R&D Project Entrenchment

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October 16, 2009

Abstract

A common perspective is that consistent research and development investment facilitates innovation and enhances firm performance, while volatile R&D spending implies myopic strategic decision-making in the firm. Yet, companies routinely tie their annual R&D budgets to fluctuating sales. This poses the question of why firms choose to inject volatility into the R&D process. One potential explanation focuses on the agency problem that arises in opaque R&D projects. More specifically, we argue that firms that are able to develop mechanisms and internal controls to curtail funding in underperforming R&D projects exemplify effective corporate governance. Using a large panel of almost 19,000 firm-years from 1996 to 2006, we find that research and development volatility is positively related to several different proxies of R&D success and firm performance. We interpret this evidence to suggest that volatile R&D expenditures, instead of denoting managerial myopia, can indicate the creation of internal governance mechanisms to mitigate R&D project manager entrenchment.

JEL Classification: G31, G34, L25
Keywords: Project Entrenchment, R&D Manipulation, Corporate Governance, Project Management

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A common view is that firms should consistently invest in research and development (R&D) in order to create the least amount of disruption in their R&D labs. Kor & Mahoney (2005) note that stable investments in research and development allows firms to develop sustainable competitive advantages. Dierckx & Cool (1989) suggest that productive R&D is the result of knowledge accumulation that requires steady investment over time. The implication is that volatility in research and development spending is associated with unsuccessful R&D outcomes and weak firm performance. Further, prior research suggests that managers routinely manipulate research and development expenditures to smooth earnings or to meet earnings forecasts (Degeorge, Patel & Zeckhauser 1999). For instance, Elliot, Richardson, Dyckman & Dukes (1984) and Bushee (1988) observe that managers can adjust their R&D budgets in order to smooth corporate earnings. Baber, Fairfield & Haggard (1991) argue that managers reduce research and development expenditures when earnings will be less than analysts' forecasts. Generally, managers are thought to make myopic decisions regarding R&D investments, focusing on short-term earnings instead of concentrating on value creation. Instead, firms that minimize or resist opportunities to disrupt the R&D process are thought to add the most value for shareholders of the firm.

Yet, the rule of thumb in the R&D literature is that annual R&D expenditures are based on a fixed percentage of sales (e.g. the annual R&D budget is fixed at 5% of sales) (Scherer 2001; Tubbs 2007). If stability in R&D leads to greater value creation, then it seems surprising that firms inject volatility into the R&D budget by using a fixed percentage of sales that fluctuate over time to set their annual R&D budgets. Our key insight is that governance of the R&D process requires firms to devise mechanisms that enable them to cut labor intensive R&D projects that are underperforming. Eliminating R&D projects in the firm can be difficult because these projects can be quite opaque and their managers have incentives to continue or expand the project (Bernardo, Cai & Luo 2001; Stein 2003). R&D is intensive in its use of highly skilled labor; further it can be a stochastic process. R&D projects can endure for 10 to 12 years without producing a rent-generating patent (Bernardo, et al. 2001: 333). This unpredictability adds greater difficulty to the identification and reduction of unsuccessful projects.

In our framework, firms may choose to set R&D budgets as a fixed percentage of sales in order to facilitate the pruning of slow moving or underperforming projects. We focus on the ability to curtail investments in the lowest performing R&D projects, freeing up resources to fund new, more promising projects. This position is consistent with prior research arguing that too much stability within the R&D function underpins the not-invented-here (NIH) syndrome (Katz 1982; Katz & Allen 1982). Thus, we posit that creative destruction in the R&D process induces research and development expenditure volatility, leading to greater research and development success (such as patents, patent citations, new products, etc.) and improved firm performance.

In contrast, the other type of long-term investment that is recorded in the accounting reports – capital expenditures – is seldom set as a fixed percentage of sales (Lins & Servaes 1999). Our interpretation is that firms do not have the same concerns when they specify their level of capital expenditures each year. We argue this because the performance associated with physical assets is easier to observe; such assets can readily be sold to other firms, suggesting lower potential costs to investors in the firm. In contrast, it is difficult to observe R&D performance and the salvage value of a failed R&D project is often minimal.

Our arguments focus on the limited transparency of research and development projects, the difficulty in observing and evaluating their performance, and the private benefits to the manager from continuing the project (Hoskisson & Hitt 1988; Stein 2003). Firms seek to structure R&D activities to limit funding to R&D projects managers until they have demonstrated the viability of their projects (Bowman & Hurry 1993; McGrath 1997; Childs, Ott & Triantis 1998; Childs & Triantis 1999; Bernardo, et al. 2001; Stein 2003; Henderson & Stern 2004). Due to the opaque nature of the research and development process, successful firms provide only marginal funds to project managers until their projects achieve certain verifiable milestones. This staged financing approach to controlling R&D investments leads to lumpy increases in project funding that depend on the timing of the verification stages.[1]

Our empirical analysis investigates the relation between research and development volatility and

[1] Staged-financing is also used by venture capitalist and commercial mortgage lenders to mitigate agency conflicts in start-up firms and in construction loans (Melnik and Plaut, 1986; Gompers, 1995). While it could be more efficient to fully fund these projects up-front, the potential for rent-seeking managers to extract or waste the funds leads to staged financing to mitigate this commitment problem (Neher, 1999).

several proxies of R&D success, including the number of patents granted, patent citations, the number of new product launches, and new product success. We also examine the relation between research and development volatility and stock-market based firm performance (e.g.: Tobin's q). To further differentiate between earnings manipulation and creative destruction perspectives on research and development volatility, we evaluate the impact that increases in R&D spending, and decreases in R&D spending, have on firm performance. Finally, we evaluate how the firm's short-term earnings performance influences the relationship between R&D expenditure volatility and firm performance.

This research contributes to the literature in several important ways. First, we theoretically develop the notion that volatility in research and development expenditures can stem from effective governance and oversight of the R&D funding process. Second, we explore approaches that firms use to limit overinvestment in the research and development process. We also develop testable hypotheses to differentiate between earnings manipulation and creative destruction explanations for R&D volatility. Third, we document that R&D volatility is positively related to proxies of research and development success and firm performance. Our central message is that R&D expenditure volatility need not imply myopic decision-making. Instead, it can indicate effective corporate governance of the R&D process.

1. R&D MANIPULATION AND ENTRENCHMENT

Firms engage in research and development to create competitive advantages and increase firm value (Pakes 1985; Jaffe 1986; Lev & Sougiannis 1996; Hall, Jaffe & Trajtenberg 2005). Yet, managing this R&D process is challenging as these projects have considerable technological uncertainty and can be opaque to non-scientists. In addition, breakthroughs are difficult to predict or forecast, while cash expenditures are easy to observe. Prior research suggests that firms often adjust their research and development expenditures to meet earnings forecasts, disrupting the research process and destroying firm value (Elliott et al. 1984; Baber et al. 1991; Dechow & Sloan 1991; Perry & Grinacker 1994; Bushee 1998; Degeorge, et al. 1999; Cheng, 2004).

This has been interpreted to imply sthat volatility in R&D expenditures is a symptom of myopic decision-making by managers, leading to lower firm performance.[2]

Since prior evidence suggests that R&D can be reduced in order to meet short term earnings targets, R&D expenditure volatility can be indicative of earnings management activity (manipulation). These short term changes to R&D expenditures to meet earnings goals can interfere with the real work underway in the R&D lab. This literature suggests that, if a firm reduces the funding to an R&D project at a time when the project is nearing a major accomplishment, then the opportunity cost to the firm can be enormous. The manipulation hypothesis is implicitly based on the idea that consistently investing in R&D over time makes the most progress towards valuable innovations and enhances firm value. Grabowski (1968) argues that fluctuations in R&D hurt firm performance. Research workers have highly specialized skills that make them particularly well-suited to a unique research project. These R&D team members cannot easily be fired and rehired, depending upon the firm's short-term financial condition (Hambrick, MacMillan & Barbosa 1983). Kor & Mahoney (2005) posit that firms making inconsistent R&D investments lose their ability to create sustainable competitive advantages.

