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Does R&D expenditure volatility affect stock return?

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ABSTRACT

The relation between the volatility of R&D expenditure and stock return may be influenced by disruptive adjustment costs, emerge from earnings management, or reflect the actions of managers attempting to control the overinvestment of technocrats. Using 5,178 publicly listed US firms from 1980 to 2018, we find a negative relation between R&D volatility and return, which is moderated by firm size. We conclude that investors react negatively to the disruptive effect of changes to R&D expenditure, except for small firms. In small firms, the benefit of the governance mechanism of varying R&D expenditure to control overinvestment outweighs the cost of disruption.

1. Introduction

Research and development (R&D) is critical to the competitive advantage, long-term growth, and value of a firm (Gu, 2016; Hall et al., 2005; Kung and Schmid, 2015; Lev and Sougiannis, 1996; Li, 2011). A common contention is that R&D expenditures should remain stable over time to develop sustainable competitive advantages (Kor and Mahoney, 2005) or avoid large adjustment costs (Brown and Petersen, 2011; Hambrick et al., 1983; Swift, 2008). Implicitly, these arguments suggest that investors should view volatility in R&D expenditures unfavorably.

The detrimental effect of volatility in R&D expenditures on firm value may arise from firms managing or manipulating their R&D expenditures for various objectives. Managers may adjust their R&D spending to smooth corporate earnings or reduce R&D expenditures when earnings fail to meet the forecasts of analysts or when a firm faces financial constraints or shortage of cash (Bushee, 1998; Chen et al., 2016; Cheng, 2004; Degeorge et al., 1999; Li, 2011; Xu and Yan, 2013; Tong and Zhang, 2014).

However, an alternative view states that volatility in R&D expenditures enhances firm value by governing the entrenchment of management and curtailing overinvestment (Bowman and Hurry, 1993; Chen et al., 2016; Gompers, 1995; Lovas and

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Ghoshal, 2000; Neher, 1999; Swift, 2008). Accordingly, the volatility of R&D expenditure provides insight into the internal governance and oversight mechanisms for R&D investment decisions.

While a large body of literature has investigated the relation between the level of firm R&D investment and stock return (e.g., Eberhart et al., 2004, 2008; Gu, 2016; Kung and Schmid, 2015; Li, 2011), little attention has been given to the effect of adjustments to R&D expenditure and its volatility on stock return. Moreover, with the exception of Mudambi and Swift (2011), Swift (2008), and Swift (2013), few studies have jointly considered R&D expenditure (intensity) and R&D volatility. Recent studies have related R&D intensity and R&D volatility to firm growth and return on asset, but not to stock return. Thus, the market's interpretation of the firm's value when investing in R&D is limited.

R&D expenditure can increase or destroy wealth. Changes to R&D expenditure may be either viewed favourably or negatively by the market with a commensurate stock price outcome. Empirically, this issue remains unresolved, thus motivating investigation. The literature provides an incentive to develop hypotheses to clarify and resolve the relation between R&D expenditure volatility and firm return. Specifically, we may anticipate a negative relation because R&D volatility imposes disruption costs or because R&D volatility is caused by firms engaging in earnings management. Alternatively, the relation may be positive because R&D volatility indicates the deployment of a governance mechanism for controlling overinvestment. However, the literature also indicates a complex relation where R&D volatility interacts with various firm characteristics. The resolution of these competing arguments is an important empirical question.

Our research focuses on the association between stock return and the level and volatility of R&D expenditure. To conduct our empirical analysis, we use 5,178 listed US firms from 1980 to 2018 to calculate the volatility in their R&D expenditures. Initially, we broadly replicate the analysis of Li (2011), who highlights the role of financial constraints, before supplementing it with industry dummy variables. Next, we establish our baseline results by adding R&D volatility terms to this model to empirically investigate the impact of R&D expenditure volatility on stock return.

Our first subsequent focus is whether volatile R&D expenditures asymmetrically affect stock return depending on whether the most recent change is an increase or decrease. Second, we consider how the relation between R&D volatility and stock return is affected by firm size. We also partition our data into four subperiods to compare the stability of our results over time. For robustness tests, we consider alternative measures of our main independent variable, which measures R&D volatility.

We contribute to the literature by providing a direct test of Li's (2011) attribution of the positive relation between R&D intensity and firm return to the risk of incurring disruption costs if the R&D expenditure is curtailed. Our analysis shows that firms with a history of volatile R&D expenditures, which are most likely to vary R&D expenditure, have lower returns, while the positive association between R&D intensity and return persists. Accordingly, we attribute this positive relation to R&D expenditure as genuinely value-adding, with the market responding accordingly.

Our contribution continues by demonstrating that the relation between volatility in R&D expenditure and firm return is nonlinear and can be negative and positive. We resolve the competing hypotheses to explain this relation and determine that disruption costs can negatively affect firm returns. Our analysis discounts an alternative explanation that R&D volatility negatively affects returns because it indicates earnings management where firms myopically reduce spending on R&D to improve their reported earnings or to smooth earnings by overinvesting in R&D. However, we also show that the negative relation between R&D volatility and return depends on firm size, in which the relation becomes positive for small firms. We attribute this positive relation to the governance mechanism where managers impose the volatility of R&D expenditures to control technocrats, which is valued by the market. While ever-present, the governance effect is most prominent in small firms and subsumes the negative effect of disruption to the R&D function.

The rest of the paper is organized as follows. In Section 2, we review the literature and develop our hypotheses. Section 3 discusses our sample collection process and the empirical research design. Then, we present the key empirical findings in Section 4 and conclude our paper in Section 5.

2. Related literature and hypotheses development

2.1. R&D, financial constraints, and stock return

2.1.1. R&D and stock return

Numerous studies have examined the relation between R&D intensity (R&D expenditure relative to firm size) and stock returns with mixed results. Chan et al. (1990) do not find any significant relation between R&D intensity and subsequent abnormal stock returns. Other studies show that R&D intensity (Chan et al., 2001; Lev et al., 2005; Penman and Zhang, 2002) and unexpected R&D increase (Eberhart et al., 2004, 2008; Woolridge, 1988) are associated with high subsequent stock returns.

Several studies have found that the stock price return depends on the industry of the firm. Specifically, the relation is significantly positive for firms in the high-technology industry but significantly negative for low-technology firms (Chan et al., 1990; Zantout and Tsetsekos, 1994). Szewczyk et al. (1996) find that abnormal returns attributed to R&D expenditures are positively related to the investment opportunities of a firm, indicating that R&D expenditures add greater value for firms with better growth opportunities, such as those in high-technology industries.

