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Is R&D Risky?

Abstract

Many studies use R&D intensity or R&D spending as proxies for risk-taking, but we have little evidence that either associates positively with firm risk. We analyze the relations between R&D intensity (R&D spending to sales) and R&D spending on the one hand and eleven different indicators of firm risk on the other, using data from 1,907 to 3,908 firms in various industries over 13 years. The analysis finds a general lack of consistent positive association between R&D and firm risk, making the use of R&D as an indicator of risk taking questionable. Furthermore, R&D intensity and spending do not correlate positively, suggesting they measure different constructs. We discuss potential reasons for these non-significant results.

Is R&D Risky?

INTRODUCTION

Since Bowman (1980), a substantial research tradition in strategy has addressed risk. Most of the literature attempts either to explain firm risk-taking or to estimate the influence of risk-taking on firm performance (Bromiley & Rau, 2010).

Strategic management research has adopted a number of measures of risk and risk taking (Bromiley and Rau, 2010). Many studies measure risk-taking by R&D intensity or R&D spending (Barker and Mueller, 2002; Chen and Miller, 2007; Devers, McNamara, Wiseman, and Arrfelt, 2008; Hoskisson, Hitt, and Hill, 1993; Miller and Bromiley, 1990). However, researchers also use R&D spending or intensity to measure other constructs including time horizon (Bushee, 1988; Lundstrom, 2002), resources as defined by the resource based view (Mahoney and Pandian, 1992), information processing demands (Henderson and Fredrickson (1998), and other constructs. Indeed, Ketchen, Ireland, and Baker (2013) questions interpreting R&D as reflecting any specific construct given that scholars have claimed it reflects so many different constructs.

We adopt a different perspective on this problem considering whether R&D intensity or R&D spending as an indicator of firm risk-taking associates positively with other measures of firm risk – its nomological validity. We begin by considering the conceptualization of the risk construct in strategic management research. Strategy discussions sometimes use the terms risk and risk-taking interchangeably and mix a variety of concepts including a preference for a desired level of risk, behaviors or activities that increase risk, lack of ability to predict performance, and variability performance outcomes. We also review some theories used in strategic management research that portray R&D as a means to reduce risk and more particularly, potential variability in a firm's outcomes and discuss their implications for our analyses and expected findings.

Following these discussions of R&D and risk in strategic management scholarship, we present analyses testing four potential relations between R&D spending or intensity and other measures (both ex ante and ex post) of firm risk. These include models where R&D spending or intensity creates risk so that R&D positively influences contemporaneous or subsequent firm risk, and models where a general risk propensity influences R&D so firm risk influences contemporaneous or subsequent R&D spending or intensity. While we think R&D spending or intensity influencing current or subsequent firm risk best fits arguments that R&D is risky, we include the additional relations for completeness. For robustness, we perform the analyses with 11 different risk metrics including ones based on stock price, variation in ROA, downside risk in terms of ROA, and analyst forecasts.

This paper contributes to strategic management research by examining the validity of R&D intensity and R&D spending as proxies for risk-taking. Evaluating measurement validity is critical in generating credible research (Boyd, Bergh, Ireland, Ketchen, 2013; Boyd, Gove, and Hitt, 2005a,b; Ketchen, Ireland, and Baker, 2013; Podsakoff, Shen, and Podsakoff, 2006; Venkatraman and Grant, 1986). Despite the recognition of the importance of rigorous construct measurement in strategic management, however, '…as to date, relatively little emphasis has been placed on measurement issues within strategic management' (Boyd *et al*., 2013, p.3). Our study thus represents a step toward addressing an important measurement issue in strategic management research.

RISK PREFERENCES, BEHAVIORS, AND OUTCOMES

Many papers across strategy, accounting, and finance have used R&D as a proxy for risk-taking, or, equivalently, used risk-taking theoretical arguments to develop hypotheses to explain R&D (see, for example, Barker and Mueller, 2002; Baysinger and Hoskisson, 1989; Chen, 2008; Chrisman and Patel, 2012; Devers, McNamara, Wiseman, and Arrfelt, 2008; Eberhart, Maxwell, and Siddique, 2008; Gentry and Shen, 2013; Hill and Snell, 1988; Hoskisson and Hitt, 1988; Hoskisson, Hitt, and Hill, 1993; Kor, 2006; McAlister, Srinivasan, and Kim, 2007; Wedig, 1990).

When we describe a firm activity as risky, we implicitly claim that doing this activity increases firm risk. That is, if a firm action is a legitimate form of firm risk-taking, it should positively influence firm risk. However, the term risk has several different connotations in strategic management research. Risk can refer to firm preferences, behaviors or actions, or outcomes.

Let us begin by examining the treatment of firm risk preferences i.e., firms' desired levels of risk, in strategic management theories. The most commonly used theories to generate hypotheses regarding firm risk-taking do not have risk preference as a construct. For example, in expected utility theory, decision makers do not have an explicit value or preference associated with risk; rather, risk preference is a derived description that reflects the curvature of the utility function. In the behavioral theory of the firm (Cyert & March, 1963), risk does not appear as a construct. The behavioral theory of the firm explicitly assumes that organizations do not have consistent preferences, which rules out their having consistent risk preferences. Prospect theory, also often used to explain firm risk, is an individual level theory that explains choice based on how one values specific potential outcomes and weights their probabilities. Again, risk preference per se is not a construct in the theory although one can infer a risk preference from the pattern of choices predicted by the theory (see Bromiley, 2010).

These theories without direct risk preferences differ from both agency theory's treatment of risk and the prescriptive literature on risk. Agency theorists often assume managers are risk averse and that managerial risk aversion influences firm behavior. However, explicit model derivations based on agency theory and managerial risk aversion often reflect risk aversion as the curvature of a utility function (e.g., Shavell, 1979).

The prescriptive literature on risk management often assumes a consistent firm risk preference (Andersen, Garvey, and Roggi, 2014; Andersen and Schroder, 2010; Fraser and Simkins, 1987). Regulators and advisory organizations call for firms to have explicit 'risk appetites' (Fraser and Simkins, 2010). However, what risk appetite means and how to measure it in practice remain controversial (Hubbard, 2009). Bromiley, Rau, and Mcshane (forthcoming) distinguish between operational risks which the firm should manage risk if it improves the expected value of outcomes, and strategic risks where management cares about the risk itself because the potential damage of events exceeds what the firm finds acceptable.

That risk preference per se does not appear in the theories used to predict risk creates problems when we want to develop proxies for risk preference. Instead of attempting to develop proxies for a core concept of the underlying theory, the proxies relate to a derived characteristic generally of behavior or outcomes.

Empirical measures of firm level risk fall broadly into four camps. First, some measures depend on stock price (c.f., Montgomery and Singh, 1984; Chatterjee and Lubatkin, 1990). Most commonly, these reflect systematic and unsystematic risk. Systematic risk refers to the portion of the variability in the stock price associated with market variations while unsystematic risk includes the remainder of stock price variation.

Second, some measures depend on accounting returns. Most of these use variability in return on assets (ROA) although some use return on equity or other metrics (Bowman, 1980;

Fiegenbaum and Thomas, 1986, 1988). Building on March and Shapira (1987), Miller and Reuer (1996) added measures of downside risk.

Third, some studies use the variability in stock analyst forecasts of firm income or return on assets arguing that variability in these forecasts should associate positively with uncertainty of the income streams, a concept of risk (Bromiley, 1991).

Fourth, some studies have used various indicators based on levels of discretionary firm activity as reflected in firm accounting data including R&D (Miller and Bromiley, 1990; Palmer and Wiseman, 1999).

These risk measures appear to address different constructs. Stock-based measures derive from investor behavior in response to firm and other information. Here, the risk appears as the risk to stockholders of the firm's equity. In the capital asset pricing model, systematic risk should influence stockholder returns while unsystematic risk should not. More recent finance scholarship has extended the set of firm measures considered to influence stock returns and claimed that these are associated with systematic risk (Fama and French, 2015).