We consider an alternative perspective, focusing on how firms create value by limiting entrenchment and overinvestment. Schumpeter (1942) argues that creative destruction underpins much of the progress witnessed in the industrial age. To Schumpeter, creative destruction takes place when new, superior forms are created that replace old, inferior forms. For instance, creative destruction occurred when craft automobile manufacturers were replaced by the mass manufacturers, or when the mainframe computing paradigm was replaced by the personal computing paradigm (Mazzucato 2002). Evidence continues to emerge that provides more insight into the positive role that creative destruction plays in economic growth. For instance, recent empirical research suggests that turnover in the top ten companies in an economy is associated with superior economic performance (Fogel, Morck & Yeung 2006). Economies that replace old, declining firms with new fast growing firms generate economic growth more quickly.

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[2] R&D expenditure volatility is a measure of the fluctuation in firm level R&D spending over time. A firm with relatively low R&D spending volatility invests about the same amount on R&D each time period. A firm with relatively high R&D spending volatility changes its R&D expenditure frequently and substantially over time.

At the macroeconomic level, it has been argued that volatility and growth are positively related. For example, Schumpeter (1939) argued that business cycles promoted the efficiency of firms, because the opportunity costs of investing in productivity improvements are smaller during recessions. Therefore during periods of depressed demand, it is efficient to transfer resources from production to R&D. In subsequent work, Hall (1991) suggests that the higher unemployment during recessions improves matching between workers and jobs. This slump occurs because the first workers fired are likely to be those least efficient in their current positions. Recessions allow the economy to "re-sort" workers, improving productivity. Joining these two arguments provides a link to Schumpeter's (1942) notion of creative destruction, since both increased R&D spending by firms and re-sorting of workers (some of whom may become self-employed entrepreneurs) are the basis for the emergence of new technologies.

In the same way that changes in the level of employment at the macroeconomic level can improve economic productivity, changes in the level of R&D expenditure within the firm can be beneficial. We argue that active management of R&D within the firm can lead to volatility in research and development spending. Firms that are able to reduce or eliminate the worst performing R&D projects should have positive gains. During periods of low R&D spending, firms have the opportunity to explore, thereby discovering valuable new opportunities. Lovas and Ghoshal (2000) argue that managers should promote an environment of "guided evolution" within the firm that promotes the de-selection of inferior alternatives in favor of better opportunities. Yet, research and development project managers have incentives to continue the projects on which they are working, making project turnover difficult. Consequently, those firms that are able to mitigate overinvestment in R&D and reduce funding for lagging research and development should outperform those with more static R&D expenditures.

When describing the governance of investments in R&D-intensive firms, Bernardo et al. (2001) argue that division managers are motivated to control larger amounts of firm resources in order to enjoy the reputation and perquisites of managing larger organizations. Stein (2003) adds that when firms are dealing with intangible assets such as R&D, it is difficult to compel project managers truly to disclose the prospects for long-run projects, because management does not have currently available data that can be used to evaluate or refute their claims. Entrenched managers can thwart executives' efforts to understand the quality of the firm's R&D projects, creating the need for governance policies to mitigate this problem.

While project prospects remain unobserved, the firm can limit entrenchment by keeping the project's expenditure low (Bowman & Hurry 1993). Once the value of the R&D project becomes clearer, firms should either ramp up or decrease the expenditures on that project. Firms that limit the financing to their R&D projects in order to mitigate managerial opportunism can then exploit these projects when the project provides verifiable results.

In one sense, high R&D intensive firms can be thought of as performing a similar role as venture capitalists; both fund a variety of projects with technological uncertainty. Investing in multiple projects helps the firm and the venture capitalist to average out these projects' risks and to reap high rewards with the handful of successful projects. Yet, both venture capitalists and executives of R&D intensive firms face the concern that the individual project managers have incentives to conceal the true prospects of success of their individual initiatives. One way to combat managerial opportunism is to implement staged-financing. Using a staged-financing framework, investors withhold incremental funding until managers can provide demonstrable results from the previous round of financing (Neher 1999). Gompers (1995) posits that staged-financing is more prevalent when firm management is more entrenched and when firm opacity is higher.

Staged-financing is used to limit both moral hazard and uncertainty problems in external capital markets (Neher 1999) because investing in start-up firms subjects the investor to project viability risk and managerial opportunism. By employing staged-financing logic, venture capitalists are able to mitigate managerial incentives to waste resources. We suggest that firms use staged-financing in the internal market (i.e.: within the firm) to achieve similar results, namely to mitigate moral hazard problems with R&D project managers and reduce technological uncertainty. That is, firm decision-makers fund R&D projects for specific time intervals, and do not release subsequent funds until interim R&D project milestones are reached.

2. R&D VOLATILITY AND SUCCESS

If R&D expenditure volatility is due to myopic investment decisions by management, then changes in R&D spending are likely to interfere with innovation. Changes in R&D spending may result in employee turnover within the R&D function. These changes can also disrupt the work environment of R&D workers (Grabowski 1968; Hambrick, et al. 1983). Firms that interrupt R&D investment have less knowledge and a diminished ability to learn (Kor & Mahoney 2005). Such firms making frequent and substantial changes in R&D spending may sacrifice long-term R&D performance in favor of short-term earnings predictability (Elliott et al. 1984; Baber et al. 1991; Dechow & Sloan 1991; Perry & Grinacker 1994; Bushee 1998; Degeorge, et al. 1999; Cheng 2004).

Other research suggests that too much stability within the firm's R&D function can be detrimental to the firm's innovative capability. Katz (1982) argues that stable and long-lived R&D project teams become more isolated from key information sources both within and outside their organizations. In addition, Katz and Allen (1982) suggest that while stability in R&D project teams can be conducive to better performance, *too much* stability underpins the not-invented-here syndrome. Against this backdrop we argue that one aspect of effective monitoring and governance in the R&D process occurs by rechanneling and redistributing R&D funding to mitigate problems of team members become increasingly inward-looking.

In this context, firms delivering complex products and systems – usually highly customized one-off projects – present a good template for study since entrenchment possibilities are naturally limited (Hobday, 1998; Gann and Salter, 2000). Such firms tend to develop highly sophisticated communication and control mechanisms between their business and technical arms, very much in line with our argument for the active management of R&D.

Some recent work on user-driven innovation also has interesting links to our research. As pointed out by von Hippel and Katz (2002), in the traditional new product development process, manufacturers first were required to develop an accurate understanding of user needs. As user needs become increasingly sophisticated, this process is becoming increasingly expensive. It is reported that manufacturers that transfer "need-related" aspects of innovation to users, maintaining a shared understanding of the product through "toolkits," improve the time and cost aspects of their innovation processes. We interpret this model to imply two things – first that manufacturers implementing user-driven innovation produce improved innovation performance, and second that such manufacturers have greater flexibility in deploying and redeploying their R&D expenditures.

Firms invest in R&D for several reasons. First, both scientists and management seek to create patents, but for different reasons (Mudambi & Swift 2009). Scientists are motivated to create patents as a form of prestige, and to enhance their professional reputations among their peers (Gittelman & Kogut 2003). Firm management seeks new patents so that those patents can be exploited internally to create commercially valuable innovations, or so that those patents can be licensed to other innovators for profit. Second, firms conduct R&D in order to generate successful new products, in support of revenue and profit growth objectives. The implication is that R&D is valuable to the firm and that any short-term manipulation will be harmful. Thus, the manipulation hypothesis suggests:

Hypothesis 1A: R&D expenditure volatility is negatively related to firm R&D-related outputs (i.e:. number of patents, patent citations, number of new products, and new product success).

Similarly, firms that manipulate R&D expenditure in order to improve short-term earnings predictability at the expense of long-term R&D performance should produce fewer innovations. In turn, such firms should exhibit weaker overall performance. This leads to our second hypothesis:

Hypothesis 2A: R&D expenditure volatility is negatively related to firm performance.

In contrast, the creative destruction perspective suggests that volatile R&D spenders may be actively managing their R&D project portfolios, permitting creative destruction (Schumpeter 1942) to work within the R&D function. Such firms may conduct more efficient and effective R&D. This leads to the following alternative hypothesis:

Hypothesis 1B: R&D expenditure volatility is positively related to firm R&D - related outputs.

The creative destruction argument suggests that research and development expenditure volatility is evidence of effective R&D management. Firms that are aggressively culling underperforming projects while pressing R&D project managers for demonstrable gains in other projects may yield greater innovations. In turn, such firms should exhibit stronger overall performance. Thus, the creative destruction version of our second hypothesis is:

Hypothesis 2B: R&D expenditure volatility is positively related to firm performance.