2.1.2. R&D, financial constraints, and stock return

Firms are not always able to undertake all value-increasing investment projects because of the increased cost of external capital generated by market frictions (Greenwald et al., 1984; Myers and Majluf, 1984). If a firm cannot fully fund an R&D project, the project and investment opportunity may be suspended or terminated. This suspension or termination may lead to low future growth and reduced operating performance and firm value. Previous research has shown that, compared with non-R&D-intensive firms, R&D-intensive firms are often subject to great financial constraints because of pronounced information asymmetry and agency problems (Hall, 1992; Hall and Lerner, 2010; Himmelberg and Petersen, 1994). Li (2011) suggests that, for R&D-intensive firms, the risk of being unable to fund R&D is greater if financial constraints increase. However, Almeida et al. (2013) indicate that financial constraints may improve the efficiency of firms in generating patents by mitigating the agency problem of misuse of free cash flows; such signals may also signal the optimism that R&D expenditures are value-adding.

By modeling and empirically considering the impact of financial constraints on R&D investments, Li (2011) finds a robust positive constraints-return relation among R&D-intensive firms. However, this study shows that the R&D intensity-return relation is only positive among firms that are financially constrained, leading Li (2011) to conclude that the return depends on a substantial interaction effect between financial constraints and R&D intensity.

Ex ante R&D expenditure can either be wealth increasing, wealth destroying, or in the worst case, lead to bankruptcy. Zhang (2015) examines the R&D expenditure in the context of financial distress. By calculating the R&D expenditure as a time-weighted average of R&D expenditure in the previous five years, Zhang (2015) identifies a positive relation between R&D expenditure and the probability of delisting and financial distress. The relation becomes pronounced when firms are financially constrained and during recessionary periods.

2.2. Steady versus volatile R&D expenditures and hypotheses development

As Mudambi and Swift (2011) note, R&D intensity and R&D volatility represent different elements that contribute to firm performance. While initially researchers focused on R&D intensity, more recently studies have included R&D volatility to understand firm performance. Kang et al. (2017) provide an excellent summary of the conflicting arguments for the stability and volatility of R&D investment.

A common view is that firms should steadily invest in R&D to cause the least amount of disruption in their R&D function. Kor and Mahoney (2005) state that inconsistent R&D expenditures may cause firms to lose their ability to create sustainable competitive advantages. Swift (2008) explains that firms reducing or terminating the funding of an R&D project as it approaches completion may incur significant opportunity costs. Moreover, the adjustment costs of R&D expenditures may be large because the R&D labor force comprises highly skilled technology workers who cannot be easily recruited (Hambrick et al., 1983). Furthermore, Brown and Petersen (2011) argue that firms face large costs from the loss of proprietary information or when innovative ideas are revealed. Therefore, volatile R&D expenditures may cause poor firm performance because of the disruption to the R&D function and the high adjustment costs associated with changes to this expenditure.

An alternative research stream suggests that managers manipulate R&D expenditures to smooth earnings or achieve other income objectives (Baber et al., 1991; Berger, 1993; Bushee, 1998; Cheng, 2004; Degeorge et al., 1999; Elliott et al., 1984; Jensen, 2005; Perry and Grinaker, 1994). Specifically, Baber et al. (1991) argue that managers can reduce R&D expenditures when earnings fail to meet the forecasts of analysts. Meanwhile, Bushee (1998) and Elliott et al. (1984) find that managers routinely adjust their R&D spending to smooth corporate earnings. When the earnings are smoothed by increasing the R&D investment beyond the optimal level, the overinvestment incurs loss of value to shareholders.

Volatile R&D expenditures are examined by Xu and Yan (2013) who argue that a history of volatile R&D spending increases the difficulty of detecting the manipulation of the R&D expenditures of a firm. Tong and Zhang (2014) examine the opportunistic managerial behavior where R&D expenditures are cut to fulfill short-term earnings goals. They determine that the capital market penalizes managerial myopia, especially for firms with high investor sophistication. Generally, managers are thought to make myopic decisions on R&D investments, focusing on short-term earnings instead of maximizing shareholder value.

Therefore, volatility in R&D expenditures indicates the earnings management activity (manipulation) of managers and signals the myopic management decision-making.[1] According to the argument for manipulation, firms exhibit poor overall performance and low stock return if they manage their R&D expenditures to fulfill short-term earnings forecasts at the expense of long-term growth.

On the basis of the discussions above, we formulate the following hypothesis:

H1. Consistent with High Adjustment Costs or Earnings Management: All else being equal, R&D expenditure volatility is negatively related to firm stock return.

[1] Prior literature documents that the adjustment of R&D investment can be used by firms to conduct real earnings management (see more details in Cohen et al. (2008), Enomoto et al. (2015), Roychowdhury (2006), among others).

In contrast to the shareholder-manager agency conflict where the volatility in R&D expenditures indicates a possible manipulation of earnings, stable R&D expenditures signify a likely agency problem between managers and technocrats. An information asymmetry between managers and technocrats prevents managers from being able to discern worthy from inferior R&D projects, requiring them to create governance practices to control the opportunistic behavior of the technocrats. R&D project managers are reluctant to reduce or terminate investments in the R&D project even if evidence exists that the project will be less profitable. That is because project managers have incentives to increase the resources under their control and power, reputation, and compensation (Bernardo et al., 2001; Jensen, 1986). Moreover, Stein (2003) and Chen et al. (2016) argue that intangible assets, including R&D, challenge the enforcement of the full disclosure of the prospects of R&D projects because of their complexity and the insufficient expertise of managers.

Bowman and Hurry (1993) indicate that firms can mitigate the entrenchment of project managers (technocrats) by decreasing the expenditures of projects. A solution to project manager entrenchment is the creation of staged financing, in which investors or senior managements withhold incremental funding until project managers have provided evidence of a successful application of previous rounds of funding (Neher, 1999). Moreover, Neher (1999) and Gompers (1995) also state that staged financing mitigates project managerial opportunism and moral hazard, especially for opaque firms.

Swift (2008, 2013) proposes the argument that steady R&D expenditures, instead of facilitating innovation and firm performance, may indicate managerial entrenchment and overinvestment. He concludes that successful firms are able to limit overinvestment in R&D, such that volatile R&D expenditure is an indicator of sound internal governance and oversight mechanisms for R&D investment decisions. Moreover, Mudambi and Swift (2011) indicate that R&D volatility is a proxy for value-adding proactive management because it proves that a firm optimizes the balance between activities that perform R&D (exploration) and activities where R&D is exploited. However, they caution that technocrats and researchers may obstruct these efforts.

Accordingly, we expect that firms that are able to apply this governance mechanism can outperform their peers who maintain steady R&D expenditures. We formulate the following hypothesis:

H2. Consistent with Overinvestment-control: All else being equal, R&D expenditure volatility is positively related to firm stock return.