The measures based on variability in actual firm performance (both variability of performance and downside risk) attempt to reflect uncertainty about the firm's income stream, sometimes termed income stream uncertainty.

Measures based on variability in analyst forecasts appear to reflect uncertainty about the firm's future income stream. However, the extent to which these measures reflect good estimates of such uncertainty or income variability remains unclear.

Measures based on firm spending or ratios of firm spending attempt to reflect firm risk-related behaviors. These measures tie more closely to firm decisions than more distant measures like variability in ROA, but the extent to which they actually reflect risk rather than other factors remains an open question. Most such measures have been used as proxies for other concepts in addition to risk (Ketchen, Ireland, and Baker, 2013).

If we distinguish among firm preference, behavior, and outcomes, all the measures deal with actual or predicted behavior and outcomes rather than preferences per se. Researchers may want to develop unobtrusive measures of firm risk preference based on letters to the shareholders in annual reports, CEO discussions with analysts, etc. as they have in other domains.[1]

Compounding this issue, studies using R&D intensity or spending as a proxy for risk taking (or using risk-related arguments to explain R&D intensity or spending) seldom specify their risk constructs. Miller and Bromiley (1990), for example, claimed to have found three risk dimensions: income stream variability, equity risk (both stock market beta and unsystematic risk), and strategic risk that included R&D intensity, capital intensity, and leverage. While Miller and Bromiley (1990) labelled this third dimension a form of risk, the paper had no direct evidence that the dimension reflected risk.

From a measurement standpoint, not clearly specifying a construct makes it difficult to assess the validity and reliability of measures for the construct. Specifically, the relations between R&D intensity or spending and the other empirical measures of risk that we discuss above become open to question. We now turn to the construct of risk in strategy scholarship.

THEORETICAL TREATMENTS OF RISK-TAKING AND R&D

Many strategy studies associate R&D with risk taking, even though the underlying theory may not explicitly make this connection. Consider again the behavioral theory of the firm (Cyert and March, 1963), perhaps the most common theory underlying strategy work on risk. As we discussed earlier, this theory does not assume a firm risk preference. Rather, firms with

1 We thank one of the reviewers for this point. This may be a promising avenue for future research.

performance below aspirations look for ways to raise performance above aspirations. Bromiley (1991) claims that such actions generally increase firm risk. Likewise, strategy applications of prospect theory relate firm conditions to the subsequent action or outcome (see Holmes, Bromiley, Devers, Holcomb, and McGuire, 2011, for a review of these studies).

There are two issues here. First, these theories do not assume firms have consistent risk preferences. Rather, we observe factors that theory argues may influence observed behaviors that may reflect an implicit risk preference, or factors that theory argues will influence observed behaviors that are risky. This leads to the second issue, that these theories do not specifically explain R&D. Rather, the theories explain a general orientation of the firm to taking risky actions or having risky outcomes; researchers extend these theories to explain an observed behavior namely, R&D, under the assumption that R&D equates to risk taking. For example, Chen and Miller (2007) directly track March and Shapira's (1987) and Shapira's (1995) explanation for managerial risk taking up to the end where Chen and Miller (2007) replace risk taking with R&D intensity. If at a given time a firm has a predilection toward risky activities, we would expect it to undertake a number of risky actions. Indeed, Bowman (1982; 1984) examines the conditions of the firm that should encourage risky action and finds a positive association with several forms of risky action including acquisitions and litigation. Alternatively, performance below aspirations has been shown to increase risk-taking (e.g., Bowman, 1984; Fiegenbaum and Thomas, 1988; Singh, 1986; Wiseman and Bromiley, 1996), but there is no reason that risk-taking would only appear in R&D.

At the other extreme, some theories suggest a null or even negative relation between firm risk and R&D. For example, competitors' technological innovation might explain R&D but would not necessarily associate with an increase in other forms of risky activity or firm risk. In some rapidly changing industries like cell phones, not doing R&D may increase a firm's chances of low performance. Cohen and Levinthal (1989) highlights industry conditions, finding that an industry's technological opportunity and appropriability influence firm R&D spending, a relation mediated by the firm's capacity to recognize, assimilate, and exploit information.

Alternatively, R&D might reduce firm risk, the opposite of R&D as risk taking. A firm's R&D projects are individually risky, so the aggregation of such projects constitutes a portfolio. If project size were constant, higher R&D means a larger portfolio and lower overall risk, i.e., less variable average performance. This follows the fundamental insight of portfolio theories in finance that portfolios (e.g., of R&D projects) can buffer the investor from the unsystematic (i.e., uncorrelated) risk associated with the portfolio's constituent investments. This logic would result in a negative influence of R&D on firm risk. Some scholars seeing R&D as increasing risk may implicitly mix the two levels of analysis (project and firm).

Strategy work based on real options logic uses a similar reasoning. In a real options logic, spending on R&D creates options for firms in new technologies. Additional options may let the firm reduce its risk in the same way investors can use options to reduce the risk associated with stocks[2]. While the use of real options by strategy researchers and practitioners appears to be gaining in popularity (Driouchi & Bennett, 2012), the evidence for the real options logic is somewhat mixed. Using a sample of Japanese manufacturing firms and their overseas affiliates, Belderbos, Tong, and Wu (2014) finds that, under certain conditions, multinational operations (which give firms options) enable firms to reduce downside risk. Huchzermeier and Loch (2001) develops a model that identifies the kinds of operational uncertainty that may reduce real option value. In contrast, Reuer and Leiblein (2000) finds that, contradictory to the predictions of real

2 Note that this does not necessarily imply managers are risk averse; having additional alternatives may simply let managers improve firm performance.

options theory, U.S. manufacturing firms' investments in FDI and international joint ventures (both seen as creating real options) do not reduce firm downside risk. Hartmann and Hassan (2006) surveyed the largest pharmaceutical companies, arguing that such firms are the ones most likely to use real options. Considering the use of various techniques across 20 decision categories, Hartmann and Hassan (2006) found the most common valuation method is NPV, used at a minimum by twice as many firms as use real options. Across 20 areas of application, real options were never reported as being used by more than 36% of firms and had an average reported usage of 14%. Indeed, a majority of the respondents in their study reported not even knowing about real options. Miller and Shapira (2003) finds that outside of the classroom for instruction on options, even MBAs trained in options facing clearly defined options problems often do not behave in ways consistent with options theory.

More fundamentally, in a real options logic, increased variance in the outcomes of R&D investments is a positive, not a negative, because the firm can choose to exploit the high positive outcomes and not undertake the negative (McGrath and Nerkar, 2004). This resembles thinking in the field of enterprise risk management (an evolution of the concept of risk management from a focus on insurance and hazards to include operational and strategic risks) that advocates both reducing some risks while profiting from risk management in risks where the firm has an advantage. Specifically, in the context of an individual firm, risk management and innovation (measured as R&D spending) are 'contemporaneous phenomena and self-reinforcing processes. This may speak to the dynamic nature of total risk management whereby effective risk management leads to higher performance outcomes, while higher performance provides the means for excess liquidity that can be invested in innovation, which in turn can enhance the corporate risk management capabilities, and so forth' (Andersen, 2008, p.172). However, the real options logic seldom appears in practitioner or academic discussions of enterprise risk management. Instead, academic studies adopt real options as a theoretical frame to explain risk outcomes. The positive value associated with variability in outcomes from the options logic goes against the risk reduction emphasis in most practitioner discussions of risk management (see, Fraser and Simkins, 2010).

Under the argument that R&D creates options and options reduce firm risk, we would not use a theory associated with increased risk taking to explain R&D. Rather, firms wanting to reduce risk would increase R&D to create options that increase strategic flexibility making the firm less dependent on any given project (Wiltbank, Dew, Read, and Sarasvathy, 2006). Associating R&D with a desire to reduce risk is directly contrary to the immense majority of the strategy work that uses R&D as a proxy for risk taking.