3. CUTTING R&D EXPENDITURES

The R&D manipulation hypothesis suggests that firms cut R&D myopically to meet short term accounting goals. Therefore, decreases in R&D expenditure should have the greatest negative impact on firm performance, while gains could be still be positive. This leads to third hypothesis, which focuses on the performance impacts of cutting R&D spending. The manipulation hypothesis version is:

Hypothesis 3A: Firm performance is negatively related to decreases in R&D expenditure.

Alternatively, we argue that firms limit the financing to their projects to control agency problems, allowing them more readily to reduce spending in poorly performing projects. This creative destruction perspective suggests that successful firms aggressively cull lagging R&D projects and that decreasing research and development expenditures can be particularly valuable, since it frees up firm resources that may be redeployed in the future once new, more promising opportunities are discovered. A related viewpoint on R&D spending focuses on how firms use a portfolio of different projects in order to reduce technological uncertainty (Bowman & Hurry 1993; McGrath & Nerkar 2004). This real options approach suggests that firms have relatively flat R&D spending until a break-through is discovered, at which time the firm increases investment in this project. Consequently, the real options view could also be used to argue that R&D volatility could be indicative of a well managed portfolio of R&D projects, because volatility is increased when firms exercise their R&D options.

Our creative destruction argument suggests firms use staged financing to decrease technological uncertainty and to limit project manager opportunism. Therefore, we would expect both R&D increases (technology uncertainty resolved) and decreases (opportunism limited) to be value increasing. If the creative destruction hypothesis holds, then we should observe that firm value is positively related to both the ramping up of investments in promising projects and the culling of underperforming R&D projects. Therefore, decreases in R&D expenditure should have positive and significant impact on firm performance.

Hypothesis 3B: Firm performance is positively related to decreases in R&D expenditure.

4. R&D VOLATILITY AND EARNINGS-RELATED RISK

The business press routinely observes that managers are under great pressure to meet current earnings targets (Hansen & Hill 1991). Prior research has documented two circumstances under which firms change their level of R&D expenditure in a manner consistent with this view. R&D spending is more likely to be reduced when the CEO approaches retirement (Dechow & Sloan 1991) or when the firm is likely to miss an earnings objective (Baber et al. 1991; Perry & Grinacker 1994). Yet others have argued that high performing firms do not use R&D in order to manipulate earnings in the short-run. Firms with high operating cash flow volatility not only delay research and development investment during periods of weak operating performance, but also permanently forego R&D investment (Minton & Schrand 1999). Further, firms can not recover from this period of decreased R&D investment by increasing spending during periods of strong operating performance. Firms that spend the same amount of R&D in half the time create a lower stock of knowledge than firms that maintain the same level of R&D expenditures over a longer time period (Dierckx & Cool 1989).

If R&D expenditure volatility is evidence that entrenched executive managers are using R&D spending as a buffer that can be used to improve short-term earnings performance, then any relation between R&D expenditure volatility and firm performance should depend on the firm's earnings performance. The behavioral theory of the firm (Cyert & March 1963) implies that firms manage their performance relative to aspirations, and measure risk as the likelihood of missing performance aspirations. Subsequent research has supported this assertion. Executive decision makers (Mao 1970; March & Shapira 1987) and financial analysts (Baird & Thomas 1990) describe risk as the frequency and magnitude of negative outcomes. When considering firm risk, measuring the extent to which the firm misses its earnings objective has theoretical and practical appeal (Miller & Leiblein 1996).

This leads to our fourth hypothesis. Presumably, high-performing firms do not use R&D expenditures to manipulate short-term earnings (Dierckx & Cool 1989; Minton & Schrand 1999). Therefore, firms that successfully link R&D expenditure volatility to superior firm performance should exhibit more earnings-related risk. Firms with the strongest relation between R&D expenditure volatility and firm performance should also have a history of more frequent and substantial earnings target misses.

Hypothesis 4: The relationship between R&D expenditure volatility and firm performance is higher among firms with higher earnings-related risk.

5. DATA AND VARIABLES

In order to test our hypotheses, we gather financial, economic and R&D-related data on a sample of publicly traded U.S. manufacturing firms. Financial and economic measures are relatively objective. However, R&D performance can be measured in many different ways.

Based on the knowledge creation and innovation literature, we measure R&D-related output in three ways. First, we use firm patents and patent citations as a proxy of patent portfolio impact (Pakes 1985; Jaffe 1986; Henderson & Cockburn 1994; Shan, Walker & Kogut 1994; Cockburn & Henderson 1998; Zucker, Darby & Armstrong 2002). However, patents do not capture all forms of firm innovation (Roberts & Amit 2003). Therefore, new product introductions are used as a second measure of innovation output (Coombs, Narandren & Richards 1996; Barnett & Freeman 2001; Roberts & Amit 2003; He & Wong 2004; Nerkar & Roberts 2004). New product releases may be evidence of firm innovation, but most new products fail (McMath & Forbes 1998; Bobrow & Shafer 1987). If a firm launches many new products that fail in the market, such a firm may be overinvesting in R&D. Therefore, we use new product success as a third measure of valuable innovation activity (Gatignon, Weitz & Bansal 1990; Nerkar & Roberts 2004).

A. The Data

Our sample frame is generated from the Compustat Annual North America databases (Standard & Poors 2009), which provide accounting and market information on all publicly traded firms in the U.S. We constructed several specific data sets to test our hypotheses. We draw financial and economic data from Compustat and use information from the Compustat Segments file to estimate each firm's level of diversification. A measure of industry concentration is taken from the U.S. Economic Census (U.S. Census Bureau 2002). Following Hall, et al. (2005), all manufacturing firms (NAICS codes 31 through 3399) are selected. This data set covers the years 1997 to 2006. Each observation represents one firm-year. After removing observations with missing values, the data set contains 18,928 firm-year observations. We constructed additional data sets to test hypotheses 1A and 1B. These hypotheses relate to firm level knowledge creation and innovation. As noted above, we use three measures of R&D-related output. Each of these measures necessitates the construction of a specific data set. In general, there is an indeterminate time lag between an R&D investment and the granting of a patent, or the issuance of a new product. In constructing the additional datasets, we link firm-level innovative output (in the form of patents, new product releases and new product success) over a five year window (2002 to 2006) to ten years of firm-level R&D investments (1997 to 2006). The ten year R&D window is composed of five years preceding the patent window and five years concurrent to the patent window.[3]

*Patents and patent citations***.** All patent and patent citation data are taken from the most comprehensive available data source, namely the NBER U.S. Patent Citations Data File (Hall, Jaffe & Trajtenberg 2001). This dataset has recently been updated to include patents and citations through 2006. This file contains detailed information on over 3 million U.S. patents from 1963 to 2006, and all citations made to these patents from 1975 to 2006. To the extent possible, these patents have been matched to U.S. publicly traded firms listed in the Compustat databases.

New product releases. Several researchers have used the business press as a source for new product releases (Coombs, et al. 1996; Barnett & Freeman 2001; Roberts & Amit 2003; He & Wong 2004; Nerkar & Roberts 2004). The Lexis-Nexis Academic database (Lexis-Nexis 2007) is used to search the PR Newswire and Business Wire press release distribution services for new product press releases that were issued by the 3,184 firms in our sample during the 2002 to 2006 study period. We find 6,479 new product releases from the firms in our sample during that time period.

New product performance. The new product performance dataset consists of new product releases in the U.S. pharmaceutical industry (NAICS 3254) from 2002 to 2006. Following Gatignon, et al. (1990) and Nerkar and Roberts (2004), we use the total sales of a new product in its first full year on the market as a

[3] As discussed later, our results are robust to the selection of other time lags between R&D expenditure and knowledge creation.

measure of new product performance. New product sales data for the pharmaceutical industry were obtained from IMS New Product Focus™ (IMS Health 2007). For each new drug introduction, IMS reports the name of the drug, the firm that produces the drug, the year and month that the drug was released, and its annual sales. Of the 752 drug launches reported by IMS during this time period, we are able to match 450 to publicly-traded firms reporting in the Compustat financial database.

B. Dependent Variables

*Firm Performance***.** Firm performance is measured using a well-known proxy for Tobin's q (Chung & Pruitt 1995). Tobin's q is defined as the ratio of the market value of a firm to the replacement cost of its assets. Firms with q greater than one are creating economic value, since such firms can be sold for more than it costs to obtain their assets (Chung & Pruitt 1995).