2.3. Interactions with R&D volatility

Li (2011) demonstrated that the relation between R&D intensity and firm return depends on whether firms are financially constrained. Similar interaction effects are anticipated for the relation between R&D volatility and return. While the relation to stock return has not been tested, studies have examined the R&D volatility – performance relation using growth and return on assets as measures of performance.

Mudambi and Swift (2011) find that firm growth is negatively related to R&D volatility for small firms but positively related for large firms. Moreover, the relation depends on industry, with firm growth being positively (negatively) related to R&D volatility for fast (slow) clockspeed industries. Using a measurement referred to as organizational slack, which is primarily related to firm liquidity and its ability to support new R&D projects in a timely manner, Swift (2013) finds that greater slack strengthens the positive relation between R&D expenditure volatility and performance. He uses Tobin's q to measure firm performance.

The relation between R&D volatility and firm performance is also related to mechanisms that monitor the decision-making of managers. Using an index as a measure of corporate governance, Patel et al. (2018) demonstrates that governance moderates the negative relation between the growth of a firm and R&D volatility. This relation also exists for return on assets. Technological capability, which is defined as the number of researchers divided by the total employees, is shown by Kang et al. (2017) to provide explanatory power in determining the relative importance of stability or the volatility of R&D investments for a firm. Accordingly, the literature points to the relation between R&D volatility and firm return is more complex than a simple linear relation.

3. Research design

3.1. Sample and data

Our sample comprises US listed firms from 1980 to 2018.[2] From the 35,318 firms listed in the US at some time between 1980 and 2018, we select the firms with the ratios of R&D expense to Sales (R&D) that are less than unity and firms for which we can calculate standard deviations of R&D during the sample period. The resulting sample contains 5,178 firms. After matching the monthly stock return data, the initial unbalanced sample size becomes 886,601 firm-month observations, which reduces to 435,624 when we consider our main variable of interest $RD_{Volatility}$. The principal data source is Worldscope from the Datas-

[2] Our sample commences in 1980, coinciding with the availability of data from Datastream. By commencing in 1980, we avoid the issue highlighted by Daniel et al. (2001) and Eberhart et al. (2004) that prior to 1974 firms had more discretion over their R&D reporting. The accounting treatment of R&D expense reporting was standardized in 1974 (Financial Accounting Standards Board Statement No. 2).

tream platform, which provides the data for most of the variables in this study. Industry classification is based on Siccodes 5 of the Fama-French industry codes. [3]

We conduct further testing using dummy variables to distinguish industry and R&D-increased versus decreased firms. Then, we examine the interaction with firm size.

(1) Industry dummies
We use five industry groupings of Fama and French based on Compustat SIC codes as follows: Consumer, Manufacturing, High Technology, Health, and Others.
(2) R&D-increased versus R&D-decreased
The R&D-increased (decreased) classification is created from firms exhibiting a positive (negative) change in R&D expense. A total of 382,824 (198,768) firm-month observations are in the R&D-increased (decreased) group, which we code as 1 (0).
(3) Firm Size
We use the natural log of market equity (ln(ME)) at the end of year t-1 to measure the firm size. In addition to interacting with $\text{R\&D}_{\text{Volatility}}$, we use the size as a control variable, as the existing literature has found a small-cap effect in the predictability of individual stock returns (Semenov, 2015).

Table A1 in Appendix A presents the sample selection process.

3.2. Definition of key variables

3.2.1. Dependent variable: Stock return (R)

Following Li (2011), the stock return (R) is the monthly return in percentage, which is calculated using the Return Index (RI) from Datastream.

3.2.2. Independent variables

3.2.2.1. R&D intensity ($RD_{Intensity}$). Following Bah and Dumontier (2001), Chan et al. (2001), Eberhart et al. (2004), and Lev and Sougiannis (1996, 1999), among others, R&D intensity is defined as the ratio of R&D expense to sales.

3.2.2.2. R&D expenditure volatility ($RD_{Volatility}$). We recognize that various ways are available for measuring R&D expenditure volatility. To ensure that our results are robust to the alternative definitions of R&D expenditure volatility, we conduct robustness tests using two alternative R&D volatility measures.

Following Patel et al. (2018), $\text{RD}_{\text{Volatility}}$ is measured using the standard deviation of the residuals from the R&D expenditure trend of the firm over the past five years, divided by the five-year mean expenditure. Specifically, we regress the R&D expenditure (RD_{it}) on a linear time trend over the past five years as follows:

$$RD_{it} = \alpha_i + \beta_i t + \varepsilon_{it} \tag{1}$$

where t ranges from 1 to 5 (corresponding to a rolling five-year period) for firm i.

Then $\text{RD}_{\text{Volatility}}$ is calculated as follows:

$$RD_{Volatility,i} = \frac{S_i}{x_i} \tag{2}$$

where S_i is the five-year rolling standard deviation of the residuals from regression (1), while x_i is the mean R&D expenditure of firm i over the five-year rolling period.

For robustness tests, we use two alternative measures. The first is Swift's (2008) R&D volatility measure that uses the coefficient of variation. This measure is defined as the ratio of the three-year rolling standard deviation of the R&D expenditure of a firm to its three-year mean R&D expenditure, which is listed as follows:

$$RD_{VolStd} = \frac{stddev_i}{mean_i} \tag{3}$$

where stddev_i is the three-year rolling standard deviation of the R&D expenditure of a firm, while mean_i is the three-year mean of the R&D expenditure.

The second alternative measure for R&D expenditure volatility is the absolute value of the proportionate change in R&D expense ($\text{RD}_{\text{VolAbs}}$). We calculate $\text{RD}_{\text{VolAbs}}$ as follows:

$$RD_{VolAbs} = \left| \frac{RD_t - RD_{t-1}}{RD_{t-1}} \right| \tag{4}$$

[3] Refer to http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html for more details.

3.2.3. Control variables

3.2.3..1. Kaplan-Zingales index (KZ). KZ is used to measure financial constraints. Following Lamont et al. (2001), the KZ index is calculated using the following equation:

$$KZ = -1.001909 \times \frac{CashFlow}{K} + 0.2826389 \times Tobin'sQ + 3.139193 \times \frac{Debt}{TotalCapital} \\ -39.3678 \times \frac{Dividends}{K} - 1.314759 \times \frac{Cash}{K} \tag{5}$$

where the independent variables are calculated according to the following definitions based on the Datastream item numbers:[4] K is the capital assets, defined as net property, plant, and equipment (Item WC2301); annual data Cash Flow/K is (Item WC01551 + Item WC01151)/Item WC02301; Tobin's Q as (Item WC03999 + Item WC08001 – Item WC03501 – Item WC03263)/Item WC03999; Debt/Total Capital as (Item WC03251 + ItemWC03051)/(Item WC03251 + Item WC03051 + Item WC03999 – Item WC03351); Dividends/K as (Item WC05376 + Item WC05401)/Item 02301; and Cash/K as (Item WC02001/ Item 02301).