The relation between R&D and other risk constructs

To the extent that R&D constitutes risk-taking, it could have two basic relations to other risk constructs. First, R&D could be an activity that incurs risk. R&D projects often fail. Alternatively, R&D may develop new products, but new product introductions frequently fail. Under this logic, R&D results in activities that increase contemporaneous or subsequent firm risk. We see this argument most consistent with studies that see R&D as a proxy for risk-taking.

Second, firm risk might influence current or subsequent R&D. A firm's preference for risk could take a variety of forms – new product introduction, changes in sales process, etc. In this case, we might expect a contemporaneous association of R&D with other measures of firm risk. Firm risk might influence subsequent R&D if changes in the firm's desired risk level influenced other risky activities faster than it influenced R&D.

In summary, our paper examines whether R&D positively influences contemporaneous or subsequent firm risk, or firm risk positively influences contemporaneous or subsequent R&D. We examine these relations for both R&D intensity and spending but, due to space limitations, we present R&D intensity results here and other results in an online appendix.

MEASURES

We used all data available in Compustat from 2000 to 2012. Since calculation of some of the risk variables uses multiple years of data, the number of usable firms and observations vary from roughly 1,900 to 3,900 firms, and 10,000 to 25,000 observations. As noted, studies assuming R&D is risky sometimes do not specify their risk constructs. Consequently, we explore the association of R&D with several firm risk indicators associated with variability in stock price, income stream, and analyst forecasts.

- Stock market beta – the conventional risk measure in capital asset pricing models from finance (Lintner, 1965; Sharpe, 1964), estimated as β_i by the following formula: $R_{it} = \alpha_i + \beta_i R_{mt} + \varepsilon_{it}$, where R_{it} is the rate of return for stock i during period t and R_{mt} is the market rate of return during the period. We estimate firm betas with both daily and monthly data. The daily estimates use one year of daily stock return data while the monthly estimates use current and four subsequent years of monthly data. Many in finance prefer to use monthly data across multiple years to estimate betas, claiming this gives more reliable estimates of beta than daily data. However, using multiple years of data to estimate betas makes linking beta to a specific year problematic.

- Stock market unsystematic risk. We use the standard deviation of the error terms as estimated in the equation above to estimate unsystematic risk.

- Income stream uncertainty as reflected in variability in analyst forecasts. We include both the coefficient of variation in analyst forecasts for earnings per share (standard deviation of the forecasts divided by the mean of the forecasts, used in Brown, Richardson, and Schwager (1987) as a risk measure), and the standard deviation in analyst forecasts for earnings per share without normalization (Bromiley, 1991). The coefficient of variation has undesirable properties when variables can have mean values near zero.

- Income stream uncertainty as reflected in variability in accounting performance (Bowman, 1980; 1982). Following the majority of strategy research literature on risk, we measure performance by ROA. We calculated the variability using the standard deviation of ROA across years t to t+2, t to t+3, and t to t+4, giving three measures of variability.

- Downside risk as defined by Miller and Leiblein (1996) measured as the magnitude of performance shortfalls relative to prior year, calculated over years t to t+4. As suggested by Miller and Leiblein (1996), we calculated both first-order and second-order root lower partial moments, defined as the following formula:

$$RLPM_{\alpha}(\tau; j) = [(1/5)\sum_{t=1}^{5}\delta_{jt}^{\alpha}]^{1/\alpha} \quad , \qquad (3)$$

where δ_{jt} is the downside performance discrepancy as a function of aspired-to-target return (τ_{jt}, measured by historical ROA) and actual return of the firm (r_{jt}, measured by current period ROA), calculated as = $\tau_{jt} - r_{jt}$ if $\tau_{jt} > r_{jt}$, and 0 otherwise. Again, following the most common practice in the literature, we use ROA as the performance metric.

Scholars generally represent R&D in one of two ways: actual spending, and the ratio of R&D spending to sales (termed R&D intensity). Frequently, papers have not offered a strong justification for using one measure rather than the other, although some papers argued that R&D

intensity might be more desirable as it controls for firm size. Consequently, we perform the analysis using both R&D intensity and R&D spending (in $ billion, deflated by dollar's value in year 2009), but report the results using R&D intensity as primary results in the paper. The results using R&D spending, reported in an online appendix, are very similar or even more supportive for our findings and claims. We handle missing data on R&D expenditures in two ways. In the primary results, we code missing data on R&D expenditures as missing dropping such observations from the analysis. In the robustness checks, we code missing data on R&D expenditures as zero R&D expenditures. The two approaches give similar results.

Our models include several conventional control variables. We include firm growth opportunity, measured by the ratio of market to book value, since high growth firms may face higher risk. We include firm total assets and sales (in $ billion) and number of employees to control for firm size. We control liquidity with the ratio of current liabilities to total assets and the ratio of current assets to total assets. We included year dummies for possible unobserved year effects. We include firm fixed effects in the estimation making industry dummies redundant.

We consider both models that allow an immediate association between risk and R&D and ones where all the explanatory variables are lagged one year from the period over which the dependent variables are calculated. All non-ratio financial measures were converted into constant dollars using the dollar value in 2009 as the deflator. Given the substantial differences in scale, some of the parameter estimates either appeared the same across estimates when rounded or rounded to zero. Consequently, we rescaled R&D intensity for the different tables. In rows 1 and 2 of Table 2, we rescaled R&D intensity by dividing it by 1000. Rescaling makes the parameter values not comparable across tables, but does not change statistical significance.

ESTIMATION

We use a panel regression estimator with fixed effects for firms for several reasons. First, studies using R&D as a risk indicator often use panel estimation and a Hausman test to choose between random and fixed effects. Consequently, researchers both try to explain within-firm variation in R&D and use R&D to explain within-firm variation in outcomes. Second, a panel estimate controls for stable firm factors that may influence both R&D and risk levels. Our Hausman tests favored the fixed over the random effects specification. While some of the dependent variables cannot be negative, none took the value of zero, making a tobit or similar estimator unnecessary.

We found strong evidence of serial correlation in the errors. Consequently, the results use the Stata xtregar procedure with a correction for serial correlation. The estimates of serial correlation, rho, in Tables 2 were positive and statistically significant ranging from 0.23 to 0.73 with a mean of 0.48 supporting use of the estimator with a serial correlation correction. The results used robust standard errors clustered by firm.

Outliers were handled by winsorizing the data at top and bottom one percent. Stock return data were winsorized at the one percent level before calculation of beta and unsystematic risk.

RESULTS

Table 1 presents the descriptive statistics. With the large sample size, all the correlations are statistically significant ($p<.001$). The mean correlation among the risk measures is 0.23.

--- Insert Table 1 here ---

Table 1 offers one outcome that some may find surprising: R&D spending and R&D intensity have a very small negative correlation where one might expect a positive association. We wondered if this might be an artifact of our data selection so we downloaded all the R&D

spending and sales data available in Compustat and looked at the correlation between R&D spending and R&D to sales. It was still negative. We tried a panel estimation with fixed effects for firms. In both R&D spending explained by R&D intensity and R&D intensity explained by R&D spending, the parameter estimate on the independent variable was negative but statistically insignificant.

This lack of association calls into question the casual use of R&D spending and R&D intensity interchangeably. While our intent in this note was not to explore the differences between using R&D spending and R&D intensity in strategy research, we note that though both measures relate to the amount of resources a firm devotes to formal R&D efforts, R&D intensity accounts for the size of the firm whereas R&D spending does not. Cohen and Klepper (1996) supports the use of R&D intensity rather than R&D spending as a measure of R&D efforts; this study finds that larger firms have an advantage in R&D because of "the larger output over which they can apply the results – and thus spread the costs – of their R&D" (p. 241).