Patent Portfolio Impact. The number of patents granted to a firm, and the number of citations a firm's patents have received from subsequent patents, are commonly used to measure the impact of a firm's patent portfolio (Pakes 1985; Jaffe 1986; Henderson & Cockburn 1994; Shan, Walker & Kogut 1994; Cockburn & Henderson 1998; Zucker, et al. 2002; Hall, et al. 2005). A highly cited patent is judged to be more "valuable" than a patent that has received relatively few citations from other patents over time (Hall, et al., 2005).

Hall, et al. (2001) observe that the number of patents granted has increased sharply since 1983, and that each patent is receiving more citations over time. In addition, the number of patents granted and the number of citations received per patent varies by technological field (Hall, et al. 2001). Finally, patent citations are truncated at the date of observation. *Ceteris paribus*, a patent that was granted last year has received fewer citations than a patent that was granted five years ago, because the former patent has been available to cite for less time. As a result, care must be taken when comparing patents and patent citations from different industries and different years. Due to these systematic differences in patent grant rates and patent citation activity over time and among industries, we adopt Hall et al.'s (2001) "fixed-effects" approach. Each patent's citation count is divided by the average number of citations received for all patents granted in the same industry, during the same year. Firm-patent portfolio impact is therefore measured as follows:

$$\text{Patent portfolio impact} = \text{patents}_{f,t} * \frac{\text{citations received}_{f,t}}{\left[\frac{\text{citations received}_{i,t}}{\text{patents granted}_{i,t}}\right]}$$

where f = firm, i = industry, and t = year.

In order to correct the skewness of the distribution of patent portfolio impact, this variable is re-centered away from zero by adding one, then log-transformed.

New product introductions. The Lexis-Nexis Academic Databases (Lexis-Nexis 2007) hold all press releases circulated by Business Wire and PR Newswire. We searched those wire services for each firm within our sample that reported financial results in Compustat between 1997 and 2006. A simple count of new product press releases was made for each firm, from all press releases issued from 2002 to 2006. If more than one press release was issued for the same product, only the first press release was counted. In order to correct the skewness of the distribution of new product introductions, this variable is re-centered away from zero by adding one, then log-transformed.

New product success. The IMS New Product Focus database provides year-end sales results for new drugs. Since very few drugs were released on January 1, some analysis is required in order to estimate a new drug's first full year of sales. For a full discussion of how first-year annualized sales are estimated from yearly sales data, please see Appendix One. Since this variable is right-skewed, it is transformed by taking the square root of the measure.

C. Independent Variables

R&D Expenditure Volatility. We have argued that R&D expenditure volatility can be an observable marker for successful proactive management. We measured it over the ten year study period as the standard deviation of the residuals from the firm's R&D expenditure trend over the study period. This measures R&D volatility net of R&D expenditure growth. The calculation is performed using a two-step process. First, we regress R&D expenditure on a linear time trend:

$\text{R\&D expenditure}_{i,t} = A_{0\,i} + A_{1\,i}\, t + e_i$,

where t ranges from 1997 to 2006 and i = firm

Estimating this equation gives us the trend value of R&D expenditure. Residuals around this trend line are calculated as the actual R&D expenditure minus the trend value of R&D expenditure. The standard deviation of these residuals provides an absolute measure of R&D expenditure volatility for each firm. However, this measure is increasing in the size of R&D expenditures, so larger R&D spenders would tend to have larger standard deviations.

Therefore, in the second step, we divide the standard deviation of the residuals about the R&D time-trend by the mean R&D expenditure over the ten year study period:

$$\text{R\&D expenditure volatility} = s_i \div \bar{x}_i$$

where s = the standard deviation of R&D expenditure residuals about the time-trend, i = firm, and $\bar{x}$ = the mean R&D expenditure over time.

This provides us with a relative measure of R&D expenditure volatility that is normalized for the firm's level of R&D spending.

*Increases and decreases in R&D expenditure***.** We measure the magnitude of decreases in R&D as follows:

$$\text{R\&D expenditure decrease}_i = \sum_{t=1997}^{2006} \frac{dec_{i,t}}{\overline{\overline{R\&D_i}}}$$

where $dec_{i,t} = R\&D_{i,t} - R\&D_{i,t-1}$, t = year and i = firm. If $dec_{i,t} >= 0$ then $dec_{i,t}$ is set to zero.

Similarly, the magnitude of R&D increases in R&D is measured as follows:

$$\text{R\&D expenditure increase}_i = \sum_{t=1997}^{2006} \frac{inc_{i,t}}{\overline{\overline{R\&D_i}}}$$

where $inc_{i,t} = R\&D_{i,t} - R\&D_{i,t-1}$, t = year and i = firm. If $inc_{i,t} <= 0$ then $inc_{i,t}$ is set to zero.

Firm Unexpected Losses. As stated in Hypothesis 4, we expect that R&D expenditure volatility will have a greater affect on firm performance in firms with higher levels of unexpected income losses. The notion of risk in the behavioral theory of the firm (Cyert & March 1963) has been operationalized as a lower partial moment (LPM) of the firm's earnings under-performance relative to target (Miller & Leiblein 1996; Miller & Reuer 1996). We assume that the firm's earnings target is the average return on assets of the industry within which the firm competes from the previous year (Miller & Leiblein 1996; Miller & Reuer

1996). LPM measures have some appealing theoretical properties. It has been demonstrated that downside risk reduces an individual's utility regardless of the individual's risk preferences (Menezes, Geiss & Tressler 1980). The general form of the LPM measure is:

$$RLPM = \sqrt{(1/m)\sum_{1}^{m}(x)^{n}}$$

where m = number of time periods used in the measure, n is an arbitrary integer greater than or equal to two, and x = target – actual. If target < actual, then x is set to zero.

. We use the Miller & Leiblein (1996) specific form of the RLPM where m is equal to five and n is equal to two. This measure of unexpected firm losses exhibits extreme levels of skewness, and is therefore transformed using the following calculation (Tabachnik & Fidell, 2001: 83):

RLPM = 1 ÷ (RLPM + 1) * -1.

D. Control Variables

There is a broad literature providing empirical support for many different factors that affect firm performance. We seek to control for these influences before testing our research hypotheses.

Tobin's q is generally viewed to be an indication of the firm's future growth prospects (Hayashi and Inoue, 1991; Lang, Ofek & Stulz 1996). Firm sales growth over the previous year is included to control for this influence. Earnings per share (net income divided by shares outstanding) is included to capture the affect of firm profitability on Tobin's q (Erickson & Whited, 2000), and the level of firm sales is included to control for firm size (Chesher, 1979; Montgomery & Wernerfelt, 1988). R&D intensity is included as a control variable, since several researchers have shown a relationship between R&D intensity and firm performance (Morck & Yeung 1991; Hall, et al. 2005). Highly concentrated industries are viewed as less competitive; firms in such industries enjoy high entry barriers and may appropriate economic rents (McGahan & Porter 1997; Cheng 2005). Therefore, we include the U.S. Economic Census' measure of industry concentration (market share of the twenty largest firms in each four digit NAICS industry). Firm value has been shown to decrease over corporate diversification (Berger & Ofek 1995; Campa & Kedia 2002). An entropy index (Theil 1967) is used to measure firm diversification (Hitt, Hoskisson & Kim 1997), which is calculated as follows:

$$\text{Firm diversification} = \sum_{n=1}^{\#ofdivisions} \left[P_n * \ln(1 \div P_n) \right]$$

where P_n = percentage of firm revenues derived by division n. Multiple divisions that are reported in the same six digit NAICS code are treated as one division.

Lang, Ofek and Stulz (1996) find that firm leverage effects Tobin's q. The firm's debt ratio (long-term debt divided by total assets) is included to control for the influence of leverage.

In practice, many firms set R&D spending targets as a percentage of expected firm sales (Scherer 2001; Tubbs 2007). In all specifications, we include a measure of sales volatility, which is calculated using the same methodology as R&D expenditure volatility, in order to control for the volatility in firm sales over time.

Finally, we seek to capture the unique effects that are attributable to very small firms. Thus, we include a dummy variable that is set to one if annual firm sales is less than $10 million, or to zero if firm sales is greater than or equal to $10 million.

6. EMPIRICAL ANALYSIS

Table I presents the summary statistics of the sample data. Since there are different samples used in the analysis presented below, Panel A presents the descriptive statistics for the main sample that is used to test most hypotheses (Hypotheses 2A through 4). Firm size, firm debt and firm R&D intensity display high levels of skewness, and are therefore log-transformed.