3.2.3.2. Return on assets (ROA). Following Li (2011), *ROA* is measured as net income divided by total assets at the end of year $t-1$.

3.2.3.3. Natural log of market equity (ln(ME)). Following Li (2011), ln*(ME)* is measured by the natural log of market capitalization at the end of year *t-1*. This variable is used to proxy for the firm size. We control for the possible impact of firm size on stock return, as the existing literature finds a small-cap effect in the predictability of individual stock returns (e.g., Semenov, 2015).

3.2.3.4. Natural log of the ratio of book equity to market equity (ln(BE/ME)). Following Li (2011), ln*(BE/ME)* is the natural log of the ratio of book equity (BE) to market equity (ME) at the end of year $t-1$. This variable is used to identify whether a firm is under- or overvalued.

3.2.3.5. Momentum. The return over the previous six-months. (Similar to Li (2011), we leave a one-month gap to the current month).

Table B1 in Appendix A presents the definitions of the variables.

3.3. Empirical methodology

We use an unbalanced panel linear model with fixed time effects to empirically investigate the impact of R&D expenditure volatility on stock return. Initially, we confirm the finding Li (2011) obtained using the Fama and Macbeth (1973) procedure by applying the panel analysis method. Next, we supplement Li's (2011) model with industry dummy variables and include terms for R&D volatility to create our baseline model expressed in Eq. (6).

$$R = \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility} \\ +\beta_6 ROA + \beta_7 \ln(ME) + \beta_8 \ln\left(\frac{BE}{ME}\right) + \beta_9 \text{Momentum} + \beta_{10} \text{Consumer} \\ +\beta_{11} \text{Manufacturing} + \beta_{12} \text{High\_Technology} + \beta_{13} \text{Health} + \varepsilon \tag{6}$$

The dependent variable, namely, stock return (R), is the monthly return in percentage. The R&D intensity ($RD_{Intensity}$) of the firm is captured by its R&D expense scaled by sales. The R&D expenditure volatility ($RD_{Volatility}$) is obtained using the Patel et al. (2018) volatility measure. According to the hypotheses, we expect a negative relation between R&D expenditure volatility and stock return if the high adjustment cost and earnings management hypothesis is applicable, while a positive relation is expected if the overinvestment-control hypothesis applies.

First, we extend our empirical analysis by introducing the dummy variable "Change" to capture the differences between firms that increase their R&D expenditure and those that decrease expenditure. Second, we introduce the interaction terms between $RD_{Intensity}$ and firm size, and $RD_{Volatility}$ and firm size. The full specification of this model is shown in Eq. (7). The subsequent analysis over sub-periods and robustness tests using alternative measures of R&D volatility are based on this model.

[4] Item numbers in the Datastream annual data have the following definitions: WC01151 (Depreciation, Depletion, & Amortization), WC01551 (Net Income before Extraordinary Items/Preferred Dividends), WC02001 (Cash & Short-term Investments), WC02301 (Property, Plant, & Equipment - Gross), WC03051 (Short-term Debt & Current Portion of Long-term Debt), WC03351 (Total Liabilities), WC03501 (Common Equity), WC03251 (Long-term Debt - Total), WC03263 (Deferred Taxes), WC03999 (Total Liabilities & Shareholders' Equity), WC08001 (Market Capitalization), WC05376 (Common Dividends (Cash)), and WC05401 (Preferred Dividends (Cash)). To calculate the KZ index for a firm in a particular year, the firm requires valid annual data.

$$R = \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility}$$

$$\begin{aligned} R = {} & \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility} \\ & + \beta_6 Change + \beta_7 ROA + \beta_8 \ln(ME) + \beta_9 RD_{Intensity} \times \ln(ME) \\ & + \beta_{10} RD_{Volatility} \times \ln(ME) + \beta_{11} \ln(\tfrac{BE}{ME}) + \beta_{12} \text{Momentum} \\ & + \beta_{13} \text{Consumer} + \beta_{14} \text{Manufacturing} + \beta_{15} \text{High\_Technology} + \beta_{16} \text{Health} + \varepsilon \end{aligned} \tag{7}$$

4. Empirical findings

4.1. Summary statistics and correlation analysis

Table 1 summarizes all variables used in our main analyses from 1980 to 2018 and reports their pairwise Pearson correlation coefficients. Panel A shows that, for the whole period, the overall average stock return is 1.7% per month. The average R&D intensity as measured by the ratio of R&D expense to sales is 8.5%, while R&D volatility is 13.8%. These values are broadly consistent with Mudambi and Swift (2011) and Patel et al. (2018). The mean KZ, which represents the financial constraints, is −0.62 in our sample and compares with the index value of 3.5 (−2.8) above (below), which firms ranked by financial constraints to be in the top (bottom) quartile.[5] The average ROA is −8.1%, but the distribution is slightly skewed with a median of 5.0%.

A further analysis reported in Panel B shows that firms in the high-technology and health industries comprise 55% of our sample and have similar distributions of R&D intensity with means of 13% and 10%, respectively. By contrast, firms in the remaining industries have a mean of 4%. In unreported results, we note that the firms identified by Mudambi and Swift (2011) as fast clockspeed represented in our sample have slightly higher levels of R&D expenditure as a proportion of sales than our average high-technology firms. Slow clockspeed firms have low levels of R&D expenditure, which is equivalent to the median in our consumer and manufacturing firms. The correlation analysis results in Panel C show that stock return has low correlations with our other main variables.

4.2. Primary results

Table 2 summarizes our regression results concerning the impact of R&D expenditure volatility on stock return. We replicate Li (2011) in Model (1) and augment this result with industry dummy variables in Model (2). Next, we add the R&D volatility term and its interaction with the financial constraint KZ index in Model (3). Similar to Li (2011), Model (1) shows the apparent importance of financial constraints on the relation between R&D intensity and stock return. The KZ index in our sample ranges between −5.7 for the 10th percentile of firms and 2.7 for the 90th percentile of financially constrained firms. With the coefficient for $KZ \times RD_{Intensity}$ being significantly positive, the relation between R&D intensity and return for the most financially constrained firms is positive, whereas, the relation becomes negative for firms without constraints.[6] Accordingly, these results are consistent with Li's (2011) conclusion that only financially constrained firms exhibit a positive R&D-return relation.

