 provides descriptive statistics for our three samples related to R&D investment, future earnings and future patents, in Panels A, B, and C, respectively. Our test of H1 (R&D investment) includes firms with zero R&D, whereas our tests of H2 (return on R&D investment) do not. We focus our discussion below on the statistics displayed in Panel A, unless otherwise noted. All continuous, unlogged variables are winsorized at the 1st and 99th percentiles. Consistent with prior research (Chava and Purnanandam 2010; Dong et al. 2010), we use the natural logarithm of vega and delta to measure the sensitivity of CEO wealth to changes in stock volatility and price (*Vega* and *Delta*, respectively) given extreme skewness in the untransformed distributions. The median of unlogged *Vega* (*Delta*) is 48.72 (203.73). Thus, a one percent increase in implied volatility (stock price) increases the median CEO's wealth by approximately $48,720 ($203,730). These compare favorably with Coles et al. (2006) who report median vega

[18] Our test of H1 analyzes the relation between R&D and vega, using R&D as the dependent variable. Dropping firms with zero reported R&D would yield a censored distribution, violating a requirement of OLS. Accordingly, we report results for H1 using a larger sample that includes firms with no R&D, consistent with the sample used in Coles et al. (2006).

and delta estimates of $34,000 and $206,000, respectively, for an earlier period. We scale R&D investment by lagged total assets (*R&D)* and multiply by 100. Mean *R&D* is 3.04 percent of assets. The mean (median) unlogged value of total assets (*Asset*) is 12.6 billion (1.7 billion). The use of Execucomp and additional data requirements results in a sample of fairly large firms.

We calculate future return on assets (*ROA3*) using average earnings over the three years following the R&D expenditure, scaled by total assets in year *t*. We measure earnings using earnings before interest, taxes, depreciation, and amortization (i.e., EBITDA) plus R&D and advertising expense, similar to Ciftci and Cready (2011) who also examine the value created by corporate investment. We multiply this measure by 100 and report mean (median) *ROA3* of 28.68 (24.14). We calculate *Patent* as the total number of patents granted over years *t* to *t+1*, divided by total assets in year *t-1* times 100. Mean (median) *Patent* is 2.80 (0.98).

Table 2 reports Pearson (Spearman) correlations below (above) the diagonal using all available data for each pairwise correlation. Boldface indicates statistically significant correlations ($p < 0.05$). *Vega* relates positively to *Delta* (Pearson $\rho = 0.53$), highlighting the importance of controlling for *Delta* in evaluating the role of *Vega*. We also observe a positive correlation between *Vega* and *R&D* in the cross-section, supporting the presumed positive association between option compensation and risk-taking (Coles et al. 2006). Moreover, *ROA3* relates positively to *R&D, Vega*, and *Delta*, while *Patent* relates positively to *R&D* and *Vega*.

Before moving to a formal test of our hypotheses, we begin with a basic analysis that identifies how managers respond to large vega "shocks" under the assumption that these managers may face the greatest incentive to increase risk aversion. Specifically, we identify firms in the highest quintile of the change in vega from *t-1* to *t* and plot the mean *R&D*, *ROA3*, and *Patent* from *t-3* to *t+3* for these observations in Figure 1. Consistent with the tenor of our predictions, we observe that R&D investment and future returns (*ROA3* and *Patent*) increase up to the vega shock year but reverse course and decline in the following years. For example, relative to year *t-1*, R&D spending drops 23% over the next three years. Likewise, earnings (*ROA3*) drop 24% over that period. These preliminary results suggest that managers respond to a large increase in risk-taking incentives by subsequently reducing the riskiness of their investments, resulting in lower returns on those investments. These results challenge the notion that vega uniformly incentivizes risky investment. We next employ formal hypotheses tests.

Test of H1 – level of R&D

Our first test examines the relation between vega and the level of R&D spending. H1 predicts a positive but diminishing relation between the level of R&D spending and vega. As a foundation for that analysis and to facilitate comparison with prior research, we begin with a multiple regression model similar to that in Coles et al. (2006) that tests whether vega exhibits a positive relation with R&D investment. We then introduce quadratic terms that allow for nonlinear incentive compensation effects.

$$R\&D_{i,t} = \alpha + \beta_1 Vega_{i,t-1} + \beta_2 Vega^2_{i,t-1} + \beta_3 Delta_{i,t-1} + \beta_4 Delta^2_{i,t-1} + \beta_5 Asset_{i,t} + \beta_6 Growth_{i,t} + \beta_7 Lev_{i,t} + \beta_8 Adv_{i,t} + \beta_9 Tang_{i,t} + \beta_{10} Tenure_{i,t} + \beta_{11} CashComp_{i,t} + \beta_{12} Surplus_{i,t} + \beta_{13} Sale_{i,t} + \beta_{14} Ret_{i,t} + \beta_{15} CapEx_{i,t} + \beta_{16} LagR\&D_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

We use lagged values of *Vega* and *Vega* ^{2} to mitigate endogeneity between investment and compensation policy choices (i.e., minimize the chance that investment decisions impact compensation). Based on evidence in Coles et al. (2006), we expect $\beta_1 > 0$.[19] However, our

[19] Similar to interactive settings with uncentered variables, the coefficient on the lower order *Vega* term in a quadratic model reflects the effect of *Vega* at 0 (or close to 0), where the quadratic term drops out. Given *Vega* does take a value of 0 for some observations in our sample, we do not center it and predict it takes a positive value, consistent with lower levels of *Vega* increasing risk-taking (before the quadratic term dominates). Mean-centering would alter the coefficient on *Vega* but not *Vega*^{2}.

particular interest is in whether higher vega is associated with a diminishing rate of investment in R&D. If R&D is a concave function of *Vega*, the second derivative of the relation should be negative, which would result in a negative coefficient on the $Vega^2$ term ($\beta_2 < 0$). We include *Delta* and $Delta^2$ to capture other ways stock-based compensation might influence manager behavior and impact R&D investments, although we make no prediction of a non-linear relation with *Delta*. We also control for several firm characteristics that likely influence R&D spending and compensation contract design. *Asset* controls for the fact that larger firms are less likely to incur losses and invest more in R&D. Higher growth (*Growth*), higher cash surplus (*Surplus*), and higher sales revenues (*Sale*) yield greater expected economic rents, which likely generate future earnings and dictate investment policy. Greater leverage (*Lev*) implies fewer growth prospects and potentially some level of financial distress, which could impact investments. Advertising (*Adv*) and capital expenditures (*CapEx*) represent other investment outlays that could serve as substitutes for R&D. Tangible assets and CEO tenure (*Tang, Tenure*) are potential determinants of firm risk. We also control for the CEO's cash compensation (*CashComp*), fiscal year returns (*Ret*), prior-year R&D (*LagR&D*), and year fixed effects. Importantly, we include either firm or CEO-firm fixed effects to control for cross-sectional variation in unobservable firm and manager characteristics that could explain the relation between vega and R&D, thus focusing our tests on intertemporal variation to capture within firm or CEO-firm relations.[20]

[20] Including CEO-firm fixed effects to further control for CEO characteristics that could influence risk-taking behavior, including their innate risk aversion and private wealth. In contrast to firm-specific wealth, which we hypothesize increases CEO sensitivity to firm volatility and discourages risky investment, greater outside wealth (Becker 2006) or total personal wealth (Calvet and Sodini 2014) could reduce risk aversion.

Table 3 displays the results of estimating equation (1).[21] We include firm fixed effects in columns (1) and (2) and include CEO-firm fixed effects in column (3). The results in column (1) exclude the squared terms, $Vega^2$ and $Delta^2$, to more closely mirror Coles et al.'s (2006) analysis and confirm their inferences.[22] We observe a significant positive coefficient on *Vega* (β_1 = 0.049, p = 0.004), consistent with the overall conclusion of Coles et al. (2006) that greater sensitivity to stock volatility encourages risky investment. With the squared terms included in column (2), the coefficient on *Vega* increases in magnitude (from 0.049 to 0.143) and remains significant (p = 0.004), while the coefficient on $Vega^2$ is negative (β_2 = -0.015) and significant (p = 0.043). This result implies that investments in R&D increase with vega but at a declining rate, consistent with H1.[23] Thus, we find that higher levels of vega result in a declining rate of R&D investment relative to more moderate levels of vega.[24]

Results in column (3) with CEO-firm fixed effects again indicate a significant positive *Vega* coefficient (β_1 = 0.134). While the coefficient on $Vega^2$ is negative (β_2 = -0.016) and similar in magnitude to the firm fixed effects model, it is insignificant at conventional levels (p = 0.127). Given that the magnitude of the coefficient remains relatively stable, the decline in significance is likely the result of the loss of power in fixed effect estimation, which increases

[21] As mentioned previously, we include observations with zero R&D expense to avoid truncating the distribution. Following prior research, we set missing values of R&D to zero for the purpose of this analysis (Chambers et al. 2002; Coles et al. 2006; Ciftci and Cready 2011). We find similar results using a Tobit estimator, which corrects for bias associated with censored distributions.