Firm R&D intensity is only weakly correlated with firm R&D expenditure volatility, suggesting they capture different dimensions of firm behavior. As expected, firm R&D intensity is positively correlated with Tobin's q. Firm size is positively correlated with corporate diversification, implying that larger firms are more diversified (Rumelt, 1974). The measures taken from our three additional samples of R&D-related outputs are summarized in Table I Panel B. There are relatively fewer observations for the measure of new product success because this data is available only for the pharmaceutical industry (NAICS 3254).

A. Primary Tests

Multiple regression analysis is used to test each hypothesis. For all equations using Tobin's q as the dependent variable, we present heteroskedasticity-corrected estimates using estimated generalized least squares (EGLS). For all equations using patents or new products as the dependent variable, tobit regression is used since the dependent variable is left-truncated at zero.

Hypothesis 1A predicts that there is a negative relationship between R&D expenditure volatility and R&D-related output. Hypothesis 1B states that the relationship is positive. In tests of Hypotheses 1A and 1B that rely on data from multiple industries, industry concentration at the three digit NAICS level is used to control for industry effects.

As noted above, our patent data is drawn from the NBER U.S. Patent Citations Data File (Hall, et al. 2001), and relates to the years 2002 to 2006. Firm financial data from Compustat is taken from 1997 to 2006. The results of the analysis using patent portfolio impact as the dependent variable are presented in Table II columns one and two. The regression analysis using only control variables is shown in column one and the estimate of the specification including R&D expenditure volatility is shown in column two. The log likelihood ratio indicates that the explanatory power of the specification including R&D volatility (column two) is statistically significantly greater than the controls-only specification (column one). The parameter estimate on R&D expenditure volatility is positive and statistically significant. Using firm knowledge production as the dependent variable, we find evidence that R&D expenditure volatility is positively related to R&D-related outcomes. This is inconsistent with Hypothesis 1A but is consistent with hypothesis 1B.

Next, we use firm new product releases as a measure of R&D-related output. We estimate the relationship between the firm's total number of new product releases from 2002 to 2006 and the firm's average financial results from 1997 to 2006. The results of this analysis are shown in Table II columns three and four. The results of the regression analysis using control variables only is shown in column three, and the specification including R&D expenditure volatility is shown in column four. Once again, the log likelihood ratio is statistically significant, and the parameter estimate on R&D expenditure volatility is positive and statistically significant. Using new product releases as our measure of R&D output, we find evidence that

R&D expenditure volatility is positively related to R&D-related outcomes. This provides further evidence in favor Hypothesis 1B, and counter to Hypothesis 1A.

Finally, we test our competing hypotheses using new product success as our dependent variable. We estimate the relationship between the firm's total new product success from 2002 to 2006 and the firm's average financial results from 1997 to 2006. Since these hypotheses are tested with data from the pharmaceutical industry, industry control variables are excluded from these specifications. The results of this analysis are shown in Table II columns five and six. The log-likelihood ratio is not statistically significant, and the parameter estimate on R&D expenditure volatility is positive but not statistically significant. Using new product success as our measure of R&D output, we find insufficient evidence that R&D expenditure volatility is related to R&D-related outcomes. Based on two of the three measures of R&D-related performance used, the effect of R&D expenditure volatility is positive and statistically significant.

Hypotheses 2A and 2B offer competing predictions about the relationship between R&D expenditure volatility and firm performance. The results of the regression analysis testing these hypotheses are shown in Table III. Column one shows the regression estimates using control variables only. Column two shows the regression estimates including the measure of R&D expenditure volatility. We see that the explanatory power of the specification using only control variables shown in column one is statistically significant. An incremental F-test shows that the explanatory power of the specification shown in column two is statistically significantly greater than the controls-only model shown in column one. The parameter estimate on R&D expenditure volatility is positive and statistically significant. This is inconsistent with hypothesis 2A but is consistent with hypothesis 2B.

Hypothesis 3A predicts that decreases in R&D expenditure are negatively related to firm performance. Hypothesis 3B predicts that decreases in R&D expenditure are positively related to firm performance. In order to test these hypotheses, we remove the measure of R&D expenditure volatility and replace it with our measures of R&D expenditure increases and decreases. The results of this specification are presented in column three of Table III. The result of the incremental F-test shows that the explanatory power of this specification is statistically significantly greater than the base specification shown in Table III, column one. In Table III column three, note that decreases and increases in R&D expenditure are simultaneously statistically significant. This provides evidence supporting hypothesis 3B and refuting hypothesis 3A.

Hypothesis 4 predicts that the relationship between R&D expenditure volatility and firm performance is higher among firms that experience higher levels of unexpected earnings losses. This can be tested by adding the measure of firm unexpected losses and the interaction of R&D expenditure volatility and unexpected losses to the specification presented in Table III, column two. The results of this regression analysis are shown in column four of Table III. Once again, the incremental F-test is statistically significant. The parameter estimate on the interaction of R&D expenditure volatility and firm risk is positive and statistically significant, which is consistent with hypothesis 4.

7. Tests of Robustness

Recent research has found that industry clockspeed is an important variable that influences the performance of firms (Nadkarni & Narayanan 2007). One might question whether industry clockspeed (i.e. the speed at which business is conducted within a particular industry) causes the observed positive link between R&D volatility and firm performance. At first glance, it may be reasonable to suspect that firms that are competing in high-clockspeed industries may be higher-performing firms that adjust R&D expenditures more frequently. This would imply that industry clockspeed influences both R&D expenditure volatility and firm performance, but that no direct causal relationship exists between R&D volatility and firm performance.

In Table IV, we compare the relationship between firm performance and R&D expenditure volatility in two industry subsamples – a fast clockspeed industry subsample and a slow clockspeed industry subsample. We chose the chemicals industries (NAICS 325) as an example of a slow clockspeed industry. We use the computer and electrical products (NAICS 334) to examine fast clockspeed industries (Fines 1998; Nadkarni & Narayanan 2007). We find that the relation between firm performance and R&D expenditure volatility is positive and statistically significant in both sub-samples.

R&D expenditure volatility can be measured in alternative ways. One simple way to measure R&D expenditure volatility is to use a coefficient of variation. We find similar results to those reported using this alternative measure of R&D expenditure volatility.

In the main section of this paper, we have estimated the relationship between ten years of R&D expenditure volatility and five years of patents granted in the second half of that ten year period. The selection of these study windows is ad hoc. In Table V, we estimate the relationship between R&D expenditure volatility and patent citations using other time periods. In column one, we show the relationship between R&D expenditure volatility measured from 1997 to 2001, and citations made to patents granted from 2002 to 2006. These data provides results consistent with the tests provided in the main section of our paper. In column two, we show the relationship between R&D expenditure volatility measured from 1991 to 1998 and citations made to patents granted from 1999 to 2006. Again, we observe results similar to the tests provided in the main section of our paper. Finally, in column three we show the relationship between R&D expenditure volatility measured from 1993 to 2001 and citations made to patents granted from 2002 to 2006. Using these timeframes, we see that the parameter estimate on R&D expenditure volatility is positive, but statistically significant only at 90%. This could be because it is highly unlikely that R&D expenditure today would result in patents more than ten years in the future.

We also evaluate whether R&D expenditure volatility is endogenous. We approached this issue in the following way. We use a two-stage least squares (2SLS) model for firms with sales greater than $100 million in order to estimate the relationship between R&D expenditure volatility and firm performance.

The key issue is the issue of instrument(s). We use the population of the headquarters county as instrument. The underlying rationale is that it is may be more difficult for firms located in rural areas to monitor R&D processes, especially in larger more distributed firms. For instance, it may be more difficult for senior management to travel to and from headquarters located in a remote location, thus impacting the firm's ability to proactively adjust the firm's R&D expenditure. One attractive feature of this instrument is that it is not a managerial choice (at least in the short run unless the firm relocates). We proceed using a headquarters population as an instrument. We estimated an F-statistic for variable exclusion on the headquarters county population variable, which is statistically significant. This indicates that the explanatory power attributable to this one variable is adequate. In addition, note that the F-statistic on the stage one equation is greater than 10, which indicates that the independent variable estimators in stage one are unbiased (Staiger and Stock, 1997).