With the introduction of industry dummy variables in Model (2), the apparent importance of financial constraints is diminished. Manufacturing, high-technology, and health are distinguished by their significantly positive coefficients from consumers and other firms. Separating these two groups by using the industry dummy variables reveals a substantial positive relation between R&D intensity and return while decreasing the influence of industry variation on the estimated relation between return and the KZ interaction term.

Li (2011) attributed the positive R&D-return relation for financially constrained R&D intensive firms to the increased risk of them having to suspend or disrupt their R&D projects. However, we directly test the effect of disrupting R&D on firm returns in Model (3), where we introduce our $RD_{Volatility}$ term and its interaction with financial constraints. We use the measure of R&D volatility from Patel et al. (2018), which captures the disruption through the propensity of a firm to vary R&D expenditures relative to trend over a rolling five-year period.

The significantly negative coefficient on $RD_{Volatility}$ in Model (3) shows that disrupting R&D expenditure adversely affects the return performance. Although the $KZ \times RD_{Volatility}$ interaction term is significantly positive, the magnitude of the coefficient is sufficiently small for the relation between R&D volatility and return, although moderated by high financial constraints, to remain negative within the range of values for KZ (−5.692 to 2.656 corresponding to the 10th and 90th percentiles, respectively) in our sample. Notably, the coefficient for $RD_{Intensity}$ remains significantly positive, while the influence of financial constraints on the R&D-return relation is restored. These results indicate that a reinterpretation of Li's (2011) result is appropriate. The R&D expenditure that is undertaken when a firm is financially constrained must be genuinely value-adding to improve firm returns, while firms with a propensity to vary R&D expenditure reduce their returns.

The negative relation between $RD_{Volatility}$ and return supports our assertion that R&D volatility is consistent with adjustment costs associated with disruption adversely affecting firm performance. It is also consistent with our conjecture that

[5] See http://ycharts.com/glossary/terms/kz_index for more details.

[6] That is, $\frac{\partial R}{\partial RD_{Intensity}}$ ranges between −0.0080 and 0.0062 for values of KZ ranging from −5.7 to 2.7 where higher scores indicate great financial constraint.

Table 1
Descriptive statistics. This table summarizes the key variables used in this study. Panel A describes the basic characteristics of these variables for the period 1980–2018, Panel B provides a breakdown of R&D Intensity by industry, while Panel C presents their pair-wise Pearson correlation coefficients. Return is the monthly stock return, $RD_{Intensity}$ is the ratio of R&D expense to sales, following Patel et al. (2018), $RD_{Volatility}$ is measured as the standard deviation of the residuals from the firm's R&D expenditure trend over the past five years, divided by the five-year mean expenditure, KZ measures financial constraints, ROA is net income divided by total assets, ME is market capitalization, BE is book equity, and Momentum is lagged six-month return. Industry classifications are based on the Fama-French Siccodes5 definitions.

Panel A: Descriptive Statistics of Main Variables

Variable	N	Mean	Median	Std Dev	10-percentile	90-percentile
Return	886,601	0.017	0.000	0.25	−0.200	0.212
$RD_{Intensity}$	675,288	0.085	0.044	0.11	0.003	0.210
KZ	586,092	−0.618	−0.011	4.57	−5.692	2.656
$RD_{Volatility}$	435,624	0.138	0.095	0.14	0.031	0.291
ROA	736,908	−0.081	0.050	0.46	−0.339	0.154
ln (ME)	746,724	12.100	12.123	2.52	8.866	15.359
ln (BE/ME)	680,172	−0.824	−0.758	1.00	−1.973	0.235
Momentum	819,440	0.085	0.019	0.54	−0.437	0.581

Panel B: R&D Intensity by Industry Type

Consumer	59,988	0.04	0.01	0.09	0.00	0.11
Manufacturing	91,680	0.04	0.02	0.08	0.00	0.08
High Technology	289,848	0.13	0.10	0.12	0.01	0.26
Health	80,604	0.10	0.07	0.12	0.01	0.21
Other	153,168	0.04	0.02	0.08	0.00	0.10

Panel C: Correlations of Key Variables

	1	2	3	4	5	6	7
1. Return							
2. $RD_{Intensity}$	0.008						
3. KZ	0.009	−0.159					
4. $RD_{Volatility}$	0.000	−0.013	0.061				
5. ROA	−0.012	−0.385	−0.272	−0.220			
6. ln(ME)	−0.035	−0.075	−0.127	−0.277	0.332		
7. ln(BE/ME)	0.045	−0.093	0.068	0.070	−0.117	−0.429	
8. Momentum	−0.002	0.006	0.024	−0.002	0.024	−0.007	−0.062

volatility caused by earnings management is penalized by the market, as well as being disruptive and reducing returns. Therefore, hypothesis H1 is supported. Conversely, the negative relation does not support the conjecture that R&D volatility reflects the actions of managers controlling overinvestment by technocrats, thus failing to support hypothesis H2.

4.3. R&D change and firm size

4.3.1. R&D increases versus R&D decreases

Our result, in which R&D volatility is negatively related to firm return, is consistent with our disruption and earnings management hypothesis. In this section, we distinguish these possibilities by separating the impact of R&D increases and decreases. Additional analysis (not reported) shows that the increases in R&D expenditure represent 66% of changes in expenditure. However, they tend to be marginally smaller in size than decreases in R&D expenditure. Accordingly, we have an a priori expectation that our earlier reported results related to R&D volatility will be driven by increased R&D expenditure.

Disruption occurs when R&D expenditure is varied irrespective of whether it is motivated by an intention to manipulate earnings or for a different reason. Moreover, disruption costs are incurred, albeit asymmetrically, irrespective of whether expenditure is increased or decreased. Changes to R&D expenditure that are motivated by earnings management produce suboptimal levels of investment in R&D. Either R&D expenditure is decreased to improve the reported earnings of the firm, which causes underinvestment or increased smooth earnings producing overinvestment in R&D. Both are viewed unfavorably by the market, thus reducing returns.

The market reacts positively to increases in R&D expenditure when they signal higher expected future earnings when the increase is value-adding, which implicitly precludes overinvestment. By implication, if the signaling effect of changes to R&D expenditure affects returns more than volatility, the negative relation between return and R&D volatility must be driven by disruption costs rather than overinvestment.

In Model (1) of Table 3, the variable "Change" takes on the value "1" if the R&D is increased and "0" if it is decreased. The coefficient for "Change" is significantly positive, providing evidence that the market views increases to R&D favorably. The

Table 2
Impact of R&D volatility on stock return (baseline test).