[22] Coles et al. (2006) report a significant positive coefficient on vega using industry fixed effects but an insignificant coefficient after including firm fixed effects. Based on this result, they note that the relation between vega and R&D is likely strong in the cross-section but not in the time-series. However, our sample period is nearly twice as long as theirs, which adds significant power to within-firm (time-series) tests. Note that we also find a positive relation between *Vega* and *R&D* when using industry fixed effects.

[23] We perform a number of robustness and sensitivity tests related to all hypotheses tests, which we summarize in Section 4.

[24] Note that this inference differs significantly from Shen and Zhang (2013), who conclude that high-vega compensation encourages managers to overinvest in R&D. However, as discussed in Section 2, they focus on a small set of firms exhibiting large increases in R&D spending.

noise in the model. As mentioned, our sample includes an average of only 4.4 observations per CEO-firm combination (compared to 8.2 observations per firm in columns (1) and (2)). Overall, however, the results of our test of H1 generally suggest non-monotonicity in the relation between vega and R&D investment, which we explore further in the following sections.

Test of H2 – future earnings

Our tests of H2 examine alternative measures of return on R&D investment, with the expectation that the rate of return on R&D will be a concave function of vega. We initially test this hypothesis using future earnings as a proxy for R&D return. Similar to H1, we first estimate the linear relation before adding quadratic terms to the following model:

$$\begin{aligned} ROA3_{i,t+1\ to\ t+3} = \alpha + R\&D_{i,t}\big(&\beta_1 + \beta_2 Vega_{i,t-1} + \beta_3 Vega^2_{i,t-1} + \beta_4 Delta_{i,t-1} + \\ &\beta_5 Delta^2_{i,t-1} + \beta_6 Asset_{i,t}\big) + \beta_7 Vega_{i,t-1} + \beta_8 Vega^2_{i,t-1} + \beta_9 Delta_{i,t-1} + \\ &\beta_{10} Delta^2_{i,t-1} + \beta_{11} R\&D^2_{i,t} + \beta_{12} Asset_{i,t} + \beta_{13} Growth_{i,t} + \beta_{14} Lev_{i,t} + \beta_{15} Adv_{i,t} + \\ &\beta_{16} CapEx_{i,t} + \beta_{17} ROA0_{i,t} + \beta_{18} Loss_{i,t} + \beta_{19} Loss * ROA0_{i,t} + \varepsilon_{i,t+1\ to\ t+3} \end{aligned} \quad (2)$$

The terms in parentheses capture the future earnings generated by a dollar of *R&D* conditional on the lagged incentive structure and firm size.[25] We refer to this composite weighting as "the return on R&D."[26] Our parameters of interest are β_2 and β_3. If *Vega* leads to riskier investment with greater expected returns, we expect $\beta_2 > 0$. If this increase occurs at a diminishing rate, as predicted in H2, we should find that $\beta_3 < 0$.[27] Similar to equation (1), we include *Delta* and

[25] All variables used in interactions are centered about their mean values to facilitate interpretation of the coefficients of these variables' main effects. Centering also reduces multicollinearity in interactive models, stabilizing standard error estimates. Note that we center *Vega* and *Vega*^{2} separately (rather than centering *Vega* before squaring) so that the interaction between *Vega* and *R&D* still reflects the effect of *Vega* on the return on R&D at low levels of *Vega*, similar to equation (1).
[26] Pakes and Schankerman (1984) suggest that R&D generally contributes to the firm's revenue stream up to two and a half years following the expenditure. We use a three-year window beginning in year t+1 to fully capture this range but consider alternative windows in later analyses.
[27] Curtis et al. (2015) document a significant decline in the return on R&D over time. However, this decline is steepest from 1980 to 1994, and, more importantly, relatively flat over the latter years of their sample period, which corresponds to the years we study.

Delta^2 for control purposes. We also include firm characteristics that likely contribute to future earnings and R&D spending (e.g., *Asset*, *Growth*, *Lev*). We include *R&D*^{2} to control for any potential non-linearity in the basic relation between R&D spending and future profitability. Advertising (*Adv*) and capital expenditures (*CapEx*) represent other investment outlays that contribute to future earnings and could serve as substitutes for R&D. We control for current ROA (*ROA0*) to address concerns that current profitability may influence the current level of vega and R&D.[28] Last, losses do not generally persist, so we include a loss indicator (*Loss*) as well as an interaction between *Loss* and *ROA0*. Importantly, we again include year fixed effects and firm or CEO-firm fixed effects when estimating equation (2).

We report results in Table 4, where we control for firm fixed effects in columns (1)-(4) and CEO-firm fixed effects in column (5).[29] Initial results reported in column (1) demonstrate a positive relation between *R&D* and future profitability. We also observe a direct, albeit negative, relation between *Vega* and future profitability in column (1) but fail to find that the rate of return on R&D (i.e., *Vega*R&D*) increases linearly with *Vega* ($\beta_2 = -0.020$, $p = 0.660$). In column (2), as predicted, the return on R&D varies non-linearly with *Vega.* β_2 is now significantly positive ($\beta_2 = 0.182$, $p = 0.070$), and β_3 is significantly negative ($\beta_3 = -0.029$, $p = 0.059$). We find little evidence in column (3) that *Delta* relates to future profitability, either directly or through R&D.

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[28] We recognize that many papers within the executive compensation literature suggest the potential for endogeneity between executive compensation and firm performance, whereas our research design treats vega as exogenous with respect to future earnings. Research finds little support for the notion that *future* pay-offs influence current compensation (Holthausen, Larcker, and Sloan 1995; Rajgopal and Shevlin 2002), though current profitability may influence the current level of vega. Failing to control for current profitability may result in an omitted variable bias. Therefore, we include current ROA (*ROA0*) in equation (1), although results are not sensitive to its inclusion or exclusion.

[29] The complexity of this model could raise concerns about multicollinearity. While high collinearity between two variables (e.g., X and Z) can lead to serious problems, high collinearity between XZ and X and between XZ and Z is generally not problematic (Jaccard and Turrisi 2003). After dropping all interaction and squared terms from our models and estimating variance inflation factors (VIFs), we do not observe any VIFs exceeding three. Further, we center variables as discussed earlier, which further mitigates multicollinearity concerns.

The results for the full model reported in column (4) represent our test of H2. The negative coefficient on *Vega*^{2}**R&D* (β_3 = -0.030, p = 0.041) supports H2 and suggests that the accounting return on R&D is a concave function of *Vega.* Coupled with the significantly positive coefficient on β_1, these results suggest that the profitability of *R&D* increases with *Vega,* but at a decreasing rate. Several control variables included in the full model also have significant explanatory power. Confirming Ciftci and Cready's (2011) evidence that the return on R&D increases in firm size, the coefficient on *Asset*R&D* is positive.

When we control for CEO-firm fixed effects in column (5), the coefficients of interest (β_2 and β_3) increase in absolute magnitude but provide weaker statistical support for H2, likely due to the low power discussed earlier. Overall, our results in Table 4 support H2 and are consistent with the conclusion that higher levels of vega do not uniformly correspond to value-increasing investments in R&D. More specifically, as vega increases within a firm or CEO-firm over time, future profitability attributable to R&D implies decreasing marginal benefits.