In the second stage, we find that R&D volatility is related to firm performance. This first stage equation is estimated as follows[4]:

R&D expenditure volatility = B_0 + B_1 (Population of HQ) + e.

In the second stage, we estimate the following equation using the first stage estimate of R&D expenditure volatility (B_0 + B_1 Population of HQ):

Tobins q = A_0 + A_1-A8 (YR_3-YR_{10}) + A_9 Industry Concentration + A_{10} Firm Growth + A_{11} Firm Profitability + A_{12} Firm Size + A_{13} Firm Leverage + A_{14} Corporate Diversification + A_{15} R&D Intensity + A_{16} Sales Volatility + A_{17} (B_0 + B_1 HQ population) + e.

In Table VI, the results of Stage One are presented in Column One, and Stage Two in Column Two. The results of the 2-SLS are consistent with the results in the main part of the paper.

Finally, we evaluate the issue of causality. While we argue that higher levels of R&D expenditure volatility drive superior firm performance, it is possible that firms with superior business model (which may be indicated by a higher Tobin's q) possess both higher firm value and R&D expenditure volatility. In order to evaluate this possibility, we include a new regressor – the lagged value of Tobin's q. This specification controls for the influence that the firm's prevailing operating performance may have on this relationship. The results of this analysis are presented in Table VII. As expected, the parameter estimate on the lagged value of Tobin's q is positive and highly statistically significant. In addition, the explanatory power of this specification is much higher (R^2 = 0.59) than any other specification. The parameter estimate on R&D expenditure volatility is still positive and statistically significant at 90% confidence level. This suggests that R&D expenditure volatility causes superior performance, and not vice-versa.

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[4] Since the performance of small firms is quite erratic over time, we drop small firms from our sample in order to develop a better stage one estimate of R&D expenditure volatility.

8. Conclusion

We began by identifying a fundamental conflict in the existing research on R&D management. There is a broad collection of research suggesting that successful innovation at the firm level requires consistent, sustained R&D investment (Grabowski 1968; Hambrick, et al. 1983; Dierckx & Cool 1989; Kor & Mahoney 2005). However, another stream of research links innovative performance to a firm's ability to combat successfully R&D project entrenchment (Hoskisson & Hitt 1988; Bernardo, et al. 2001; Stein 2003). We posit that such active management of the firm's R&D portfolio requires it to identify quickly and ramp up its most promising projects, while simultaneously pruning support for those with less potential. Our study has attempted to provide theoretical and empirical support for this new perspective on firm-level volatility in research and development expenditures. Intuitively, our analysis suggests that successful firms seek to mitigate R&D project entrenchment by using staged-financing, which limits incremental funding until material progress is demonstrated. In general, our findings support the assertion that firms implementing such policies are more effective at generating higher levels of R&D-related outputs and superior firm performance.

Our first finding indicates that R&D expenditure volatility is positively associated with multiple forms of firm innovation. R&D volatility drives higher levels of firm knowledge creation, and more new product releases; we find a positive but non-significant relationship between R&D volatility and new product success. This evidence is consistent with our assertion that high-performing firms combat R&D entrenchment by limiting funding to existing projects until project managers reach important project milestones, while quickly culling underperforming R&D projects.

Our second finding indicates that the positive relationship between R&D expenditure volatility and performance extends not only to R&D-related outputs, but also to overall firm value. This result suggests that investors highly value proactive R&D management techniques that result in volatile R&D expenditures. Our evidence implies that the research and development volatility can stem from staged financing that limits project manager opportunism and fosters superior R&D outputs. Further, it is encouraging to note that our results are robust to multiple measures of innovation and firm performance.

Our third finding demonstrates that the beneficial role of R&D volatility stems not only from increases in R&D expenditure, but also from decreases (Table III, column three). This finding can be interpreted as support for the value of firm-level creative destruction. Searching for new R&D opportunities, exploiting opportunities once they are discovered, and eliminating bad R&D projects are all important components of an effective R&D management policy. Recall that, in the estimates presented Table III column three, the estimated coefficient associated with R&D expenditure increases greater than that associated with R&D expenditure decreases. This result implies that while growth in R&D expenditure is a major driver of firm value creation, elimination of underperforming R&D projects is an important complementary action.

Our theory and analysis recognizes that R&D intensity does create shareholder value. As seen in all of our estimates, the effects of R&D intensity on firm value and R&D-related outputs are positive and highly significant, a demonstration that is consistent with the large literature on R&D management (Pakes 1985; Jaffe 1986; Hall, et al. 2005). Our key result is that the explanatory power of R&D expenditure volatility on both financial and R&D-related performance is observed after controlling for the influence of R&D intensity.

This study provides extensive evidence that, *ceteris paribus*, firms that frequently change R&D expenditure create greater firm value as well as superior R&D-related outputs. Researchers have long recognized that traditional financial decision-making techniques (such as net present value analysis) are inappropriate for evaluating R&D investment opportunities (Hoskisson & Hitt 1988). Our new findings suggest that the active management of the firm's R&D portfolio, manifesting itself in the form of a highly volatile pattern of R&D expenditure, is a crucial source of value creation. Our findings also suggest that this value creation is based on superior innovative performance. Therefore, this study identifies a new avenue of research in R&D management. Future research could investigate whether firms that successfully link R&D expenditure volatility to superior firm performance have distinguishing structural characteristics. Case study inquiry can also help us to understand the processes within the firm that underpin the link between R&D volatility and firm performance.

Schumpeter (1942) argued that churning the population of firms through creative destruction and macroeconomic volatility are related determinants of economy-wide innovation. His insights reinforce the value of intense inter-firm competition as a selection mechanism. We extend the Schumpeterian insight to the intra-firm domain, and provide evidence that R&D expenditure volatility at the firm level creates value. Indeed, the active management of a firm's R&D portfolio seems to appear in the form of intra-firm 'creative destruction' as promising research projects expand at the expense of those with less promise. The effective implementation of such an intra-firm selection mechanism appears to be a competency that underlies both innovative and financial performance.

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TABLE I

Panel A: Main Dataset Summary Statistics

Variable *	Simple Statistics Mean	Std Dev	Pearson Correlation Coefficients 1	2	3	4	5	6	7	8	9	10	11	12
1. Tobin's Q	0.28	1.19												
2. R&D Expenditure Volatility	0.29	0.27	0.15											
3. R&D Expenditure Increases	1.20	0.99	0.20	0.71										
4. R&D Expenditure Decreases	-0.84	0.97	-0.08	-0.78	-0.35									
5. Firm R&D Intensity	0.32	0.73	0.28	0.12	0.11	-0.10								
6. Firm Earnings Risk	-0.83	0.20	0.44	0.38	0.21	-0.40	0.43							
7. Sales Volatility	0.27	0.29	0.31	0.41	0.35	-0.33	0.52	0.59						
8. Firm Growth	0.50	8.34	0.03	0.04	0.05	-0.02	0.03	0.07	0.12					
9. Firm Profitability	-0.38	50.43	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00				
10. Firm Size	4.46	2.51	-0.25	-0.31	-0.20	0.30	-0.46	-0.63	-0.47	-0.05	-0.01			
11. Industry Concentration	56.90	15.50	0.12	0.04	0.07	-0.02	0.18	0.18	0.15	0.02	0.00	-0.04		
12. Corporate Diversification	0.17	0.34	-0.16	-0.10	-0.09	0.08	-0.18	-0.29	-0.19	-0.02	0.00	0.45	-0.10	
13. Debt-Ratio	0.13	0.19	0.07	0.05	-0.01	-0.07	-0.03	0.13	0.03	-0.01	0.00	0.09	-0.03	0.09

* Notes: Tobins q = ln(q); R&D Volatility = standard deviation of R&D residuals about time trend / mean R&D expenditure;
R&D Increases = total R&D increases / mean R&D; R&D Decreases = total R&D decreases / mean R&D; Firm R&D Intensity = ln((R&D/Sales)+1)
Firm Unexpected Losses = 1/(RLPM+1)*-1; Sales Volatility = standard deviation of sales residuals about time trend / mean sales;
Firm Growth = percentage sales growth; Firm Profitability = EPS; Firm Size = ln(Sales+1); Industry Concentration = Marketshare of top 20 Firms;
Corporate Diversification = Entropy Index; Debt-Ratio = ln((Long-Term Debt / Total Assets)+1)