The negative correlation between R&D spending and R&D intensity highlights the need for greater theoretical clarity about the underlying constructs measured. The use of R&D spending or intensity as indicators of outlays for research and development appears undisputable. The problem comes when we want to use such indicators as proxies for other constructs.

Table 2 summarizes the estimation results using lagged and contemporaneous R&D intensity explaining Risk in t.[3]

--- Insert Table 2 here ---

First, we consider the influence of R&D intensity on firm risk. For contemporaneous influence, row 1 of Table 2, we find four negative statistically significant coefficients (beta with

3 To conserve space, we summarize the results omitting all parameter estimates except those directly related to our discussion.

monthly data, standard deviation of ROA with a three year horizon, and coefficient of variation and standard deviation of analyst forecasts), two positive statistically significant coefficient estimates (the two downside risk measures), and five statistically insignificant. For delayed influence, in row 2 of Table 2, we find five positive statistically significant coefficients (in the equations explaining the stock market beta using monthly data, the standard deviation of ROA using all three horizons, and the standard deviation of analyst forecasts), none negative and statistically significant, and six statistically insignificant. In total, of the 22 parameter estimates, we have seven positive and statistically significant, four negative and statistically significant and 11 statistically insignificant.

The results for contemporaneous and one period lag influences in many cases have opposing signs. Thus, R&D intensity has negative and statistically significant influences on contemporaneous beta forecasts (calculated using monthly data), standard deviation of ROA on a three year horizon, and standard deviation of analyst forecasts, but positive and statistically significant influences on delayed values of these variables.

Second, we consider the influence of firm risk on R&D intensity. For contemporaneous influence, row 3 of Table 2, we find two positive statistically significant coefficients (standard deviation of ROA with a three year horizon and one of the downside risk variables), four negative statistically significant (monthly beta, standard deviation of ROA with a 5 year horizon, standard deviation and coefficient of variation in analyst forecasts), and five statistically insignificant. For subsequent R&D, row 4 of Table 2, we find two positive statistically significant coefficients (beta with daily data, standard deviation of ROA with a three year horizon) and nine statistically insignificant. In total, of the 22 parameter estimates, we have four positive and statistically significant, four negative and statistically significant, and 14 statistically insignificant.

Considering all the parameters in Table 2, we have 11 positive statistically significant parameters, eight negative statistically significant parameters and 25 statistically insignificant parameters. The results do not support a general positive association between R&D intensity and firm risk.

Results using R&D spending appear in an on-line appendix (see Table 2a). The results are substantively similar to those using R&D intensity. Specifically, with R&D spending, across all four sets of estimates, we have 11 positive statistically significant parameters, seven negative statistically significant parameters, and 26 statistically insignificant parameters. The results thus do not support a general positive association between R&D spending and firm risk.

To assess robustness, we also ran the first model (R&D intensity influences contemporaneous and subsequent risk) with several alternative specifications. First, we examined whether our results vary for industries with different levels of R&D intensity (see rows 2 and 3 in online Tables 3a and 3b). Second, we used random effects instead of fixed effects (row 4 in online Tables 3a and 3b). Third, we included linear and squares on R&D (row 5 in online Tables 3a and 3b). Fourth, we controlled for variation in exogenous factors by industry and year by including the industry mean of the dependent variable (calculated without the firm of interest) as a control variable[4] (row 6 in online Tables 3a and 3b). Fifth, we allowed for the possibility that R&D expenditures are determined endogenously with risk. Here, we instrumented R&D intensity using two period lags on growth, assets, current assets, debt, employees, and sales (row 7 in online Tables 3a and 3b). Sixth, we estimated the models treating non-reports of R&D as zero R&D expenditures (instead of missing as done in the previous analyses; see row 8 in online

4 We also replicated all our analyses with this control. The results are very similar to those reported in the paper, with some of them having fewer positive coefficients and more negative coefficients.

Tables 3a and 3b). In addition, we repeated all the above specifications for the alternative model: R&D spending influences contemporaneous and subsequent firm risk (online Tables 4a and 4b).

The results from these robustness checks are similar to those obtained from our analyses above. Aggregating across all 176 parameter estimates in online Tables 3a and 3b, we have 61 positive statistically significant coefficients, 26 negative statistically significant coefficients, and 89 statistically insignificant coefficients. While there are more positive, statistically significant parameter estimates than negative, they still constitute only one third of the parameters estimated. Aggregating across the 176 parameter estimates in online Tables 4a and 4b, we have similar results with 48 positive statistically significant coefficients, 35 negative statistically significant coefficients, and 93 statistically insignificant coefficients.

DISCUSSION

The results provide two major findings. First, R&D spending and R&D intensity have a close to zero correlation which highlights a need to differentiate between the two more clearly. Second, R&D (measured either as R&D spending or R&D intensity) does not have a consistent, positive association with the standard measures of firm risk. This stands in stark contrast to the many studies that explicitly or implicitly assume firm R&D spending or R&D intensity reflect risk taking.

The low correlation between R&D spending and R&D intensity suggests we need different theories for the two. If explaining firm decisions on R&D activity, then R&D spending seems the more appropriate measure because firms choose explicit levels of R&D spending. If dealing with the effects of exploration or innovation efforts, then R&D intensity appears more reasonable.

While R&D spending and R&D intensity do not correlate positively, examination of the correlations among the risk measures in Table 1 indicates that all the risk measures correlate positively except for coefficient of variation of analyst forecasts. Consequently, while not all the risk measures may reflect the same underlying construct, they may reflect related constructs.

The second major finding relates to results on both R&D spending and R&D intensity; these differ substantially across risk measures. Different time structures of R&D-risk relations change the results. Even results on closely related risk measures differ. For example, the results for beta calculated using monthly data differ from the results for beta calculated using daily data. The results from R&D intensity explaining contemporaneous monthly beta are statistically significant but with the opposite sign to results from R&D intensity explaining next year's beta, even though much of the data used to estimate the two is identical. Likewise, the statistically significant negative parameter on R&D intensity explaining contemporaneous standard deviation of ROA with a three-year horizon is almost identical but with the opposite sign to lagged R&D intensity explaining the same variable.

The modest correlations among the risk metrics along with these results that vary substantially across risk metrics support Miller and Bromiley's (1990) conclusion that the different measures of firm risk reflect different constructs and that the theorizing underlying risk-related research on R&D spending and R&D intensity needs a much higher level of differentiation. Theorizing that attempts to explain the R&D-risk associations in Table 2 needs to include explanations consistent with no R&D-risk association for some measures of risk and potentially negative R&D-risk associations for other measures. A single theory of R&D and risk seems unlikely to explain these diverse results. While our purpose here is not to present such theories, let us offer suggestions for what such theorizing might look like.

Consider R&D and variation in analyst forecasts. Analyst forecasts are the only risk metric we examined based on ex ante rather than ex post information. Further, they reflect an asymmetry in information between analysts and the firm's managers. Analyst reactions may reflect historical expectations of investors, and therefore, not accurately reflect current firm R&D (Benner and Ranganathan, 2013). Alternatively, variation in analysts' forecasts means variation in forecasts of one year or less in the future. Such variation might reflect uncertainty about firm outcomes over the short term, which might differ substantially about uncertainty about firm outcomes in the long term. Another possibility is that analyst predictions and the variability in analyst predictions may influence strategic investments including R&D, especially during periods of uncertain technological change (Benner and Ranganathan, 2012). These hypothesized relations may point to a dynamic model where analyst forecasts both react to and influence firm R&D and risk (see Washburn and Bromiley, 2014 for a similar model).

Theorizing regarding beta and unsystematic risk appear likewise to call for theories specifically related to these risk measures. Much of the uncertainty associated with R&D should appear as unsystematic risk. While one can develop a theory where technological advancement buffers a firm from general market changes and so influences beta, most of the normal kinds of uncertainty associated with R&D (e.g., uncertainty about the future success of projects or new product introductions) appear to fit unsystematic risk better than systematic.