Test of H2 – patents

Our second test of H2 involves a more direct outcome of R&D investment, the number of patents subsequently granted to the firm (Hausman, Hall, and Griliches 1984; Hall, Griliches, and Hausman 1986; Griliches 1990; Hirshleifer, Hsu, and Li 2013). Prior research suggests that the relation is nearly contemporaneous (i.e., one or two lags of R&D spending effectively explain patent awards), consistent with firms filing for patents early in the R&D process (Hall et al. 1986). Accordingly, we define *Patent* as current and year-ahead patent awards, scaled by total assets in year *t-1,* times 100. We regress *Patent* on current R&D conditional on vega to test H2 using the following model:[30, 31]

$$Patent_{i,t\ to\ t+1} = \alpha + R\&D_{i,t}(\beta_1 + \beta_2 Vega_{i,t-1} + \beta_3 Vega^2_{i,t-1} + \beta_4 Delta_{i,t-1} + \beta_5 Delta^2_{i,t-1} + \beta_6 Asset_{i,t}) + \beta_7 Vega_{i,t-1} + \beta_8 Vega^2_{i,t-1} + \beta_9 Delta_{i,t-1} + \beta_{10} Delta^2_{i,t-1} + \beta_{11} R\&D^2_{i,t} + \beta_{12} Asset_{i,t} + \beta_{13} Growth_{i,t} + \beta_{14} Lev_{i,t} + \beta_{15} Adv_{i,t} + \beta_{16} CapEx_{i,t} + \beta_{17} ROA0_{i,t} + \beta_{18} Loss_{i,t} + \beta_{19} Loss * ROA0_{i,t} + \varepsilon_{i,t\ to\ t+1} \quad (3)$$

We report results in Table 5, where we control for firm fixed effects in columns (1)-(4) and CEO-firm fixed effects in column (5). Results for *Patent* in Table 5 follow a strikingly similar pattern to those for *ROA3* in Table 4. Across all models in Table 5, the coefficient on *R&D* is consistently positive and significant. In the linear specification, column (1), we fail to find a significant relation between *Patent* and *R&D* conditional on *Vega* (β_2 = -0.006). In column (2) where we allow for non-linearity, results indicate that the coefficient on *Vega*R&D* is significantly positive (β_2 = 0.047, p = 0.021), while the coefficient on $Vega^2$**R&D* is significantly negative (β_3 = -0.008, p = 0.004), consistent with H2. Adding the *Delta* terms in column (3) has little effect on results for *Vega*R&D* and $Vega^2$**R&D*. In column (4), results for the full model (including firm fixed effects and other controls) indicate that the positive relation between patent issuance and lagged R&D diminishes for higher vega (β_2 = 0.044, p = 0.018; β_3 = -0.005, p = 0.053).[32] These results support H2 in that the ability of R&D to generate patents diminishes as a CEO's portfolio vega increases. When we control for CEO-firm fixed effects, results in column (5) again support H2 with slightly weaker significance for the negative coefficient on $Vega^2$**R&D* (β_3 = -0.004, p = 0.076), which we attribute to lower statistical power.

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[30] Consistent with future profitability (*ROA3*), we scale patents by lagged assets and regress that on R&D scaled by lagged assets. Thus, equation (3) models the number of patents issued per dollar of R&D investment.
[31] As in the previous section, all variables used in interactions are centered about their mean values to facilitate interpretation of the coefficients of these variables' main effects.
[32] As with equation (2), excluding *ROA0* from equation (3) has little effect on the coefficient estimates relating future patents to *Vega*R&D*, indicating that potential omitted variable bias regarding the relation between current profitability and vega is not severe.

Summary of hypotheses tests

Overall, our results generally suggest that the riskiness of R&D investment (both level and return on) varies concavely with vega. To illustrate the economic significance of these results, in Figure 2 we plot the *marginal* effect of vega on investment riskiness across the distribution of *Vega* in our sample. Specifically, we plot the fitted marginal effect (combination of *Vega* and $Vega^2$ coefficients) for our three primary tests (i.e., *R&D*, *ROA3*, and *Patent*) across 50 different values of vega (corresponding to every 2nd percentile from 1 to 99). We define these percentiles based on our maximum sample (Table 3), but results are very similar using the restricted sample.

The plots provide compelling evidence that concavity in the relation between vega and R&D investment (top figure) and returns on R&D (middle and bottom figures) begins at reasonably low levels of vega and is economically meaningful. For the level of R&D investment, the plot rises quickly but levels out at about the 30th portfolio (i.e., 60th percentile) and actually declines as it approaches the highest portfolio. *Patent* (bottom figure) follows a similar pattern. Interestingly, return on R&D captured in *ROA3* (middle figure) flattens at lower levels of vega and declines over the last ten portfolios. These results illustrate the severity of concavity and support our conclusion that higher levels of risk-taking incentives do not uniformly correspond to value-increasing R&D investment.

4. Additional analyses and robustness tests

Return volatility

Our evidence indicates that investment in risky R&D increases at a declining rate with vega, consistent with greater risk aversion for managers with elevated levels of vega. We provide additional evidence regarding this interpretation by examining whether higher vega leads managers to reduce risk-taking such that it moderates the association between *R&D* and future return volatility, a broad proxy for firm risk. If higher vega induces greater risk aversion, as our prior results suggest, we should observe a positive but diminishing relation between stock return volatility and R&D spending conditional on vega. We use the following model to test this prediction:

$$RetVol3_{i,t+1\ to\ t+3} = \alpha + R\&D_{i,t}\left(\beta_1 + \beta_2 Vega_{i,t-1} + \beta_3 Vega^2_{i,t-1} + \beta_4 Delta_{i,t-1} + \beta_5 Delta^2_{i,t-1} + \beta_6 Asset_{i,t}\right) + \beta_7 Vega_{i,t-1} + \beta_8 Vega^2_{i,t-1} + \beta_9 Delta_{i,t-1} + \beta_{10} Delta^2_{i,t-1} + \beta_{11} Asset_{i,t} + \beta_{12} Growth_{i,t} + \beta_{13} Lev_{i,t} + \beta_{14} Adv_{i,t} + \beta_{15} Tang_{i,t} + \beta_{16} ROA3_{i,t} + \beta_{17} R\&D^2_{i,t} + \beta_{18} CashComp_{i,t} + \beta_{19} Sale_{i,t} + \beta_{20} Tenure_{i,t} + \beta_{21} RetVol0_{i,t} + \beta_{22} CapEx_{i,t} + \beta_{23} Age_{i,t} + \varepsilon_{i,t+1\ to\ t+3} \quad (4)$$

RetVol3 (*RetVol0*) is the average monthly stock return volatility for firm *i* in years *t+1* to *t+3* (year *t*).[33] We use a similar set of control variables as previous models in our study but add *RetVol0* and firm age (*Age*) as additional controls for firm risk. We also control for *ROA3* to account for the relation between future profitability on risk.

We report models with firm fixed effects in columns (1)-(3) and CEO-firm fixed effects in column (4) of Table 6. Interestingly and contrary to expectations, results for the linear *Vega* term in column (1) indicate a decreasing incremental effect on the relation between return volatility and R&D (β_2 = -0.010). However, when we include the $Vega^2$ terms in column (2) and all control variables in column (3), we observe positive and significant coefficients on the linear vega term (*Vega*R&D*) and negative and significant coefficients on the non-linear vega term ($Vega^2$**R&D*). Controlling for CEO-firm fixed effects in column (4), we find a positive though insignificant coefficient on *Vega*R&D* and negative and significant coefficient on $Vega^2$**R&D*, the latter of which again confirms concavity. Coupled with our prior tests, these results are

[33] We also compute *RetVol* using daily stock return volatility and obtain virtually identical results.

consistent with the overall risk-return profile of R&D decreasing at higher levels of vega and further support the view that greater levels of vega accentuate managers' risk aversion.

Manager wealth

Theory supporting our expectations of non-linearity argues that managers' increased sensitivity to volatility and losses can induce greater risk aversion. As discussed earlier, prior research (e.g., Carpenter 2000; Meulbroek 2001; Ross 2004) suggests that this may occur because managers value their options through the lens of their personal utility function and attitudes toward risk. Bebchuk and Fried (2003) further argue that managers' risk aversion is increasing in their accumulated *firm-specific* wealth. Although some evidence suggests that greater aggregate (Calvet and Sodini 2014) or external personal wealth (Becker 2006) may reduce risk aversion, managers with high concentrations of wealth in their own firm are unable to hedge their significant exposure. To explore this interpretation, we conduct analyses using an estimate of managers' accumulated firm-specific stock and option wealth (*MgrWealth*) as a conditioning variable.[34] If managers with greater firm-related wealth are more exposed and sensitive to risk arising from R&D investment, then the previously documented non-linear effect of vega on the level and return on R&D should be most evident for these managers.