Panel B: Innovation Measures - Simple Statistics

Variable*	N	Mean	Max	Min	Std Dev	Median
Firm Knowledge Stock	3,747	0.58	10.53	0.00	1.21	0.00
New Product Releases	3,271	0.21	3.91	0.00	0.65	0.00
New Product Success	561	0.01	0.63	0.00	0.07	0.00

*Firm knowledge stock = ln(patents*adjusted-citations + 1); New product releases= ln (product releases + 1) ;
New product success = new product revenue $^{0.5}$

TABLE II

R&D Expenditure Volatility and Innovation

This table provides the results from the following specification:

Firm Innovation = A_0 + A_1 *R&D Expenditure Volatility + A2 R&D Intensity + A3 Sales Volatility + A4 Firm Profitability + A5 Firm Size + A6 Firm Debt + A7 Industry Concentration + A8 Small Firm Dummy + e*

We use three different proxies for firm innovation, which are based on patent citations and new product releases. Definitions are provided below. Chi-square values are italicized below parameter estimates. **Bold face indicates significance at the 95% level.**

	Dependent Variables					
	Firm Knowledge Stock		New Product Releases		New Product Success	
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	**-3.11**	**-3.14**	**-6.06**	**-6.28**	**-1.75**	**-1.82**
	267.55	***258.95***	***125.64***	***127.45***	***24.82***	***24.39***
R&D Expenditure Volatility		**0.46**		**0.86**		0.17
		5.27		***4.46***		*1.09*
Firm R&D Intensity	**0.67**	**0.68**	-0.27	-0.16	0.06	0.07
	63.38	***63.46***	*0.99*	*0.35*	*0.32*	*0.52*
Sales Volatility	**1.35**	**1.26**	**2.18**	**1.83**	**0.56**	**7.98**
	55.95	***45.12***	***26.29***	***16.03***	***9.30***	***8.34***
Firm Profitability	0.00	0.00	0.00	0.00	-0.06	-0.06
	0.12	*0.10*	*0.17*	*0.18*	*1.19*	*0.97*
Firm Size	**0.60**	**0.61**	**0.43**	**0.45**	**0.19**	**0.20**
	663.86	***661.91***	***54.76***	***58.00***	***18.97***	***19.18***
Firm Debt	**-2.42**	**-2.45**	**-3.90**	**-4.07**	0.08	0.09
	65.41	***66.76***	***18.56***	***19.87***	*0.06*	*0.08*
Industry Concentration	0.00	*0.00*	0.01	0.01		
	1.63	*2.40*	*0.83*	*0.69*		
Dummy (if Sales < 10)	-0.07	-0.09	**-1.41**	**-1.42**	-0.42	-0.38
	0.14	*0.24*	***8.69***	***8.88***	*1.37*	*1.16*
Log-likelihood	-3284.23	-3260.45	-1614.14	-1611.97	-52.30	-51.77
Log-Likelihood Ratio		**47.57**		**4.34**		1.06
Probability of Chi-Square		0.00		0.04		0.30
	n=2929	n=2881	n=3271	n=3271	n=558	n=558

Notes:

Firm knowledge stock=ln(patents*adjusted-citations + 1); New product releases=ln(product releases + 1);
New product success = new product revenue ^ 0.5;
Firm Profitability = EPS; Firm Size = ln(Total Sales+1); Firm R&D Intensity = ln(R&D / Total Assets+1);
R&D Volatility = residuals about time trend/mean R&D; Firm Debt = ln(Long-Term Debt / Total Assets+1);
Industry Concentration = Marketshare of top 20 Firms; Sales Volatility = residuals about time trend/mean sales

Table III

R&D Volatility, Creative Destruction & Earnings Risk

Tobin's q = A_0 + A_1 R&D Expenditure Volatility + A_2 Sales Volatility + A_3 R&D Intensity + A_4 Firm Growth + A_5 Firm Profitability + A_6 Firm Size + A_7 Firm Debt + A_8 Corporate Diversification + A9 Industry Concentration + A10 Small Firm Dummy + e

	(1) Controls Only	(2) Base Model	(3) including R&D increases and decreases	(4) including unexpected losses
Intercept	**-0.32**	**-0.35**	**-0.40**	**1.12**
	-9.06	***-9.72***	***-10.92***	***10.02***
R&D Expenditure Volatility		**0.07**		**0.60**
		2.06		***3.98***
Firm Unexpected Losses				**1.73**
				15.16
(Firm Unexpected Losses) * (R&D Exp. Volatility)				**0.80**
				4.67
R&D Expenditure Increases			**0.16**	
			18.76	
R&D Expenditure Decreases			**0.10**	
			10.96	
Firm R&D Intensity	**0.16**	**0.16**	**0.16**	**0.06**
	11.14	***11.25***	***11.31***	***3.35***
Sales Volatility	**0.67**	**0.65**	**0.56**	**0.15**
	18.78	***17.03***	***14.81***	***2.97***
Firm Growth	0.00	0.00	0.00	0.00
	0.57	*0.68*	*0.49*	*0.98*
Firm Profitability	**0.00**	**0.00**	**0.00**	**0.00**
	3.21	***3.19***	***2.89***	***8.29***
Firm Size	**0.02**	**0.02**	**0.02**	**0.06**
	4.02	***4.36***	***4.84***	***9.17***
Firm Debt-Ratio	**0.53**	**0.52**	**0.54**	**0.35**
	14.88	***14.68***	***15.13***	***7.36***
Corporate Diversification	**-0.25**	**-0.25**	**-0.22**	**-0.27**

	-12.12	***-12.30***	***-10.61***	***-8.79***
Industry Concentration	**0.00**	**0.00**	**0.00**	0.00
	7.53	***7.85***	***7.20***	*1.39*
Dummy (if Sales < 10)	**0.56**	**0.56**	**0.62**	**0.38**
	19.95	***19.95***	***22.09***	***8.91***
R-Square	0.1716	0.1732	0.1835	0.2472
F-Statistic	**230.46**	**220.05**	**224.77**	**156.98**
Incremental F test		**2.05**	**14.43**	**43.23**
	n=18928	n=18928	n=18929	n=8145

Parameter estimates significant at 95% confidence level in bold-face.

Note: Equations are estimated with dummy variables for each year.

Firm Growth = percentage sales growth; Firm Profitability = EPS; Firm Size = ln(Total Sales+1);
Firm Debt = ln(Long-Term Debt / Total Assets+1); Corporate Diversification = Entropy Index;
Industry Concentration = Marketshare of top 20 Firms; Firm R&D Intensity = ln(R&D / Sales+1);
R&D Volatility = residuals about time trend/mean R&D; R&D Increases = Total Increases / Mean R&D;
R&D Decreases = Total Decreases / Mean R&D; Firm Earnings Risk = 1/(rlpm+1)*-1
Sales Volatility = residuals about time trend/mean sales

TABLE IV

R&D Volatility and Industry Clockspeed

Tobin's Q = A_0 + A_2 Firm Growth + A_3 Firm Profitability +
A_4 Firm Size + A_5 Firm Debt-Ratio + A_6 Corporate Diversification + A_7 Firm R&D Intensity +
A_8 Sales Volatility + A9 R&D Expenditure Volatility + e

	(1) Fast Clockspeed	(2) Slow Clockspeed
	Computers	*Chemicals*
Intercept	**-0.01**	**0.25**
	-2.31	***4.01***
R&D Expenditure Volatility	**0.22**	**0.13**
	3.50	***2.33***
Sales Volatility	**0.71**	**0.40**
	10.10	***7.48***
Firm R&D Intensity	**0.35**	**0.09**
	10.15	***4.90***
Firm Growth	0.00	0.00
	1.45	*-1.29*
Firm Profitability	0.00	**0.00**
	1.32	***16.42***
Firm Size	**0.06**	**0.04**
	8.75	***4.63***
Firm Debt-Ratio	**0.43**	**0.50**
	6.10	***7.44***
Corporate Diversification	**-0.46**	**-0.47**
	-10.58	***-9.15***
Dummy (if Sales < 10)	***0.57***	***0.38***
	12.06	***7.80***
R-Square	0.1476	0.1968
F-Statistic	**72.48**	**62.92**
	n=7551	n=4384

Parameter estimates significant at 95% confidence level in bold-face.

Note: Equations are estimated with dummy variables for each year.