Dependent Variable: Stock return (R)	Li (2011) (1)	Li (2011) (2)	Baseline model (3)
$RD_{Intensity}$	0.0017	0.0207***	0.0172***
	(0.30)	(6.70)	(4.64)
KZ	0.0001	0.0002	0.0001
	(0.43)	(1.56)	(−0.70)
$KZ \times RD_{Intensity}$	0.0017**	0.0006	0.0018***
	(2.19)	(1.13)	(2.65)
$RD_{Volatility}$			−0.0085***
			(−3.80)
$KZ \times RD_{Volatility}$			0.0009*
			(1.79)
ROA	0.0040*	0.0147***	0.0056***
	(1.74)	(9.61)	(2.72)
ln (ME)	−0.0223***	−0.0017***	−0.0014***
	(−53.99)	(−12.34)	(−9.54)
ln (BE/ME)	0.0068***	0.0049***	0.0045***
	(13.28)	(15.32)	(12.54)
Momentum	−0.0101***	0.0033***	0.0020***
	(−16.55)	(5.36)	(2.99)
Consumer		0.0012	0.0012
		(1.14)	(1.09)
Manufacturing		0.0029***	0.0022**
		(3.23)	(2.36)
High Technology		0.0031***	0.0024***
		(4.24)	(3.09)
Health		0.0043***	0.0037***
		(4.50)	(3.80)
Obs.	444,957	444,957	330,849
	0.0025	0.0006	0.0002

This table presents the results from a panel regression with time-fixed effects using the equation:

$$R = \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility}$$
$$+\beta_6 ROA + \beta_7 \ln(ME) + \beta_8 \ln(\tfrac{BE}{ME}) + \beta_9 \mathrm{Momentum} + \beta_{10}\mathrm{Consumer}$$
$$+\beta_{11}\mathrm{Manufacturing} + \beta_{12}\mathrm{High\_Technology} + \beta_{13}\mathrm{Health} + \varepsilon$$

where R is the monthly stock return, $RD_{Intensity}$ is the ratio of R&D expense to sales, following Patel et al. (2018), $RD_{Volatility}$ is measured as the standard deviation of the residuals from the firm's R&D expenditure trend over the past five years divided by the five-year mean expenditure, KZ measures financial constraints, ROA is net income divided by total assets, ME is market capitalization, BE is book equity, and Momentum is the lagged six-month return. Industry classifications are based on the Fama-French Siccodes5 definitions. T stats are in parentheses.

*** Significant at the 0.01 level.
** Significant at the 0.05 level.
* Significant at the 0.10 level.

coefficient for $RD_{Volatility}$ maintains its statistical significance and magnitude. Within the 10th to 90th percentile range of values for $RD_{Volatility}$, the contribution of this term is subsumed by the new "Change" term.[7] Accordingly, we conclude that earnings management is not responsible for the negative relation between R&D volatility and stock return. Instead, disruption costs, which are associated with the abandonment of research projects and the loss of expertise and future capability, separation costs and write-downs in the value when R&D expenditure is decreased, and costs associated with initiating new projects when it is increased are responsible.

4.3.2. Firm size

Unlike situations where the deliberate actions of the management can cause volatility in R&D expenditure, volatility is mechanically related to firm size. This relation is consistent with the correlation observed in Table 1, Panel C. That is, small firms naturally have greater volatility in R&D expenditure than large firms that undertake a greater number of discrete R&D projects. Consequently, the R&D expenditure is proportionately less "lumpy" for large firms. The market perceives the same level of volatility as a proportion of the firm size as disruptive in large firms because this level indicates the commencement, suspension, or discontinuation of greater numbers of R&D projects. Accordingly, we expect R&D volatility to affect returns negatively as the firm size increases. That is, the sign on the interaction term $RD_{Volatility} \times \ln(ME)$ is negative.

Model (2) of Table 3 shows a significantly negative coefficient for the term $RD_{Volatility} \times \ln(ME)$. This term fully subsumes the impact of the change in the sign of the $RD_{Volatility}$ term on firm return. This impact may be assessed by taking partial

[7] Based on the 10- and 90- percentiles of $RD_{Volatility}$ in Table 1, the contribution of this term to firm return ranges from −0.0002 (-0.008 x 0.031) to −0.0023 (-0.008 x 0.291). This range is smaller in magnitude than the 0.0032 contribution from an increase in R&D expenditure.

Table 3
Interaction of volatility with level of R&D expenditure and firm size.

Dependent Variable: Stock return (R)	$R\&D_{Inc}/R\&D_{Dec}$ (1)	Firm Size (2)
$RD_{Intensity}$	0.0181***	0.0953***
	(4.87)	(5.95)
KZ	−0.0001	0.0000
	(−0.59)	(0.23)
KZ × $RD_{Intensity}$	0.0019***	0.0013*
	(2.71)	(1.82)
$RD_{Volatility}$	−0.0080**	0.0850***
	(−3.55)	(7.45)
$RD_{Volatility}$ × KZ	0.0009*	0.0005
	(1.85)	(1.10)
Change	0.0032***	0.0032***
	(5.33)	(5.35)
ROA	0.0044**	0.0067***
	(2.11)	(3.17)
ln(ME)	−0.0015***	0.000
	(−9.69)	(0.18)
$RD_{Intensity}$ × ln(ME)		−0.0062***
		(−4.96)
$RD_{Volatility}$ × ln(ME)		−0.0077***
		(−8.26)
ln(BE/ME)	0.0048***	0.0049***
	(13.22)	(13.32)
Momentum	0.0020***	0.0020***
	(2.90)	(2.94)
Consumer	0.0014	0.0010
	(1.20)	(0.90)
Manufacturing	0.0023**	0.0019**
	(2.39)	(2.02)
High Technology	0.0023***	0.0027***
	(2.85)	(3.42)
Health	0.0035***	0.0038***
	(3.55)	(3.81)
Obs.	328,305	328,305
Adj R-Sq	0.0002	0.0005

This table presents the results from a panel regression with time fixed effects using the equation:

$$\begin{aligned} R = {} & \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility} \\ & + \beta_6 Change + \beta_7 ROA + \beta_8 \ln(ME) + \beta_9 RD_{Intensity} \times \ln(ME) \\ & + \beta_{10} RD_{Volatility} \times \ln(ME) + \beta_{11} \ln(\tfrac{BE}{ME}) + \beta_{12}\mathrm{Momentum} \\ & + \beta_{13}\mathrm{Consumer} + \beta_{14}\mathrm{Manufacturing} + \beta_{15}\mathrm{High\_Technology} + \beta_{16}\mathrm{Health} + \varepsilon \end{aligned}$$

where R is the monthly stock return, $RD_{Intensity}$ is the ratio of R&D expense to sales, following Patel et al. (2018), $RD_{Volatility}$ is measured as the standard deviation of the residuals from the firm's R&D expenditure trend over the past five years divided by the five-year mean expenditure, KZ measures financial constraints, Change is a dummy variable with '1' denoting an increase in R&D expenditure, ROA is net income divided by total assets, ME is market capitalization, BE is book equity, and Momentum is lagged six-month return. Industry classifications are based on the Fama-French Siccodes5 definitions. T stats are in parentheses.