Previous studies of the association between R&D and risk have tended to beta rather than other risk metrics (Ho, Xu, and Yap, 2004; McAlister, Srinivasan, and Kim, 2007; Wedig, 1990). Wedig (1990), for example, finds a positive relation between R&D intensity and systematic risk in a sample of 214 manufacturing firms using three years of data from 1972, 1977, and 1982. Firm size and market concentration reduce the influence of R&D on risk. However, Wedig

(1990) used five-year moving averages of monthly betas with a correction for firm leverage, five-year capitalization of R&D assuming R&D depreciated at 20% per year, and industry fixed effects, not firm effects. Given various methodological differences and differences in sample, we are not surprised that Wedig (1990) found results that differ partially from our results. Note that our use of R&D along with firm fixed effects follows the common practice in strategy research whereas the capitalization of R&D and industry effects appear rarely (usually in productivity studies that try to calculate a measure of firm-level knowledge stock).

McAlister, Srinivasan, and Kim (2007) find consistently negative influences of R&D intensity on systematic risk directly contradicting the hypothesis that R&D positively associates with firm risk. Being interested in advertising, they restricted their sample to New York Stock Exchange listed firms reporting advertising, resulting in a substantially smaller sample than ours (roughly 3,200 observations versus our 14,500). They also used monthly data aggregated over several years to calculate their measures of systematic risk whereas we used both monthly data over five years and daily data over a single year. They used five-year moving averages for all their predictor variables whereas we used single year observations. The differences in method and sample may explain the differences in results. However, since their results agree with our results in not supporting a general positive R&D-risk relation, we will not explore the reasons for these differences further.

The assumption that R&D increases firm risk may derive from scholars implicitly mixing levels of analysis. While individual R&D projects may be risky, portfolio effects could make firm-level technological risk independent of, or even negatively associated with, R&D. A strong portfolio effect could result in relatively low variability in aggregate outcomes even with highly variable project outcomes. This may explain R&D spending or R&D intensity – both of which capture R&D at a firm, not project, level –associating negatively with some forms of firm risk. However, the mix of positive and negative parameter estimates means the results also do not support the alternative argument that a firm's R&D efforts primarily provides a portfolio or options that reduce risk.

The lack of association between R&D and risk refers to within-firm variation in R&D and firm risk. A cross-sectional analysis could find different results, but many if not most strategy applications of R&D as risk taking use the within firm approach. Our robustness check using random effects, which includes cross-firm variation, finds far more positive statistically significant coefficients than the other analyses.

R&D projects also differ substantially. While some R&D projects involve high levels of risk, other projects do not. For example, many product line extensions require R&D spending, even though most of the funds go to low risk development activities. The proportion of high and low risk R&D projects probably varies across firms and potentially within firms over time. Perhaps a finer-grained analysis of R&D activities that differentiated between high risk research and lower risk development might better explain some forms of firm risk.

Implications for measurement

In addition to substantive reasons, we also consider the possibility that the observed results might result from R&D spending or intensity being formative rather than a reflective measures of risk.

The standard reflective measure approach assumes that the unobserved construct determines the measure. Thus, if construct A, with *reflective* indicators X, Y, and Z, correlates positively with construct B, for the most part X, Y, and Z should correlate with one another and positively with B. Consider what happens when, as is common practice with R&D, a study uses one measured indicator for a construct. With reflective indicators, the lack of multiple measures creates a noisy measure resulting in potential biases and low reliability, but the sign of the relations between the measured indicator and other constructs should generally be the same as the sign of the relation between the construct and other constructs.

R&D spending or intensity might be formative rather than reflective measures of risk. In formative measures, the construct equals a sum of factors that may not be correlated, just as an individual's wealth equals the sum of different assets. That is, if construct C with *formative* indicators T, U, and V correlates positively with construct D, there is no general assumption that T, U, and V correlate positively with one another or with D. Indeed, Podsakoff *et al*. (2006) argues that good formative indicators should not correlate highly and should not have the same correlations with other constructs.

However, assuming R&D spending or intensity are formative measures or risk creates other difficulties. For formative measures, Podsakoff *et al*. (2006, 214) claims the 'omission of one of the measures could alter the conceptual domain of the construct.' This means we cannot use a single formative indicator of construct C to test a theory that relates formative construct C to construct D.

A study claiming to use R&D intensity or spending as a formative indicator of risk must explicitly offer a theory of risk as a formative concept (the sum of independent dimensions). We could envision such a theory where firm risk depended on a sum of technological, financial, etc., factors. However, a study cannot test a theory about risk as part of a formative measure using a single formative measure like R&D spending or intensity. R&D spending or intensity could have correlations of opposite sign and different magnitude with other constructs than the aggregate risk construct or other formative measures of the risk construct. In short, the formative argument does not save R&D spending or intensity as a proxy for firm risk.

Alternatively, one might argue that R&D spending or R&D intensity influence firm risk, but only indirectly. This argument leads to a fuller model that includes the intervening variables, but does not lead to R&D expenditures as a legitimate proxy for risk taking.

The R&D intensity results raise a variety of questions about how we should normalize R&D and variables in general (see Wiseman (2009) for a general discussion of ratio variables). As shown in Table 1, R&D intensity does not have strong positive associations with R&D spending or sales so it is unlikely to proxy for these factors. In some fields, scholars often normalize all the variables in a model by the same factor, e.g., transforming national data into per capita (Firebaugh and Gibbs, 1985). Strategy scholars seldom normalize all their variables by the same denominator using income to equity, R&D to sales, working capital to total assets, etc. One might question explaining a dependent variable normalized by sales with variables normalized by assets (like ROA) or equity (like debt/equity). We lack research comparing, for example, alternative normalizations for R&D (sales, assets, employees, etc.). The entire question of normalization requires additional consideration both in the R&D context and in other measures.

These comments and findings do not pertain to using R&D spending as an indicator of spending per se or to studies that circumvent the issue of underlying construct completely. For example, Bromiley and Washburn (2011) offers an explanation of R&D spending that emphasizes the firm's budget problem and treats R&D spending as a spending category. Alternatively, Ketchen, Thomas, and Snow (1993) use hospitals' research and development efforts (measured as the amount of direct medical education divided by the number of full time interns and residents) to identify groups without claiming R&D reflects an underlying construct, a lack of specificity that avoids the pitfalls associated with using R&D as a risk measure.

However, researchers must take care that their interpretations do assume a positive link between R&D and firm risk.

CONCLUSION

Our findings directly challenge the plethora of studies that use R&D as a proxy for risk taking, or, equivalently, use a risk preference explanation for R&D. At a broader level, our study draws attention to the important issue of the relations between constructs and measure in strategic management research, and questions the legitimacy of using measures devised for other purposes (such as accounting measures) without developing a clear and explicit theory linking the construct and the measure. In some cases, knowing what not to do may be as important as knowing what to do. Our study demonstrates that researchers should avoid casual use of R&D as a proxy for risk taking, without explicitly providing a clear definition and measurement model for risk. Scholars need to reconsider the interpretation of the large number of findings based on such use, an immense task we leave for future research.