Firm Growth = percentage sales growth; Firm Profitability = EPS; Firm Size = ln(Total Sales+1); Debt-Ratio = ln(Long-Term Debt / Total Assets+1); Corporate Diversification = Entropy Index; Industry Concentration = Marketshare of top 20 Firms; Firm R&D Intensity = ln(R&D / Sales+1); R&D Volatility = residuals about time trend/mean R&D; Sales Volatility = residuals about time trend/mean sales

TABLE V

R&D Expenditure Volatility and Innovation

This table provides the results from the following specification:

Firm Knowledge = A_0 + A_1 *R&D Expenditure Volatility + A2 R&D Intensity + A3 Sales Volatility + A4 Firm Profitability + A5 Firm Size + A6 Firm Debt + A7 Industry Concentration + A3 Small Firm Dummy + e*

We use three different cuts of patent data, which are based on patent citations and new product releases. Definitions are provided below. Chi-square values are italicized below parameter estimates. Bold face indicates significant at the 5% level.

	5 Years R&D Volatility 5 Years of Patents	8 years R&D Volatility 8 Years of Patents	10 Years R&D Volatility 5 Years of Patents
	(1)	(2)	(3)
Intercept	**-3.11**	**-2.70**	**-2.60**
	245.32	***212.44***	***243.03***
R&D Expenditure Volatility	**0.44**	**0.29**	0.19
	4.69	***4.34***	*2.27*
Firm R&D Intensity	**0.61**	**0.66**	**0.55**
	55.38	***92.90***	***66.86***
Sales Volatility	**1.13**	**0.76**	**0.72**
	33.86	***23.69***	***27.68***
Firm Profitability	0.00	0.00	0.00
	0.01	*0.15*	*0.86*
Firm Size	**0.60**	**0.52**	**0.46**
	628.39	***468.41***	***481.63***
Firm Debt	**-2.46**	**-2.50**	**-2.45**
	65.74	***66.76***	***77.98***
Industry Concentration	0.00	0.00	*0.00*
	1.57	*1.84*	*2.62*
Dummy (if Sales < 10)	0.18	**0.37**	0.12
	1.10	***6.00***	*0.63*
Log-likelihood	-3295.09	-4028.13	-3342.95
	n=2873	n=3485	n=3573

Note:

Firm Growth = percentage sales growth; Firm Profitability = EPS; Firm Size = ln(Total Sales+1);
Firm Debt = ln(Long-Term Debt / Total Assets+1); Corporate Diversification = Entropy Index;
Industry Concentration = Marketshare of top 20 Firms; Firm R&D Intensity = ln(R&D / Sales+1);
R&D Volatility = residuals about time trend/mean R&D; R&D Increases = Total Increases / Mean R&D;
R&D Decreases = Total Decreases / Mean R&D; Firm Earnings Risk = 1/(rlpm+1)*-1
Sales Volatility = residuals about time trend/mean sales

TABLE VI

R&D Volatility 2SLS Model
SALES > $100 million

Stage One: R&D Volatility = A0 + A1 Population of HQ Postal Code + A2 Sales Volatility + e

Stage Two: Tobin's q = B_0 + B_1 [A0 + A1 Population of HQ Postal Code + A2 Sales Volatility]

+ B_2 Sales Volatility + B_3 R&D Intensity + B_4 Firm Growth + B_5 Firm Profitability + B_6 Firm Size + B_7 Firm Debt +

B_8 Corporate Diversification + B_9 Industry Concentration + B_{10} Small Firm Dummy + e

	(1)	(2)
	Stage One	Stage Two
Intercept	**0.24**	**-0.90**
	21.01	***-11.77***
Population of HQ Postal Code	**0.00**	
	-6.39	
R&D Expenditure Volatility (hat)		**0.89**
		2.92
Sales Volatility	**0.73**	**-0.58**
	17.40	***-2.37***
Firm R&D Intensity		**2.94**
		19.66
Firm Growth		**0.59**
		14.69
Firm Profitability		**0.00**
		0.11
Firm Size		**14.90**
		9.41

Firm Debt-Ratio		-0.03
		-0.46
Corporate Diversification		**-0.24**
		-10.29
Industry Concentration		**0.00**
		-2.64
R-Square	0.0504	0.1450
F-Statistic	**170.49**	**62.66**
F-Statistic for Variable Exclusion	**2.92**	
	n=6428	n=6296

Parameter estimates significant at 95% confidence level in bold-face.

Note: Equations are estimated with dummy variables for each year.

Firm Growth = percentage firm growth; Firm Profitability = EPS; Firm Size = ln(Total Sales)+1;
Debt-Ratio =ln(Long-Term Debt / Total Asset)+1; Corporate Diversification = Entropy Index;
Industry Concentration = Marketshare of top 20 Firms; Firm R&D Intensity = ln(R&D /Sales)+1;
R&D Volatility = A0 + A1 International Revenue as Percent of Total + A2 Population of HQ Postal Code
Sales Volatility = residuals about time trend/mean sales

TABLE VII

R&D Volatility with Lagged Tobin's q

Tobin's Q = A_0 + A_1 R&D Expenditure Volatility + A2 Tobins q (t-1) + A3 R&D Intensity + A_4 Sales Volatility + A5 Firm Growth + A6 Firm Profitability + A7 Firm Size + A8 Firm Debt + A9 Corporate Diversification + A10 Industry Concentration + A11 Small Firm Dummy + e

	(1)
Intercept	**-0.21**
	-7.58
R&D Expenditure Volatility	**0.04**
	1.77
Tobins q (t-1)	***0.70***
	128.43
Firm R&D Intensity	**0.05**
	3.84
Sales Volatility	**0.14**
	4.61
Firm Growth	**0.00**
	-8.52
Firm Profitability	***0.00***
	4.69
Firm Size	**0.01**
	4.75
Firm Debt-Ratio	**0.28**
	10.98
Corporate Diversification	**-0.07**
	-4.69
Industry Concentration	**0.00**
	4.03
Dummy (if Sales < 10)	***0.25***
	11.34
R-Square	0.5898
F-Statistic	**1215.92**
	n=16088

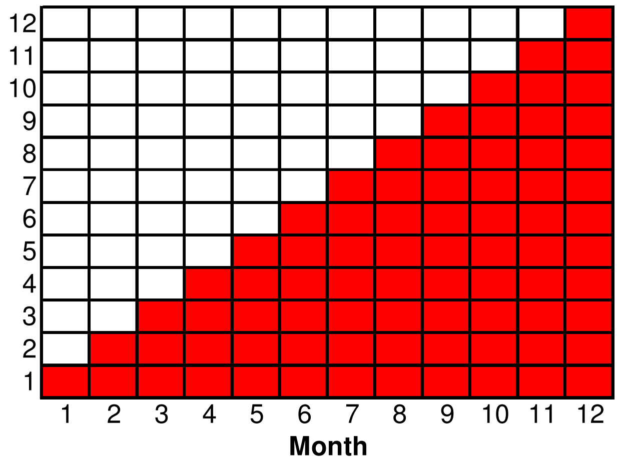
Parameter estimates significant at 90% confidence level in bold-face.

Note: Equations are estimated with dummy variables for each year.

Firm Growth = percentage sales growth; Firm Profitability = EPS; Firm Size = ln(Total Assets);
Debt-Ratio =ln(Long-Term Debt / Total Assets+1); Corporate Diversification = Entropy Index;
Industry Concentration = Marketshare of top 20 Firms; Firm R&D Intensity = ln((R&D / Sales)+1);
R&D Volatility = residuals about time trend/mean R&D;

APPENDIX

In order to estimate monthly revenue given year-end results, we assume that monthly new product revenue increases at a linear rate. Therefore, the first full year of new product sales can be considered 78 monthly sales units, as shown below.



Using this logic, we estimate the first full-year of a new drug product's sales using two different approaches, based upon which month the product was released. For products introduced before July, the following formula is used to estimate the product's first full year of sales.

$$\text{annualized first-year sales} = end - of - year - sales * \frac{78}{78 - \sum_{i=2}^{n} 14 - n}$$

where n = the month that the product is introduced, such that January = 1, February = 2, March =3, and so on. For products that were introduced July or after, the following formula is used to estimate the product's first full year of sales.

$$\text{annualized first-year sales} = (sales_{yr} - sales_{yr-1}) * \left[1 - \frac{\sum_{i=7}^{n} (14 - n)}{78} \right]$$ where n = the month that the product is introduced, such that January = 1, February = 2, March =3, and so on.