After partitioning our sample at the median value of *MgrWealth*, we re-estimate our R&D investment models (equations 1, 2, and 3) within each partition. Results in Panel A of Table 7 indicate that for *R&D* level, *ROA3* and *Patent*, the concavity is concentrated in the high *MgrWealth* subsamples. The combination of higher firm-related wealth and increasingly high

[34] *MgrWealth* is the value of the CEO's firm-related stock and option portfolio as of the fiscal year-end (in $000s). The value of the share portfolio is the number of shares outstanding times the share price at fiscal year-end. The value of the option portfolio is computed using the Black-Scholes (1973) model, adjusted for dividends following Merton (1973). *MgrWealth* estimates are obtained from the data described in Coles, Daniel, and Naveen (2013).

levels of vega lead to diminishing investment in and returns on R&D, consistent with risk-avoidance rather than risk-taking behavior.[35] That is, managers who have accumulated more firm-specific wealth, coupled with low to moderate levels of vega, engage in greater risk-taking. However, as vega increases, the greater exposure of their accumulated wealth to firm-specific volatility can accentuate manager risk-aversion and discourage risk-taking behavior. Results in Panel B are consistent with Panel A except for the *R&D* level results, where the concavity becomes insignificant in both partitions.

As an alternative partitioning variable to *MgrWealth*, we consider the average length of time to expiration for the managers' portfolio of exercisable options. Malmendier and Tate (2005) argue that managers who hold their exercisable options longer, resulting in a shorter average time to expiration, are more overconfident. A longer average time to expiration suggests that managers tend to exercise their options more quickly (and forego the time value of holding the option), consistent with less managerial self-confidence. Accordingly, we expect that managers who prefer to exercise options sooner will also exhibit relatively greater risk aversion and hence, greater concavity in vega. After partitioning the sample at the median average time to expiration, for managers who tend to exercise options earlier (i.e., higher risk aversion), we observe significant concavity with *ROA3* ($\beta_2 = 0.90$, $p = 0.04$; $\beta_3 = -0.09$, $p = 0.08$) and weaker evidence of concavity with *Patent* ($\beta_2 = 0.89$, $p = 0.04$; $\beta_3 = -0.09$, $p = 0.11$), consistent with greater risk aversion contributing to the non-linearity.[36] Alternatively, we fail to find significant concavity in *ROA3* or *Patents* for managers with a shorter time to option expiration (i.e.,

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[35] The lack of a vega effect in the low *MgrWealth* subsample may indicate a higher concentration of factors other than risk-taking that motivate the use of stock and option compensation for these firms.

[36] Note that time to option expiration is only available for the last few years of our sample period (beginning in 2007), yielding a sample of roughly 1,000 observations across the two partitions.

managers who delay exercising, suggesting lesser risk aversion). These results are qualitatively similar when including CEO-firm fixed effects in place of firm fixed effects.

Investor response

We also examine how investors price the economic outcomes induced by higher vega. Evidence that the market capitalizes R&D expenditures suggests that investors have relevant information for pricing R&D investment (Lev and Sougiannis 1996). Extending this notion, we consider whether investors condition their pricing of R&D on managers' incentives.[37] In our setting, the market's capitalization of R&D could vary with vega if investors respond to the extent of ESO compensation or the nature of the investment portfolio itself. We estimate a model similar to equation (2) but replace the dependent variable *ROA3* with raw stock returns in year *t* (*Ret*).

$$\begin{aligned} Ret_{i,t} = \alpha + R\&D_{i,t}\big(&\beta_1 + \beta_2 Vega_{i,t-1} + \beta_3 Vega^2_{i,t-1} + \beta_4 Delta_{i,t-1} + \beta_5 Delta^2_{i,t-1} + \\ &\beta_6 Asset_{i,t}\big) + \beta_7 Vega_{i,t-1} + \beta_8 Vega^2_{i,t-1} + \beta_9 Delta_{i,t-1} + \beta_{10} Delta^2_{i,t-1} + \\ &\beta_{11} R\&D^2_{i,t} + \beta_{12} Asset_{i,t} + \beta_{13} MTB_{i,t} + \beta_{14} Growth_{i,t} + \beta_{15} Lev_{i,t} + \beta_{16} Adv_{i,t} + \\ &\beta_{17} CapEx_{i,t} + \beta_{18} ROA0_{i,t} + \beta_{19} Loss_{i,t} + \beta_{20} Loss * ROA0_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (5)$$

The dependent variable, *Ret*, is defined as the fiscal year buy-and-hold stock return for firm *i*. We include earnings in year *t* (*ROA0*) in the model as a proxy for firm-specific news during the period and other control variables as well as year and industry fixed effects. Once again, we center interacted variables and are primarily interested in β_2 and β_3.

Results in Table 8 indicate concavity in the pricing of R&D conditional on vega. While the coefficient on the linear vega term (β_2) is positive (0.078) but insignificant, the coefficient on the squared vega term (β_3) is negative (-0.057) and significant (p = 0.019), implying declining

[37] We follow the approaches in studies like Lev and Sougiannis (1996) and Ciftci and Cready (2006), who relate raw returns to R&D. This approach recognizes that R&D may relate to both the unexpected and expected components of returns (Berk, Green, and Naik 2004).

rates of R&D pricing as vega increases.[38] This pattern suggests that investors recognize and discount the diminishing economic benefits of R&D when coupled with greater stock option incentives.

Capital expenditures

We next examine returns to capital expenditures, a less risky form of investment, conditional on vega to provide additional assurance that our results are explained by investment risk and not the nature of investment decisions more generally. We replace *R&D* with capital expenditures deflated by total assets (*CapEx*) in equations (1), (2), and (3), and assess its relations with R&D, future earnings, and patent awards, respectively. In untabulated results, we find no evidence of concavity using *CapEx* in place of *R&D* in any of the models, demonstrating that concavity is limited to the riskier nature of R&D investing.

Missing R&D firms

Koh and Reeb (2015) provide evidence that firms failing to report R&D expenditures ("missing R&D" firms in Compustat) are systematically different from "zero R&D" firms and likely have nontrivial innovation activity. They suggest that replacing missing R&D with the industry-average value of R&D and including a "missing R&D" dummy significantly improves specification for models in their paper. We utilize Koh and Reeb's (2015) approach and re-estimate equations (1), (2), and (3) using expanded samples. Untabulated analyses indicate that results related to *R&D* are not significant for this sample while those related to *ROA3* and *Patent*

[38] The significantly positive coefficient on the interaction between *ROA0* and *Loss* likely reflects the fact that investors price loss firms differently than profit firms, consistent with Hayn (1995). In addition, we note that despite a highly positive correlation between *ROA0* and *Ret* (Pearson $\rho = 0.31$), the lack of a significantly positive coefficient on *ROA0* parallels the results of Lev and Sougiannis (1996), who find no relation between earnings and returns for their sample of firms (see Table 5, p. 132).

indicate significant concavity when including firm fixed effects.[39] The concavity remains significant when including CEO-firm fixed effects for the *Patent* model, but not for *ROA3*.

Innovative efficiency

As an alternative measure of return on R&D investment, we examine the relation between vega and innovation efficiency (*IE*), which expresses patents as a ratio to R&D capital. We follow Hirshleifer et al. (2013) and construct *IE* as the number of patents scaled by 5-year accumulated R&D capital, where R&D is depreciated on a straight-line basis. We re-estimate equation (3), replacing *Patent* with *IE* and removing all *R&D* terms, (including interactions). In untabulated results, we find that *Vega* relates negatively (β_1 = -0.017) to *IE*, while $Vega^2$ relates positively (β_2 = 0.003). That is, low to moderate vega leads to declining innovation, while the rate of decline slows for higher vega. This does not support theory and prior empirical evidence, however we emphasize caution in interpreting these results. Specifically, recall that we find a concave relation between vega and R&D investment (H1). With accumulated R&D in the denominator of *IE*, it is difficult to disentangle whether the convex association we observe between vega and *IE* reflects true convexity in innovative efficiency or is simply a manifestation of inverting the concave relation between R&D investment and vega.[40]

Miscellaneous robustness tests

We perform a number of untabulated sensitivity tests related to the estimation of equations (1), (2), and (3), corresponding to our *R&D*, *ROA3*, and *Patent* models, respectively.

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[39] Specifically, for *ROA3* the coefficients (p-values) for *Vega**R&D* and $Vega^2$**R&D* are 0.16 (0.03) and -0.04 (0.02), respectively. For *Patent* the coefficients (p-values) for *Vega**R&D* and $Vega^2$**R&D* are 0.08 (0.04) and -0.002 (0.04), respectively.

[40] In a supplemental test, we estimate equation (1) after replacing the dependent variable (*R&D*) with the inverse of R&D capital (i.e., 1 ÷ R&D capital), the denominator of IE. Results indicate convexity in the relation with vega (β_1 = -0.005, *t*-statistic = 2.93; β_2 = 0.001, *t*-statistic = 3.26), which likely contributes to the overall convexity in the relation between IE and vega.