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Table 1: Descriptive Statistics

	Variable	Mean	Std. Dev.	1)	2)	3)	4)	5)	6)	7)	8)
1)	Stock Market Beta (monthly)	1.39	0.94								
2)	S.D. of Error Term (monthly)	0.16	0.10	0.59							
3)	Stock Market Beta (daily)	0.92	0.59	0.48	0.25						
4)	S.D. of Error Term (daily)	0.03	0.02	0.54	0.69	0.31					
5)	S.D. of ROA (3 years)	0.11	0.17	0.36	0.50	0.21	0.38				
6)	S.D. of ROA (4 years)	0.12	0.17	0.36	0.53	0.21	0.37	0.93			
7)	S.D. of ROA (5 years)	0.12	0.17	0.36	0.53	0.23	0.37	0.86	0.94		
8)	Coefficient of Variation of Analyst Forecasts	30.39	38.04	-0.40	-0.48	-0.31	-0.43	-0.31	-0.33	-0.35	
9)	S.D. of Analyst Forecasts	0.08	0.15	0.18	0.31	0.08	0.19	0.31	0.34	0.35	-0.31
10)	Downside Risk (α=1)	0.05	0.08	0.29	0.46	0.22	0.30	0.59	0.69	0.78	-0.34
11)	Downside Risk (α=2)	0.09	0.13	0.29	0.44	0.23	0.29	0.60	0.70	0.79	-0.33
12)	R&D Spending	0.07	0.24	-0.10	-0.22	-0.03	-0.19	-0.05	-0.06	-0.06	0.16
13)	R&D Intensity	0.005	0.19	0.01	0.06	0.00	0.01	0.03	0.07	0.11	-0.03
14)	Growth Opportunity	1.80	1.94	0.16	0.26	0.22	0.33	0.21	0.21	0.21	-0.06
15)	Total Assets	2.49	11.06	-0.15	-0.25	-0.11	-0.26	-0.09	-0.10	-0.11	0.17
16)	Total Sales	2.49	13.20	-0.15	-0.22	-0.10	-0.22	-0.10	-0.10	-0.11	0.17
17)	Total Employee	0.01	0.04	-0.13	-0.20	-0.10	-0.19	-0.10	-0.11	-0.11	0.21
18)	Current Ratio	0.53	0.21	0.17	0.31	0.24	0.28	0.15	0.18	0.20	-0.29
19)	Debt Ratio	0.22	0.14	-0.10	-0.15	-0.15	-0.18	-0.13	-0.14	-0.16	0.22

	Variable	9)	10)	11)	12)	13)	14)	15)	16)	17)	18)
10)	Downside Risk (α=1)	0.37									
11)	Downside Risk (α=2)	0.34	0.98								
12)	R&D Spending	-0.02	-0.07	-0.07							
13)	R&D Intensity	0.20	0.12	0.11	-0.01						
14)	Growth Opportunity	0.03	0.15	0.14	0.03	0.01					
15)	Total Assets	0.03	-0.12	-0.11	0.58	-0.01	-0.09				
16)	Total Sales	0.03	-0.11	-0.11	0.36	-0.01	-0.09	0.84			
17)	Total Assets	-0.04	-0.12	-0.11	0.24	-0.01	-0.09	0.56	0.73		
18)	Current Ratio	0.10	0.24	0.22	-0.13	0.06	0.37	-0.24	-0.16	-0.19	
19)	Debt Ratio	-0.05	-0.16	-0.16	0.11	-0.03	-0.09	0.10	0.18	0.15	0.08

N=29,836

Table 2: R&D Intensity Influencing Risk and Risk Influencing R&D Intensity

	Risk Metrics:	Stock Market Beta (monthly)	S.D. of Error Term (monthly)	Stock Market Beta (daily)	S.D. of Error Term (daily)	S.D. of ROA (3 years)	S.D. of ROA (4 years)	S.D. of ROA (5 years)	Coeff. of Variation of Analyst Forecasts	S.D. of Analyst Forecasts	Downside Risk (α=1)	Downside Risk (α=2)
		R&D intensity in t or t-1 influences firm risk in t[1]										
1	R&D Intensity $_t$	-7.540***	-0.111	-0.203	-0.000	-1.645***	-0.215	-0.032	-383.574*	-2.187***	0.942***	1.084*
		(2.289)	(0.133)	(1.560)	(0.026)	(0.446)	(0.401)	(0.379)	(164.936)	(0.532)	(0.270)	(0.470)
2	R&D Intensity $_{t-1}$	5.213*	0.125	0.353	0.005	1.696***	1.017**	1.328***	-39.228	3.385***	-0.183	-0.026
		(2.168)	(0.126)	(1.478)	(0.025)	(0.425)	(0.380)	(0.355)	(151.949)	(0.491)	(0.259)	(0.450)
		Firm risk in t influences R&D Intensity in t or t+1[2]										
3	Risk Metric $_t$	-0.087*	-0.196	-0.017	-0.319	0.318*	0.211	-0.490*	-0.001*	-0.868***	0.809*	0.366
		(0.037)	(0.566)	(0.031)	(1.873)	(0.148)	(0.187)	(0.221)	(0.001)	(0.202)	(0.333)	(0.193)
4	Risk Metric $_{t-1}$	0.044	0.720	0.060*	1.907	0.471**	0.002	0.030	-0.000	0.198	-0.198	-0.163
		(0.037)	(0.618)	(0.029)	(1.822)	(0.159)	(0.194)	(0.230)	(0.001)	(0.189)	(0.362)	(0.208)
	Range of # of Observations	12,039 ~14,006	12,039 ~14,006	24,350 ~24,458	24,428 ~24,644	15,272 ~18,071	12,721 ~15,271	10,410 ~12,718	10,763 ~11,158	10,813 ~11,188	8,369 ~10,409	8,369 ~10,409
	Range of # of firms	2,561 ~2,794	2,561 ~2,794	3,800 ~3,810	3,801 ~3,840	2,736 ~3,022	2,446 ~2,737	2,146 ~2,445	1,859 ~1,891	1,861 ~1,891	1,901 ~2,145	1,901 ~2,145

[1] Coefficients on R&D spending or R&D intensity (rescaled by dividing it by 1000) in panel estimation. Each coefficient comes from a separate model estimation. Year dummies and control variables omitted.

[2] Dependent variable R&D intensity. Explanatory variable is the risk metric at the top of the column. Each coefficient comes from a separate model estimation. Year dummies and control variables omitted.

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

Online Appendix

Table 2a: Results with using R&D spending[1]

	Risk Metrics:	Stock Market Beta (monthly)	S.D. of Error Term (monthly)	Stock Market Beta (daily)	S.D. of Error Term (daily)	S.D. of ROA (3 years)	S.D. of ROA (4 years)	S.D. of ROA (5 years)	Coefficient of Variation of Analyst Forecasts	S.D. of Analyst Forecasts	Downside Risk (α=1)	Downside Risk (α=2)
	R&D spending in t or t-1 influences firm risk in t											
1	R&D Spending $_{t-1}$	0.251** (0.097)	-0.002 (0.006)	-0.066 (0.052)	-0.002* (0.001)	-0.010 (0.016)	-0.019 (0.014)	-0.010 (0.014)	0.392 (3.129)	0.074*** (0.011)	-0.007 (0.010)	-0.010 (0.017)
2	R&D Spending $_{t}$	0.119 (0.092)	-0.006 (0.006)	-0.115* (0.052)	-0.002* (0.001)	0.030 (0.016)	0.043** (0.014)	0.025 (0.013)	9.743** (3.184)	0.053*** (0.011)	0.031*** (0.009)	0.052*** (0.016)
	Firm risk t or t-1 influences R&D Spending in t[2]											
1	RISK METRIC $_{t-1}$	-0.749 (0.986)	-33.043* (16.630)	-0.125 (0.681)	-59.963 (43.495)	-1.628 (4.553)	-7.268 (6.228)	-8.591 (7.932)	0.023 (0.029)	7.994 (8.576)	-15.721 (11.916)	-10.247 (6.895)
2	RISK METRIC $_{t}$	1.226 (0.952)	-24.434 (15.496)	-0.264 (0.711)	7.852 (44.660)	-13.294*** (3.963)	-13.128* (5.502)	-21.821** (7.167)	0.066* (0.029)	21.840* (8.869)	31.497** (10.945)	19.846** (6.386)
	Range of # of Observations	12,269 ~14,251	12,269 ~14,251	24,834 ~24,910	24,881 ~25,101	15,498 ~18,356	12,899 ~15,498	10,553 ~12,899	10,839 ~11,248	10,889 ~11,278	8,482 ~10,554	8,482 ~10,554
	Range of # of firms	2,607 ~2,841	2,607 ~2,841	3,862 ~3,874	3,862 ~3,908	2,770 ~3,061	2,474 ~2,770	2,172 ~2,474	1,875 ~1,912	1,877 ~1,912	1,926 ~2,172	1,926 ~2,172

[1] Coefficients on R&D spending (rescaled by dividing it by 1000) in panel estimation. Each coefficient comes from a separate model estimation. Year dummies and control variables omitted.
[2] Dependent variable R&D spending. Explanatory variable is the risk metric at the top of the column. Each coefficient comes from a separate model estimation. Year dummies and control variables omitted.