*** Significant at the 0.01 level.
** Significant at the 0.05 level.
* Significant at the 0.10 level.

derivatives of Eq. (6) with respect to $RD_{Volatility}$ and examining the range of values KZ and ln(ME) after estimating the coefficients reported in Table 3. This derivative is shown in Eq. (8). We calculate the values for $\frac{\partial R}{\partial RD_{Volatility}}$ over the range of values for KZ and ln(ME) reported in Table 1. Specifically, KZ ranges between −5.69 (10th percentile) and 2.66 (90th percentile), with a mean of −0.62, and ln(ME) ranges between 8.87 and 15.36, with a mean of 12.10. When we substitute the extreme cases for KZ and ln(ME), we find that the derivative $\frac{\partial R}{\partial RD_{Volatility}}$ ranges between −0.036 and 0.018. Notably, the $\frac{\partial R}{\partial RD_{Volatility}}$ is negative for average size firms and negative for the large firms, which is consistent with our expectation that R&D volatility is more disruptive in large firms. Indeed, for small firms, where R&D volatility occurs mechanically, the positive relation between R&D volatility and return indicates support for hypothesis H2.

$$\frac{\partial R}{\partial RD_{Volatility}} = +0.0850 + 0.0005 \times KZ - 0.0077 \times Ln(ME) \tag{8}$$

Table 4
Impact of R&D volatility on stock return in sub-periods.

Dependent Variable: Stock return (R)	1980–1989	1990–1999	2000–2009	2010–2018
$RD_{Intensity}$	0.5303**	0.0955***	0.1364***	−0.0779***
	(2.12)	(2.05)	(5.33)	(−3.06)
KZ	0.0007	0.0004	−0.0001	0.0002
	(0.65)	(1.14)	(−0.48)	(1.38)
$KZ \times RD_{Intensity}$	−0.0002	−0.0026	0.0024**	−0.0002
	(−0.02)	(−1.35)	(2.09)	(−0.22)
$RD_{Volatility}$	0.2292**	0.0475**	0.0935***	0.0128
	(2.20)	(2.04)	(5.16)	(0.68)
$RD_{Volatility} \times KZ$	−0.0105	−0.0002	0.0015*	−0.0010
	(−1.47)	(−0.14)	(1.87)	(−1.38)
Change	−0.0003	0.0026**	0.0040***	0.0026***
	(−0.10)	(2.28)	(3.68)	(3.11)
ROA	0.0183	−0.0082	0.0126***	−0.0009
	(0.91)	(−1.56)	(3.88)	(−0.28)
ln(ME)	0.0037**	0.0005	−0.0002	−0.0012***
	(2.42)	(1.15)	(−0.45)	(−3.49)
$RD_{Intensity} \times \ln(ME)$	−0.0442***	−0.0032	−0.0100***	0.00455***
	(−2.16)	(−0.86)	(−4.72)	(3.02)
$RD_{Volatility} \times \ln(ME)$	−0.0201**	−0.0039**	−0.0081***	−0.0032**
	(−2.29)	(−2.04)	(−5.41)	(−2.16)
ln(BE/ME)	0.0056**	0.0043***	0.0086***	−0.0001
	(2.10)	(5.60)	(13.66)	(−0.22)
Momentum	−0.0018	0.0096***	−0.0010	−0.0012
	(−0.35)	(7.27)	(−0.91)	(−0.96)
Consumer	0.0008	0.0010	0.0002	0.0012
	(0.17)	(0.48)	(0.09)	(0.82)
Manufacturing	0.0002	0.0004	0.0038**	0.0010
	(0.05)	(0.28)	(2.05)	(0.74)
High Technology	−0.0059*	0.0105***	−0.0004	−0.0000
	(−1.85)	(7.63)	(−0.23)	(−0.02)
Health	0.0099**	0.0016	0.0050***	−0.0019
	(1.98)	(0.85)	(2.74)	(−1.41)
Obs.	7,497	86,729	141,281	92,798
Adj R-Sq	−0.0080	0.0026	0.0026	−0.0003

This table presents the results from a panel regression with time fixed effects for the sub-periods 1980–1989, 1990–1999, 2000–2009, and 2010–2018 using the equation:

$$\begin{aligned} R = {} & \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility} \\ & + \beta_6 Change + \beta_7 ROA + \beta_8 \ln(ME) + \beta_9 RD_{Intensity} \times \ln(ME) \\ & + \beta_{10} RD_{Volatility} \times \ln(ME) + \beta_{11} \ln\left(\tfrac{BE}{ME}\right) + \beta_{12}\text{Momentum} \\ & + \beta_{13}\text{Consumer} + \beta_{14}\text{Manufacturing} + \beta_{15}\text{High\_Technology} + \beta_{16}\text{Health} + \varepsilon \end{aligned}$$

where R is the monthly stock return, $RD_{Intensity}$ is the ratio of R&D expense to sales, following Patel et al. (2018), $RD_{Volatility}$ is measured as the standard deviation of the residuals from the firm's R&D expenditure trend over the past five years divided by the five-year mean expenditure, KZ measures financial constraints, Change is a dummy variable with '1 denoting an increase in R&D expenditure, ROA is net income divided by total assets, ME is market capitalization, BE is book equity, and Momentum is the lagged six-month return. Industry classifications are based on the Fama-French Siccodes5 definitions. T stats are in parentheses.

*** Significant at the 0.01 level.
** Significant at the 0.05 level.
* Significant at the 0.10 level.

Moreover, the inspection of Models (1) and (2) in Table 3 confirms that the coefficient for the change in R&D expenditure discussed in Section 4.3.1 retains the same magnitude and significance. The earlier conclusion that the negative affect of R&D volatility on return is caused by disruption costs remains valid. The overall picture is one where investors react negatively to the disruptive effect of changes to R&D expenditure, except for the case of small firms where greater volatility is not only expected but welcomed by investors who appreciate a disciplined approach to spending on R&D projects.

As a side note, the effect of the increase in the coefficient for $RD_{Intensity}$ in Model (2) is largely offset by the addition of the interaction term $RD_{Intensity} \times \ln(ME)$. Moreover, the impact of this term is an order of magnitude greater than the impact of the $RD_{Intensity} \times KZ$ term. This finding indicates that the impact that R&D intensity has on firm return is moderated more by firm size than whether the firm is facing financial constraints, as proposed by Li (2011). We find that R&D intensity is positively related to returns for small firms.