Similar to our main tests, we employ either firm fixed effects or CEO-firm fixed effects. First, we require positive earnings to remove any loss effects. Second, we replace *Asset* with market value of equity (*MVE*), consistent with firm size in Ciftci and Cready (2011). Third, we add the interaction between MVE^2 and *R&D* in the model since MVE^2 arguably correlates with $Vega^2$ and $Delta^2$. Fourth, we include the fair value of stock option grants and the fair value of stock option grants squared as control variables given evidence in Hanlon et al. (2003) of a concave stock option-earnings relation. We generally find significant concavity except for the *R&D* model with CEO-firm fixed effects. We also add $Asset^2$ to each model and find that concavity remains significant except for in the *ROA3* model.

We also scale R&D by sales (i.e., R&D intensity) instead of assets. We find significant concavity only in the patents model. However, further analysis reveals that the decline in significance in the *ROA3* model is largely attributable to loss firms (for which sales may be a poor scalar). After excluding losses, which are generally transitory (Joos and Plesko 2005), we once again find a significant concave relation in the *ROA3* model with firm (though not CEO-firm) fixed effects. Last, we consider alternate performance horizons for *ROA3* and *Patent* in equations (2) and (3). For *ROA3*, we consider one- and two-year ahead horizons and find stronger results, regardless of the fixed effect structure. We also consider patent awards over 1-year (t) and 3-year (t through $t+2$) horizons. We fail to find a concave relation between R&D and patent awards with a 1-year horizon, but we do find concavity with the 3-year horizon and firm fixed effects.

While these results exhibit some variation, the vega terms of interest in equations (1), (2), and (3) remain significant at conventional levels in most tests. We believe they continue to support our conclusion that higher levels of vega lead to diminishing R&D investment and returns on R&D.

5. Conclusion

We demonstrate that the accumulation of executive stock options can have a diminishing marginal effect on risky investment. As the sensitivity of managers' wealth to stock price volatility (i.e., vega) increases, R&D spending and return on R&D (i.e., future earnings and patents awarded) initially increase. However, with higher vega, the rate of investment in and returns to R&D slow, level off, and eventually decline. These results support theory suggesting that greater stock option compensation can, in some cases, discourage risk-averse, less-diversified managers from engaging in riskier investments (Lambert et al. 1991; Carpenter 2000; Meulbroek 2001; Ross 2004). In other words, the accumulation of firm-specific wealth in the form of ESOs contributes to a lack of diversification, which can magnify managers' risk aversion and discourage risk-taking behavior. As further support, we document a concave relation between future stock return volatility and R&D conditional on vega, indicating that managers with higher vega limit their exposure to firm-level risk. We also find that the effects of vega on our R&D investment measures are concentrated among managers with greater firm-specific wealth, who likely have a preference for shielding their wealth from greater risk. Taken together, our results suggest that while low to moderate levels of vega can increase the riskiness of a firm's investment policy, greater levels of vega may encourage less profitable and less innovative investment. There appears to be a limit on managers' willingness to increase their level of risk-taking as the level of vega increases, particularly for managers who have accumulated significant firm-specific wealth.

Appendix
Variable definitions

Variable Name	Description
Adv	Total advertising expense (Compustat item XAD) for firm *i* in year *t* divided by total assets (Compustat item AT) in year *t-1*.
Age	The natural logarithm of firm *i*'s age (the number of years since it first appeared on Compustat).
Asset	The natural logarithm of total assets (Compustat item AT).
CapEx	Total capital expenditures (Compustat item CAPX) for firm *i* in year *t* divided by total assets in year *t-1*.
CashComp	The natural logarithm of total cash compensation (salary + bonus) for the CEO of firm *i* in year *t*.
Delta	The natural logarithm of delta in year *t-1*. *Delta* estimates are obtained from the data provided by Coles, Daniel, and Naveen (2013), which are computed based on the methods described in Core and Guay (2002) and Coles et al. (2006). In general, delta is the sensitivity of CEO stock and option holdings to a 1% change in price of the underlying stock, measured in thousands. $Delta^2$ is the square of *Delta*.
Growth	Sales growth for firm *i* from time *t-1* to *t*.
Lev	Financial leverage ratio, measured as total long-term debt (Compustat items DLTT plus DLC) divided by total assets for firm *i* in year *t*.
Loss	Indicator that equals one if net income (Computstat item IB) < 0 for firm *i* in year *t*, and zero otherwise.
MgrWealth	Value of the CEO's firm-related stock and option portfolio as of the fiscal year-end (in $000s). The value of the share portfolio is the number of shares outstanding times the share price at fiscal year-end. The value of the option portfolio is computed using the Black-Scholes (1973) model, adjusted for dividends following Merton (1973). *MgrWealth* estimates are obtained from the data provided by Coles, Daniel, and Naveen (2013).
MTB	The natural logarithm of the ratio of market value of equity (Compustat items CSHO*PRCC_F) to book value of equity (Compustat item CEQ) for firm *i* at time *t*.
Patent	Total number of patents granted to firm *i* over years *t* to *t+1*, divided by total assets in year *t-1* times 100.
R&D	Total R&D (Compustat item XRD) for firm *i* in year *t* divided by total assets in year *t-1* times 100. *LagR&D* is *R&D* in year *t-1*.
Ret	Fiscal year buy-and-hold stock return for firm *i*.
RetVol	The standard deviation of monthly stock returns. *RetVol0* (*RetVol3*) is return volatility corresponding to fiscal year t (*t+1* to *t+3*) times 100.
ROA	Earnings for firm *i* in year *t* divided by total assets in year *t-1* (*ROA0*). Earnings are measured as income before interest, taxes, depreciation and amortization (Compustat item EBITDA) plus R&D and advertising. *ROA3* measures earnings in a similar manner, except uses average earnings over years *t+1* to *t+3*.

Variable Name	Description
Sale	The natural logarithm of total revenue (Compustat item REVT) for firm *i* in year *t*.
Surplus	Cash surplus, measured for firm *i* as (cash flow from operations – depreciation + R&D) in year *t* / total assets in year *t-1*. (Compustat items (OANCF – DP + XRD) / AT).
Tang	Tangible assets, measured as the sum of net property plant and equipment, inventory, investments and advances (equity and other) (Compustat items PPENT plus INVT plus IVAEQ plus IVAO) for firm *i* in year *t* divided by total assets for firm *i* in year *t-1*.
Tenure	CEO tenure, measured as the days between the date the CEO became CEO (per Execucomp) and the date of the fiscal year-end in year *t*, scaled by 365.
Vega	The natural logarithm of vega in year *t-1*. $Vega^2$ is the square of Vega. *Vega* estimates are obtained from the data provided by Coles, Daniel, and Naveen (2013), which are computed based on the methods described in Core and Guay (2002) and Coles et al. (2006). In general, vega is the sensitivity of CEO options to a 1% change in implied volatility, measured in thousands as of end of fiscal year *t*. Mathematically, it is the first partial derivative of option value with respect to expected volatility, where option value is computed using the Black-Scholes (1973) option-pricing model, adjusted for dividends following Merton (1973). Thus, the sensitivity of a stock option's value with respect to a 1% change in stock-return volatility is defined as: $[\delta(\text{option value})/\delta(\text{stock volatility})] * 0.01 = e^{-dT}N'(Z)ST^{(1/2)} * (0.01)$ where: N' = normal density function Z = [ln(S/X) + T(r – d + σ2 /2)] /σ T(1/2) S = stock price X = exercise price of the option σ = expected stock-return volatility over life of option r = logarithm of risk-free interest rate T = time to maturity of the option in years d = logarithm of expected dividend yield over life of option Due to FAS 123R's impact on compensation disclosures, pre-2006 option value is the sum of three option portfolios: current year grants, previously granted unvested options, and vested options, whereas post-2006 option value is the sum of the values of all the tranches (groups based on the year in which they vest) of options outstanding.