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

Table 3a: Summary of Parameter Estimates for Robustness Checks – on R&D Intensity t on Risk t

	Robustness Condition	(1) Stock Market Beta (monthly)	(2) S.D. of Error Term (monthly)	(3) Stock Market Beta (daily)	(4) S.D. of Error Term (daily)	(5) S.D. of ROA (3 years)	(6) S.D. of ROA (4 years)	(7) S.D. of ROA (5 years)	(8) Coefficient of Variation of Analyst Forecasts	(9) S.D. of Analyst Forecasts	(10) Downside Risk (α=1)	(11) Downside Risk (α=2)
1	Original Estimate R&D Intensity	-7.540***	-0.111	-0.203	-0.000	-1.645***	-0.215	-0.032	-383.574*	-2.187***	0.942***	1.084*
		(2.289)	(0.133)	(1.560)	(0.026)	(0.446)	(0.401)	(0.379)	(164.936)	(0.532)	(0.270)	(0.470)
2	High R&D Intensity	-7.319**	-0.097	-0.506	-0.004	-1.664***	-0.189	-0.024	-336.888*	-2.257***	0.942**	1.084*
		(2.389)	(0.137)	(1.606)	(0.026)	(0.496)	(0.446)	(0.425)	(149.451)	(0.562)	(0.303)	(0.526)
3	Low R&D Intensity	5,109.124	664.526**	144.683	0.576	1,585***	1,712***	961.361**	-449,740.7	-1,177.105	487.017*	674.762
		(3,606.94)	(236.335)	(2,305.72)	(44.036)	(404.525)	(375.921)	(313.736)	(403,112)	(914.609)	(228.625)	(406.511)
4	Random Effects R&D Intensity	1.700	0.595***	-2.004	0.158***	3.348***	3.290***	2.597***	-886.5***	2.936***	2.746***	4.279***
		(1.809)	(0.129)	(1.117)	(0.021)	(0.370)	(0.351)	(0.351)	(118.116)	(0.435)	(0.209)	(0.362)
5	With Squares Main Effect R&D Intensity	30.531***	-0.193	7.846	0.155	-1.381	-0.553	-0.690	-1,724.9**	-3.575*	3.606***	3.647*
		(7.885)	(0.458)	(5.449)	(0.089)	(1.479)	(1.347)	(1.293)	(535.162)	(1.719)	(0.941)	(1.633)
	With Squares Squared Effect R&D Intensity	-1,402***	3.313	-313.764	-6.064	-9.914	12.589	23.992	56,753**	58.421	-99.550**	-95.571
		(278.624)	(16.100)	(204.692)	(3.318)	(53.736)	(47.567)	(45.074)	(21,532.6)	(68.823)	(33.705)	(58.330)
6	Controlling for Industry Mean of DV, R&D Intensity as DV	-7.617***	-0.114	-0.694	-0.001	-1.635***	-0.195	-0.048	-378.954*	-2.188***	0.927***	1.072*
		(2.280)	(0.133)	(1.523)	(0.026)	(0.446)	(0.401)	(0.380)	(162.599)	(0.530)	(0.270)	(0.469)
7	Endogenous R&D Intensity Specification	1,120.551	-22.866	-706.148	-27.233**	25.806	13.736	0.722	-18,780.75	273.052*	25.616	41.812
		(731.643)	(28.878)	(468.919)	(10.346)	(82.096)	(102.885)	(122.334)	(21,470.4)	(114.843)	(70.770)	(139.190)
8	Missing R&D Intensity as 0	4.737	-0.500	7.553	0.083	-3.385**	-0.248	-1.795	-1,463***	-4.490**	3.229***	3.060**
		(5.895)	(0.348)	(3.992)	(0.068)	(1.045)	(0.971)	(0.935)	(392.542)	(1.436)	(0.657)	(1.154)

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Table 3b: Summary of Parameter Estimates for Robustness Checks – on R&D Intensity t on Risk t+1

	Robustness Condition	(1) Stock Market Beta (monthly)	(2) S.D. of Error Term (monthly)	(3) Stock Market Beta (daily)	(4) S.D. of Error Term (daily)	(5) S.D. of ROA (3 years)	(6) S.D. of ROA (4 years)	(7) S.D. of ROA (5 years)	(8) Coefficient of Variation of Analyst Forecasts	(9) S.D. of Analyst Forecasts	(10) Downside Risk (α=1)	(11) Downside Risk (α=2)
1	Original Estimate R&D Intensity	5.213*	0.125	0.353	0.005	1.696***	1.017**	1.328***	-41.67	3.385***	-1.269***	-2.012***
		(2.168)	(0.126)	(1.478)	(0.025)	(0.425)	(0.380)	(0.355)	(151.4)	(0.492)	(0.343)	(0.596)
2	High R&D Intensity	5.699*	0.124	0.149	0.008	1.724***	1.031*	1.365***	1.801	3.315***	-1.260**	-2.000**
		(2.256)	(0.129)	(1.518)	(0.025)	(0.471)	(0.422)	(0.398)	(138.0)	(0.519)	(0.383)	(0.668)
3	Low R&D Intensity	-1,183	-20.60	-545.6	31.51	374.2	326.2	-172.7	-502,479	-365.6	-451.4	-410.3
		(1,840)	(100.6)	(1,664)	(27.55)	(237.1)	(189.4)	(145.6)	(330,230)	(718.5)	(283.1)	(504.2)
4	Random Effects R&D Intensity	9.155***	0.664***	-2.056	0.153***	4.469***	3.184***	3.354***	-700.7***	5.395***	2.071***	3.242***
		(1.759)	(0.126)	(1.076)	(0.020)	(0.354)	(0.336)	(0.327)	(108.5)	(0.400)	(0.250)	(0.436)
5	With Squares Main Effect R&D Intensity	-7.756	0.286	4.939	0.189*	5.673***	3.996**	3.005*	-775.4	6.322***	-6.708***	-8.484***
		(7.544)	(0.438)	(5.259)	(0.086)	(1.462)	(1.302)	(1.224)	(514.7)	(1.665)	(1.271)	(2.204)
	With Squares Squared Effect R&D Intensity	471.0	-6.341	-176.3	-7.010*	-147.3**	-108.5*	-60.73	29,456	-117.24	223.1***	265.48**
		(263.3)	(15.23)	(194.0)	(3.142)	(51.70)	(45.37)	(42.47)	(19,707)	(63.46)	(50.29)	(87.18)
6	Controlling for Industry Mean of DV, R&D Intensity as DV	5.094*	0.106	0.203	0.003	1.700***	0.984**	1.334***	-55.82	3.417***	-0.171	-0.009
		(2.162)	(0.126)	(1.443)	(0.024)	(0.425)	(0.381)	(0.356)	(149.8)	(0.490)	(0.259)	(0.449)
7	Endogenous R&D Intensity Specification	156.7*	5.814	-16.56	0.918	39.33**	28.09	36.97**	-1,863	23.51**	-0.726	3.433
		(68.28)	(4.385)	(21.53)	(0.508)	(13.92)	(14.35)	(13.86)	(1,184)	(7.709)	(5.562)	(9.499)
8	Missing R&D Intensity as 0	4.656	0.344	3.603	0.051	3.443***	0.887	2.653**	-594.6	8.520***	-1.000	-0.370
		(5.532)	(0.325)	(3.616)	(0.063)	(1.014)	(0.926)	(0.873)	(372.6)	(1.368)	(0.632)	(1.107)