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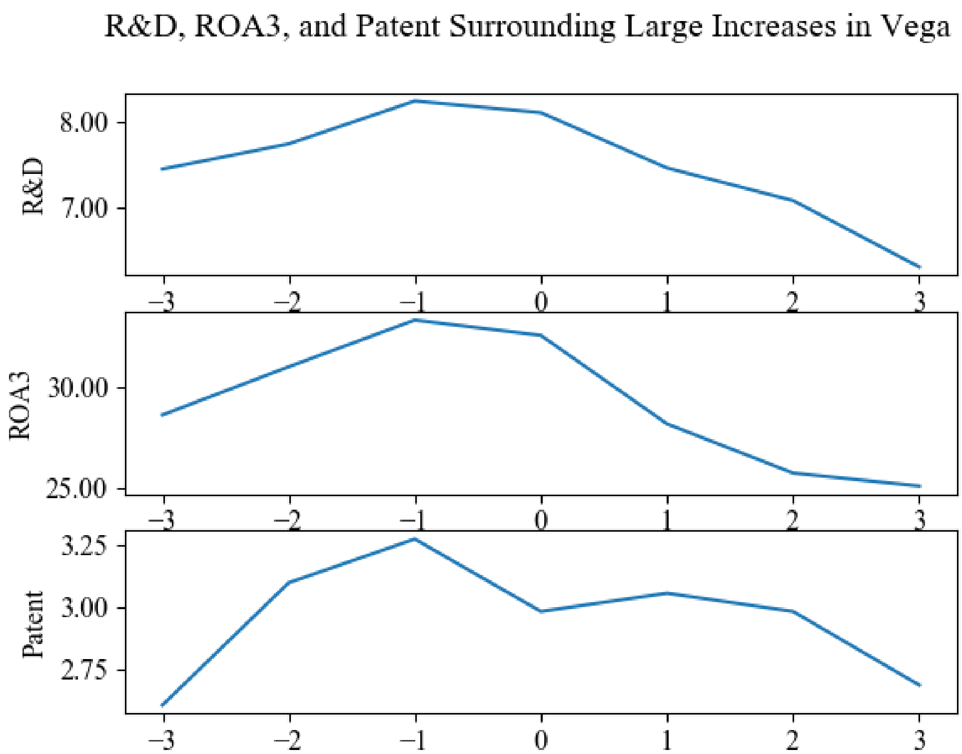
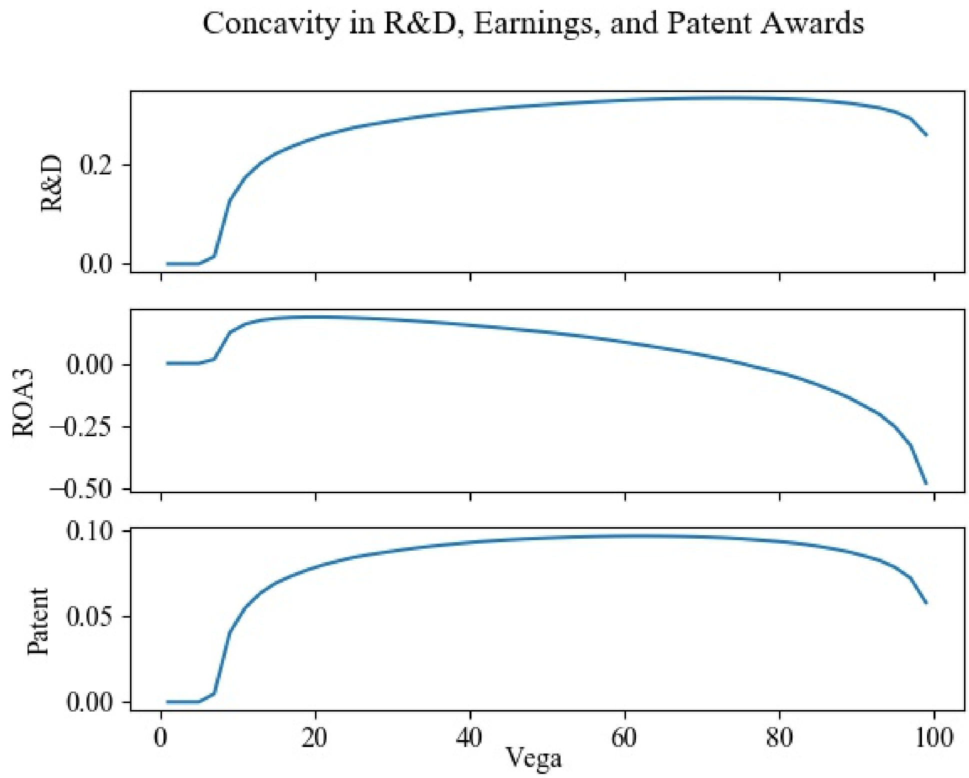
Figure 1
Mean R&D, ROA3, and Patent leading up to and following large increases in vega



This figure reports mean values for *R&D*, *ROA3*, and *Patent* for the three years prior to and following a large increase in vega (top quintile). The increase in vega is measured from *t-1* to *t* (year 0 in the graphs). *R&D* is total R&D for firm *i* in year *t* divided by total assets in year *t-1* times 100. *ROA3* is average earnings for firm i over years *t+1* to *t+3*. *Patent* is total number of patents granted to firm *i* over years *t* to *t+1*, divided by total assets in year *t-1* times 100.

Figure 2
Marginal effect of vega on R&D spending and profitability



This figure plots the fitted coefficient value for our three primary tests across 50 different values of vega (corresponding to every 2nd percentile from 1 to 99). We define the percentiles based on our maximum sample (Table 3). The figure presents the *marginal* effect of vega on R&D investment riskiness across the distribution of *Vega.*

TABLE 1
Descriptive statistics

Panel A: R&D Investment Sample

Variable	*N*	Mean	S.D.	p(25)	Median	p(75)
R&D	18,329	3.04	5.67	0.00	0.00	3.49
Vega	18,329	3.76	1.72	2.82	3.91	4.96
Vega (unlogged)	18,329	139.00	300.44	15.81	48.72	141.99
Delta	18,329	5.33	1.60	4.33	5.32	6.33
Delta (unlogged)	18,329	1,174.65	12,326.58	75.03	203.73	562.32
Adv	18,329	0.01	0.03	0.00	0.00	0.01
Asset	18,329	7.57	1.70	6.38	7.42	8.65
Asset (unlogged)	18,329	12,556.19	74,430.09	587.69	1,676.31	5,704.80
CapEx	18,329	0.06	0.06	0.02	0.04	0.07
CashComp	18,329	6.80	0.88	6.37	6.79	7.23
Growth	18,329	0.07	0.20	-0.01	0.07	0.16
Lev	18,329	0.22	0.18	0.07	0.21	0.34
Ret	18,329	12.92	47.58	-15.57	8.49	32.99
Sale	18,329	7.34	1.60	6.28	7.25	8.39
Surplus	18,329	0.06	0.09	0.02	0.05	0.10
Tang	18,329	0.45	0.24	0.25	0.43	0.64
Tenure	18,329	2.06	0.65	1.56	2.03	2.52

Panel B: Earnings Sample

Variable	*N*	Mean	S.D.	p(25)	Median	p(75)
R&D	7,657	6.98	7.02	1.79	4.46	10.23
Vega	7,657	3.88	1.63	2.98	3.99	4.98
Vega (unlogged)	7,657	143.95	314.67	18.67	53.22	144.26
Delta	7,657	5.46	1.53	4.51	5.42	6.41
Delta (unlogged)	7,657	1,434.54	15,147.20	90.02	225.14	604.63
ROA3	7,657	28.68	20.57	15.35	24.14	36.36
Adv	7,657	0.01	0.03	0.00	0.00	0.01
Asset	7,657	7.22	1.67	6.04	7.08	8.28
Asset (unlogged)	7,657	7,149.48	31,388.73	418.07	1,185.72	3,933.00
CapEx	7,657	0.05	0.05	0.02	0.04	0.07
Growth	7,657	0.08	0.22	-0.01	0.08	0.17
Lev	7,657	0.19	0.17	0.03	0.17	0.29
Loss	7,657	0.21	0.41	0.00	0.00	0.00
ROA0	7,657	23.42	14.46	14.28	20.81	30.12

Panel C: Patent Sample

Variable	*N*	Mean	S.D.	p(25)	Median	p(75)
R&D	9,313	7.11	7.07	1.80	4.59	10.53
Vega	9,313	3.85	1.62	2.95	3.95	4.94
Vega (unlogged)	9,313	137.81	298.83	18.06	50.79	138.29
Delta	9,313	5.39	1.52	4.46	5.34	6.33
Delta (unlogged)	9,313	1,257.66	13,747.86	85.16	208.13	560.31
Patent	9,313	2.80	4.43	0.10	0.98	3.39
Adv	9,313	0.01	0.03	0.00	0.00	0.01
Asset	9,313	7.15	1.66	5.96	6.99	8.18
Asset (unlogged)	9,313	6,690.61	30,247.54	386.76	1,089.43	3,572.00
CapEx	9,313	0.05	0.05	0.02	0.04	0.07
Growth	9,313	0.08	0.22	-0.01	0.08	0.17
Lev	9,313	0.19	0.17	0.02	0.17	0.30
Loss	9,313	0.21	0.41	0.00	0.00	0.00
ROA0	9,313	23.29	14.48	14.20	20.68	30.05

This table presents descriptive statistics for the samples of our three main analyses. Panel A (B, C) shows the sample for our R&D investment (Earnings, Patent) test using equation (1) (2, 3). All variables are defined in the Appendix.