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Table 4a: Summary of Parameter Estimates for Robustness Checks – R&D Spending t on Risk t

	Robustness Condition	(1) Stock Market Beta (monthly)	(2) S.D. of Error Term (monthly)	(3) Stock Market Beta (daily)	(4) S.D. of Error Term (daily)	(5) S.D. of ROA (3 years)	(6) S.D. of ROA (4 years)	(7) S.D. of ROA (5 years)	(8) Coefficient of Variation of Analyst Forecasts	(9) S.D. of Analyst Forecasts	(10) Downside Risk (α=1)	(11) Downside Risk (α=2)
1	Original Estimate R&D spending	0.119	-0.006	-0.115*	-0.002*	0.030	0.043**	0.025	9.743**	0.053***	0.031***	0.052***
		(0.092)	(0.006)	(0.052)	(0.001)	(0.016)	(0.014)	(0.013)	(3.184)	(0.011)	(0.009)	(0.016)
2	High R&D spending	0.126	-0.007	-0.099	-0.002	0.030	0.044**	0.027	8.393**	0.050***	0.032**	0.054**
		(0.097)	(0.006)	(0.055)	(0.001)	(0.018)	(0.016)	(0.015)	(2.948)	(0.012)	(0.010)	(0.018)
3	Low R&D spending	0.308	0.005	0.180	-0.000	-0.120*	-0.082	-0.067	-10.954	0.099	-0.025	-0.082
		(0.678)	(0.047)	(0.362)	(0.007)	(0.060)	(0.059)	(0.051)	(29.855)	(0.065)	(0.065)	(0.115)
4	Random Effects R&D spending	-0.039	-0.038***	0.119***	-0.009***	-0.034***	-0.018	-0.020*	20.635***	0.007	-0.014**	-0.025**
		(0.053)	(0.005)	(0.029)	(0.001)	(0.010)	(0.010)	(0.010)	(1.928)	(0.008)	(0.005)	(0.008)
5	With Squares: Main Effect R&D spending	0.464*	-0.016	-0.156	-0.009***	0.059	0.076*	0.088**	30.395***	0.083**	0.076***	0.121***
		(0.205)	(0.012)	(0.117)	(0.002)	(0.036)	(0.032)	(0.030)	(7.500)	(0.026)	(0.019)	(0.034)
	With Squares: Squared Effect R&D spending	-0.191	0.005	0.022	0.004***	-0.016	-0.018	-0.035*	-10.840**	-0.016	-0.025**	-0.038*
		(0.102)	(0.006)	(0.056)	(0.001)	(0.018)	(0.016)	(0.015)	(3.567)	(0.012)	(0.009)	(0.017)
6	Controlling for Industry Mean of DV, R&D spending	0.120	-0.007	-0.110*	-0.002*	0.030	0.043**	0.025	8.984**	0.053***	0.031***	0.052***
		(0.091)	(0.006)	(0.051)	(0.001)	(0.016)	(0.014)	(0.013)	(3.113)	(0.011)	(0.009)	(0.016)
7	Endogenous R&D spending Specification	1.841	-0.037	-0.299	-0.019*	0.023	0.018	0.045	-21.723	0.721**	0.037	0.053
		(0.957)	(0.046)	(0.449)	(0.009)	(0.142)	(0.168)	(0.131)	(34.301)	(0.237)	(0.065)	(0.130)
8	Missing R&D spending as 0	0.181	-0.005	-0.137	-0.006***	0.046	0.062**	0.052**	24.483***	0.051**	0.058***	0.093***
		(0.138)	(0.008)	(0.083)	(0.002)	(0.023)	(0.021)	(0.019)	(5.153)	(0.019)	(0.013)	(0.022)

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

Table 4b: Summary of Parameter Estimates for Robustness Checks – R&D Spending t on Risk t+1

	Robustness Condition	(1) Stock Market Beta (monthly)	(2) S.D. of Error Term (monthly)	(3) Stock Market Beta (daily)	(4) S.D. of Error Term (daily)	(5) S.D. of ROA (3 years)	(6) S.D. of ROA (4 years)	(7) S.D. of ROA (5 years)	(8) Coefficient of Variation of Analyst Forecasts	(9) S.D. of Analyst Forecasts	(10) Downside Risk (α=1)	(11) Downside Risk (α=2)
1	Original Estimate R&D spending	0.251**	-0.002	-0.066	-0.002*	-0.010	-0.019	-0.010	0.359	0.074***	-0.041***	-0.074***
		(0.097)	(0.006)	(0.052)	(0.001)	(0.016)	(0.014)	(0.014)	(3.128)	(0.011)	(0.010)	(0.018)
2	High R&D spending	0.237*	-0.002	-0.050	-0.002	-0.015	-0.026	-0.018	-0.318	0.068***	-0.045***	-0.080***
		(0.104)	(0.006)	(0.056)	(0.001)	(0.018)	(0.016)	(0.016)	(2.943)	(0.012)	(0.012)	(0.021)
3	Low R&D spending	-0.881	-0.008	0.076	-0.005	-0.105*	-0.097*	-0.135**	-13.681	-0.207***	-0.006	-0.006
		(0.567)	(0.039)	(0.290)	(0.006)	(0.048)	(0.046)	(0.043)	(23.535)	(0.051)	(0.030)	(0.054)
4	Random Effects R&D spending	-0.018	-0.036***	0.122***	-0.009***	-0.047***	-0.044***	-0.038***	14.67***	0.027**	-0.032***	-0.055***
		(0.055)	(0.005)	(0.029)	(0.001)	(0.010)	(0.010)	(0.010)	(1.943)	(0.008)	(0.005)	(0.009)
5	With Squares: Main Effect R&D spending	0.711***	0.002	-0.109	-0.004*	0.080*	0.068*	0.036	2.146	0.157***	-0.117***	-0.199***
		(0.199)	(0.012)	(0.112)	(0.002)	(0.034)	(0.031)	(0.029)	(7.075)	(0.024)	(0.024)	(0.042)
	With Squares: Squared Effect R&D spending	-0.257**	-0.002	0.018	0.001	-0.050**	-0.048**	-0.026	-0.927	-0.043***	0.039***	0.064***
		(0.097)	(0.006)	(0.053)	(0.001)	(0.017)	(0.015)	(0.014)	(3.316)	(0.011)	(0.011)	(0.020)
6	Controlling for Industry Mean of DV, R&D spending	0.242*	-0.003	-0.063	-0.002*	-0.010	-0.019	-0.011	0.311	0.073***	-0.008	-0.011
		(0.095)	(0.006)	(0.051)	(0.001)	(0.016)	(0.014)	(0.014)	(3.067)	(0.011)	(0.010)	(0.017)
7	Endogenous R&D spending Specification	4.422	0.707	0.298	-0.023	0.559	1.170	1.150*	-80.47	0.581*	0.587	1.113
		(3.551)	(0.457)	(0.577)	(0.016)	(0.368)	(0.604)	(0.552)	(56.01)	(0.256)	(0.323)	(0.619)
8	Missing R&D spending as 0	0.478***	-0.002	-0.000	-0.003*	0.033	0.020	0.016	1.708	0.113***	-0.005	0.001
		(0.136)	(0.008)	(0.076)	(0.001)	(0.022)	(0.020)	(0.019)	(4.818)	(0.018)	(0.013)	(0.023)

Standard errors in parentheses

*** $p<0.001$, ** $p<0.01$, * $p<0.05$