TABLE 2
Select correlations

	R&D	*Vega*	*Delta*	*ROA3*	*Patent*	*Adv*	*Asset*	*CapEx*	*Growth*	*Lev*
R&D		**0.107**	**0.052**	**0.348**	**0.756**	**-0.203**	**-0.071**	**0.050**	**0.348**	**-0.242**
Vega	**0.063**		**0.597**	**0.148**	**0.160**	**0.515**	**-0.045**	**0.021**	**0.164**	**0.066**
Delta	**0.038**	**0.534**		**0.295**	**0.068**	**0.408**	**0.058**	**0.186**	**0.335**	**-0.053**
ROA3	**0.356**	**0.077**	**0.270**		**0.110**	**0.042**	**0.274**	**0.325**	**0.639**	**-0.206**
Patent	**0.592**	**0.046**	-0.011	**0.091**		**-0.049**	**-0.028**	-0.008	**0.265**	**-0.134**
Adv	**-0.041**	**0.054**	**0.077**	**0.255**	**-0.037**		**-0.057**	0.004	**-0.144**	**0.305**
Asset	**-0.259**	**0.463**	**0.414**	0.013	**-0.196**	**-0.068**		**0.203**	**0.231**	**0.097**
CapEx	**-0.061**	**-0.073**	**0.060**	**0.243**	-0.011	**0.038**	**-0.072**		**0.277**	**-0.065**
Growth	**0.078**	**0.022**	**0.154**	**0.310**	0.006	0.007	**0.028**	**0.204**		**-0.260**
Lev	**-0.230**	**0.041**	**-0.059**	**-0.199**	**-0.156**	**-0.037**	**0.251**	**0.048**	**-0.034**	

This table presents Pearson (Spearman) correlation coefficients to the lower left (upper right) of the diagonal for the R&D investment sample of firms. Boldface indicates significant correlations (p<0.05). See the Appendix for variable definitions.

TABLE 3
The relation between R&D and vega

	Predicted Sign	*R&D* (1)	(2)	(3)
Vega	+	0.049***	0.143***	0.134**
		(0.004)	(0.004)	(0.034)
Vega^2	-		-0.015**	-0.016
			(0.043)	(0.127)
Delta	?	-0.021	-0.140*	-0.250***
		(0.560)	(0.086)	(0.004)
Delta^2	?		0.013	0.021**
			(0.138)	(0.032)
Asset	?	-0.728***	-0.718***	-0.544**
		(0.001)	(0.001)	(0.037)
Growth	+	1.087***	1.079***	1.349***
		(0.000)	(0.000)	(0.000)
Lev	-	-0.256	-0.255	-0.146
		(0.255)	(0.258)	(0.371)
Adv	?	2.585	2.545	2.505
		(0.160)	(0.168)	(0.468)
Tang	?	0.026	0.016	-0.323
		(0.945)	(0.966)	(0.455)
Tenure	?	-0.058*	-0.058*	-0.234*
		(0.095)	(0.084)	(0.099)
CashComp	?	0.014	0.014	0.016
		(0.534)	(0.528)	(0.679)
Surplus	-	-0.534	-0.540	-0.325
		(0.168)	(0.165)	(0.300)
Sale	?	0.146	0.143	-0.250
		(0.493)	(0.502)	(0.368)
Ret	?	0.244***	0.242***	0.221***
		(0.000)	(0.000)	(0.001)
CapEx	?	4.115***	4.115***	5.339***
		(0.000)	(0.000)	(0.000)
LagR&D	+	0.339***	0.338***	0.182***
		(0.000)	(0.000)	(0.000)
Fixed effects		Firm, Year	Firm, Year	CEO-Firm, Year
Observations		18,329	18,329	18,329
Adjusted R-squared		0.905	0.905	0.916

This table presents the results from estimating the relation between *R&D* and *Vega* (equation (1)). See the Appendix for variable definitions. Statistical significance is assessed using standard errors that are heteroscedasticity robust and clustered at the firm level. *p*-values are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

TABLE 4
The relation between future ROA and R&D investment conditional on vega

	Predicted Sign	*ROA3* (1)	(2)	(3)	(4)	(5)
R&D	?	1.639***	1.626***	1.593***	0.371	0.657**
		(0.000)	(0.000)	(0.000)	(0.110)	(0.026)
*Vega * R&D*	+	-0.020	0.182*	0.181*	0.149*	0.183
		(0.660)	(0.070)	(0.100)	(0.076)	(0.114)
*$Vega^2$ * R&D*	-		-0.029*	-0.037**	-0.030**	-0.032*
			(0.059)	(0.042)	(0.041)	(0.081)
*Delta * R&D*	?			0.217	0.104	0.138
				(0.264)	(0.397)	(0.303)
*$Delta^2$ * R&D*	?			-0.010	-0.008	-0.012
				(0.580)	(0.474)	(0.289)
*Asset * R&D*	+				0.145***	0.217***
					(0.001)	(0.001)
Vega	?	-1.715***	-0.050	0.345	0.064	-0.068
		(0.000)	(0.955)	(0.709)	(0.910)	(0.919)
$Vega^2$	?		-0.257*	-0.347**	-0.030	-0.012
			(0.055)	(0.012)	(0.735)	(0.915)
Delta	?			-0.618	0.309	0.282
				(0.597)	(0.697)	(0.791)
$Delta^2$	?			0.115	-0.039	-0.098
				(0.322)	(0.595)	(0.358)
$R\&D^2$	?				-0.000	-0.006
					(0.978)	(0.545)
Asset	?				-11.120***	-12.929***
					(0.000)	(0.000)

Growth	+				3.536***	2.610**
					(0.001)	(0.024)
Lev	-				0.204	1.180
					(0.930)	(0.697)
Adv	+				41.631***	75.592***
					(0.006)	(0.004)
CapEx	+				20.610***	16.913***
					(0.000)	(0.006)
ROA0	+				0.725***	0.649***
					(0.000)	(0.000)
Loss	?				3.169***	2.907**
					(0.003)	(0.022)
*Loss * ROA0*	?				-19.188***	-19.879**
					(0.003)	(0.014)
Fixed effects		Firm, Year	Firm, Year	Firm, Year	CEO-firm, Year	CEO-firm, Year
Observations		7,657	7,657	7,657	7,657	7,657
Adjusted R-squared		0.649	0.650	0.652	0.774	0.799

This table presents the results from estimating the relation between future earnings (*ROA3*) and *R&D* conditional on vega (equation (2)). See the Appendix for variable definitions. Statistical significance is assessed using standard errors that are heteroskedasticity robust and clustered at the firm level. *p*-values are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

TABLE 5
The relation between the number of patents and R&D investment conditional on vega

	Predicted Sign	*Patents* (1)	(2)	(3)	(4)	(5)
R&D	?	0.137***	0.134***	0.136***	0.189***	0.176***
		(0.000)	(0.000)	(0.000)	(0.004)	(0.002)
*Vega * R&D*	+	-0.006	0.047**	0.052**	0.044**	0.047***
		(0.526)	(0.021)	(0.011)	(0.018)	(0.006)
*Vega^2 * R&D*	-		-0.008***	-0.007***	-0.005*	-0.004*
			(0.004)	(0.006)	(0.053)	(0.076)
*Delta * R&D*	?			-0.033	-0.031	-0.040
				(0.127)	(0.114)	(0.192)
*Delta^2 * R&D*	?			0.002	0.002	0.002
				(0.408)	(0.268)	(0.427)
*Asset * R&D*	+				-0.028##	-0.023##
					(0.987)	(0.968)
Vega	?	-0.091	0.112	0.112	0.094	0.029
		(0.113)	(0.393)	(0.393)	(0.460)	(0.870)
Vega^2	?		-0.033**	-0.017	-0.006	0.011
			(0.040)	(0.313)	(0.728)	(0.656)
Delta	?			-0.256*	-0.188	-0.285**
				(0.057)	(0.135)	(0.042)
Delta^2	?			0.005	0.004	0.004
				(0.670)	(0.705)	(0.815)
R&D^2	?				-0.003	-0.001
					(0.223)	(0.443)
Asset	?				-0.646***	-0.682***
					(0.000)	(0.000)

Growth	+				-0.057	0.227
					(0.822)	(0.201)
Lev	-				-0.372	-0.162
					(0.248)	(0.375)
Adv	+				0.445	2.431
					(0.460)	(0.349)
CapEx	+				0.657	0.181
					(0.330)	(0.457)
ROA0	+				-0.000	0.000
					(0.978)	(0.969)
Loss	?				-0.034	0.133
					(0.851)	(0.416)
*Loss * ROA0*	?				-0.014	-0.910
					(0.989)	(0.386)
Fixed Effects		Firm, Year	Firm, Year	Firm, Year	CEO-firm, Year	CEO-firm, Year
Observations		9,313	9,313	9,313	9,313	9,313
Adjusted R-squared		0.759	0.761	0.763	0.767	0.824

This table presents the results of estimating the relation between *Patent* and *R&D* conditional on *Vega* (equation (3)). See the Appendix for variable definitions. Statistical significance is assessed using standard errors that are heteroskedasticity robust and clustered at the firm level. *p*-values are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. ## denotes significance at the 5% level for a coefficient with a sign opposite expectations.

TABLE 6
The relation between return volatility and R&D investment conditional on vega

	Predicted Sign	*RetVol3* (1) Coef	(1) p-value	(2) Coef	(2) p-value	(3) Coef	(3) p-value	(4) Coef	(4) p-value
R&D	?	0.027***	0.000	0.022***	0.000	0.020	0.144	0.027***	0.010
*Vega * R&D*	+	-0.010$^{###}$	0.999	0.015***	0.010	0.011**	0.018	0.006	0.155
*$Vega^2$ * R&D*	-			-0.004***	0.000	-0.003***	0.000	-0.002***	0.008
*Delta * R&D*	?			-0.001	0.945	0.001	0.915	-0.008	0.460
*$Delta^2$ * R&D*	?			0.001	0.341	0.001	0.480	0.001	0.174
*Asset * R&D*	+					-0.004	0.155	-0.005$^{##}$	0.965
Vega	?	-0.044*	0.063	0.031	0.464	0.078**	0.020	0.009	0.819
$Vega^2$	?			-0.013*	0.075	-0.012**	0.045	-0.001	0.914
Delta	?			-0.084	0.290	-0.044	0.534	0.119	0.174
$Delta^2$	?			0.011	0.133	0.005	0.446	-0.011	0.189
Asset	-					-0.035	0.684	-0.017	0.867
Growth	+					0.208**	0.021	0.152*	0.067
Lev	+					-0.040	0.789	0.001	0.993
Adv	?					1.627*	0.089	1.545	0.110
Tang	?					0.251	0.213	0.164	0.451
ROA3	-					-0.005***	0.001	-0.005***	0.001
$R\&D^2$	?					-0.000	0.558	-0.000	0.356
CashComp	-					0.012	0.608	0.033$^{#}$	0.905
Sale	-					-0.171**	0.011	-0.170**	0.046
Tenure	-					0.019	0.477	0.216$^{##}$	0.985
RetVol0	+					17.039***	0.000	7.211**	0.022
CapEx	-					1.428$^{###}$	0.997	1.256$^{###}$	0.992
Age	-					-0.625***	0.000	-0.617***	0.000

Year fixed effects	Firm, Year	Firm, Year	Firm, Year	CEO-firm, Year
Observations	7,403	7,403	7,403	7,403
Adjusted R-squared	0.768	0.773	0.805	0.849

This table presents the results of estimating the relation between return volatility (*RetVol3*) and *R&D* conditional on *Vega* (equation (4)). See the Appendix for variable definitions. Statistical significance is assessed using standard errors that are heteroskedasticity robust and clustered by firm. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. [#], [##] and [###] denote significance at the 1%, 5%, and 10% levels, respectively, for a coefficient with a sign opposite expectations.

TABLE 7
The effect of vega on R&D investment conditional on *MgrWealth*

Panel A: Controlling for firm and year effects

Dependent Variable:		*R&D*		*ROA3*		*Patent*	
	Predicted Sign	(1) Low *MgrWealth*	(2) High *MgrWealth*	(3) Low *MgrWealth*	(4) High *MgrWealth*	(5) Low *MgrWealth*	(6) High *MgrWealth*
R&D	?			0.165	0.033	0.098	0.173**
				(0.730)	(0.929)	(0.324)	(0.045)
Vega	+/?	0.097*	0.180**	-0.735	-0.061	-0.130	0.052
		(0.095)	(0.014)	(0.553)	(0.944)	(0.583)	(0.819)
Vega^2	-/?	-0.013	-0.020*	0.135	-0.037	0.047	-0.001
		(0.163)	(0.054)	(0.536)	(0.767)	(0.251)	(0.967)
*Vega * R&D*	+			0.003	0.395***	-0.009	0.065**
				(0.992)	(0.003)	(0.858)	(0.021)
Vega^2 * *R&D*	-			-0.002	-0.056***	0.008	-0.007*
				(0.963)	(0.004)	(0.417)	(0.056)
Control variables		YES	YES	YES	YES	YES	YES
Fixed Effects		Firm, Year	Firm,Year	Firm, Year	Firm, Year	Firm, Year	Firm, Year
Observations		9,165	9,164	3,829	3,828	4,657	4,656
Adjusted R-squared		0.921	0.898	0.764	0.797	0.781	0.802

TABLE 7 (continued)

Panel B: Controlling for CEO-firm and year effects

Dependent Variable:		*R&D*		*ROA3*		*Patent*	
		(1)	(2)	(3)	(4)	(5)	(6)
		Low	High	Low	High	Low	High
	Predicted Sign	*MgrWealth*	*MgrWealth*	*MgrWealth*	*MgrWealth*	*MgrWealth*	*MgrWealth*
R&D	?			0.533	0.152	0.125	0.120
				(0.313)	(0.740)	(0.360)	(0.126)
Vega	+/?	0.119*	0.225	-0.161	-0.817	0.031	-0.094
		(0.060)	(0.113)	(0.916)	(0.450)	(0.924)	(0.752)
$Vega^2$	-/?	-0.027	-0.011	0.102	0.045	0.024	0.020
		(0.115)	(0.222)	(0.719)	(0.774)	(0.689)	(0.605)
*Vega * R&D*	+			-0.005	0.476***	-0.001	0.061***
				(0.990)	(0.010)	(0.987)	(0.008)
$Vega^2$ ** R&D*	-			0.013	-0.064***	0.004	-0.007**
				(0.839)	(0.009)	(0.740)	(0.028)
Control variables		YES	YES	YES	YES	YES	YES
CEO-firm and Year fixed effects		YES	YES	YES	YES	YES	YES
Observations		9,165	9,164	3,829	3,828	4,657	4,656
Adjusted R-squared		0.933	0.905	0.811	0.810	0.827	0.834

This table presents the results of estimating equations (1), (2), and (3) (corresponding to the dependent variables *R&D*, *ROA3* and *Patent*, respectively), partitioned at the median of *MgrWealth*. Panel A includes firm fixed effects, and Panel B includes CEO-firm fixed effects. See the Appendix for variable definitions. Statistical significance is assessed using standard errors that are heteroskedasticity robust and clustered at the firm level. *p*-values are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

TABLE 8
The relation between current returns and R&D investment conditional on vega

Dependent Variable:		*Ret*	
	Predicted Sign	Coef	p-value
R&D	?	-0.437	0.275
*Vega * R&D*	+	0.078	0.335
$Vega^2$ * *R&D*	-	-0.057**	0.019
*Delta * R&D*	?	-0.169	0.721
$Delta^2$ * *R&D*	?	-0.023	0.583
*Asset * R&D*	+	0.546***	0.000
Vega	?	2.825**	0.047
$Vega^2$	?	-0.702***	0.003
Delta	?	-10.931***	0.009
$Delta^2$	?	0.045	0.909
$R\&D^2$	?	0.027**	0.049
Asset	?	6.811***	0.000
MTB	?	20.100***	0.000
Growth	?	24.488***	0.000
Lev	?	-8.382	0.170
Adv	?	-21.375	0.437
CapEx	?	-35.397*	0.068
ROA0	+	-0.314##	0.989
Loss	?	-23.797***	0.000
*Loss*ROA0*	?	61.536***	0.000
Year and industry fixed effects		YES	
Observations		9,993	
Adjusted R-squared		0.377	

This table presents the results of estimating the relation between stock returns (*Ret*) and *R&D* conditional on *Vega* (equation (5)). See the Appendix for variable definitions. Statistical significance is assessed using standard errors that are heteroskedasticity robust and clustered by year. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. ## denotes significance at the 5% level for a coefficient with a sign opposite expectations.