4.3.3. Subperiods test

Following Brown and Petersen (2011), who find variation in different sample periods, we split the sample period into four subsamples: 1980–1989, 1990–1999, 2000–2009, and 2010–2018. Table 4 presents our regression results. The impact of R&D volatility on stock return is not immediately apparent because of the multiple interaction terms. However, sensitivity

Table 5
Impact of R&D volatility on return using alternative volatility measures.

Dependent Variable: Stock return (R)	$RD_{Volatility}$ (1)	RD_{VolStd} (2)	RD_{VolAbs} (3)
$RD_{Intensity}$	0.0953***	0.0950***	0.1009***
	(5.95)	(6.53)	(6.93)
KZ	0.0000	0.0002*	0.0003**
	(0.23)	(1.93)	(2.10)
KZ × $RD_{Intensity}$	0.0013*	0.0009	0.0010*
	(1.82)	(1.45)	(1.69)
$RD_{Volatility}$	0.0850***	0.0675***	0.0295***
	(7.45)	(10.68)	(5.51)
$RD_{Volatility}$ × KZ	0.0005	−0.0003	−0.0002
	(1.10)	(−1.00)	(−1.09)
Change	0.0032***	0.0038***	0.0043***
	(5.35)	(6.53)	(7.07)
ROA	0.0067***	0.0096***	0.0114***
	(3.17)	(5.45)	(6.66)
ln(ME)	0.000	−0.0002	−0.0006***
	(0.18)	(−0.93)	(−3.06)
$RD_{Intensity}$ × ln(ME)	−0.0062***	−0.0063***	−0.0065***
	(−4.96)	(−5.36)	(−5.54)
$RD_{Volatility}$ × ln(ME)	−0.0077***	−0.0066***	−0.0025***
	(−8.26)	(−12.48)	(−5.70)
ln(BE/ME)	0.0049***	0.0051***	0.0052***
	(13.32)	(14.84)	(15.09)
Momentum	0.0020***	0.0030***	0.0032***
	(2.94)	(4.77)	(4.96)
Consumer	0.0010	0.0009	0.0011
	(0.90)	(0.78)	(1.02)
Manufacturing	0.0019**	0.0023**	0.0023**
	(2.02)	(2.44)	(2.47)
High Technology	0.0027***	0.0030***	0.0033***
	(3.42)	(3.91)	(4.29)
Health	0.0038***	0.0035***	0.0039***
	(3.81)	(3.58)	(4.08)
Obs.	328,305	394,971	394,976
Adj R-Sq	0.0005	0.0013	0.0008

This table presents the results from a panel regression with time fixed effects using the equation:

$$\begin{aligned} R = {} & \beta_0 + \beta_1 RD_{Intensity} + \beta_2 KZ + \beta_3 KZ \times RD_{Intensity} + \beta_4 RD_{Volatility} + \beta_5 KZ \times RD_{Volatility} \\ & + \beta_6 Change + \beta_7 ROA + \beta_8 \ln(ME) + \beta_9 RD_{Intensity} \times \ln(ME) \\ & + \beta_{10} RD_{Volatility} \times \ln(ME) + \beta_{11} \ln(\tfrac{BE}{ME}) + \beta_{12}\text{Momentum} \\ & + \beta_{13}\text{Consumer} + \beta_{14}\text{Manufacturing} + \beta_{15}\text{High\_Technology} + \beta_{16}\text{Health} + \varepsilon \end{aligned}$$

where R is the monthly stock return, $RD_{Intensity}$ is the ratio of R&D expense to sales, following Patel et al. (2018), $RD_{Volatility}$ is measured as the standard deviation of the residuals from the firm's R&D expenditure trend over the past five years divided by the five-year mean expenditure, RD_{VolStd} is the three-year rolling standard deviation of a firm's R&D expenditure divided by its three-year mean, RD_{VolAbs} is the absolute value of the proportionate change in R&D expense, KZ measures financial constraints, Change is a dummy variable with '1' denoting an increase in R&D expenditure, ROA is net income divided by total assets, ME is market capitalization, BE is book equity, and Momentum is the lagged six-month return. Industry classifications are based on the Fama-French Siccodes5 definitions. T stats are in parentheses.

*** Significant at the 0.01 level.
** Significant at the 0.05 level.
* Significant at the 0.10 level.

analysis shows that only the coefficients for $RD_{Volatility}$ and $RD_{Volatility} \times \ln(ME)$ interaction terms are pertinent to determining the sign of the relation between R&D volatility and return within the ranges that the variables may assume. Consistently, the coefficient for $RD_{Volatility} \times \ln(ME)$ remains negative over all time periods, while the coefficient for $RD_{Volatility}$ is positive in all but the 2010–2018 period. Saliently, the contribution of volatile R&D expenditures to reducing firm returns increases with firm size, and this increase is consistent in all time periods.

For large firms, the contribution of the interaction term exceeds the contribution of the $RD_{Volatility}$ term, such that the overall relation is negative in all periods. That is, the derivative of return with respect to $RD_{Volatility}$ $\left(\frac{\partial R}{\partial RD_{Volatility}}\right)$ is negative. For medium and small firms, the relation between R&D volatility and return is mixed across time periods. For medium firms, the relation is positive in 1980–1999 and negative in 2000–2018. For small firms, the relation is positive in all but the final 2010–2018 period. The overall picture from Model (3) of Table 3 that R&D volatility adversely affects firm returns more for larger firms remains true. However, the exact firm size at which the relation between R&D volatility and return changes sign is time variant.

Accordingly, our conclusion that R&D volatility adversely affects firm return consistent with disruption of the R&D process being dependent on firm size, is robust across time periods. Similarly, across time periods, our conclusion that R&D volatility is welcomed by investors in small firms to control over investment in R&D consistent with hypothesis H2 is apparent as a full or partial offset.

4.4. Robustness test

To ensure that our results are robust to the alternative measurements of our main explanatory variable, we conduct robustness tests using alternative measures of R&D volatility. We use ''rolling standard deviation'' (RD_{VolStd}) and the ''absolute value of the proportionate change in R&D expenditure'' (RD_{VolAbs}) as alternative proxies for R&D expenditure volatility. Both alternatives have a shorter term than the measure proposed by Patel et al. (2018), which we use in the main analysis and is estimated over a rolling five-year period. Consequently, they give greater weight to the ''events'' of recent changes, compared with the measure by the Patel et al. (2018), which is more analogous to ''beta'' in the sense that it measures an attribute of firm behavior.

The results of these tests are provided in Table 5, and along with the measure from Patel et al. (2018), show remarkable consistency across measures. The sensitivity analysis of their respective derivatives of return with respect to $RD_{Volatility}$ $\left(\frac{\partial R}{\partial RD_{Volatility}}\right)$ reveals identical patterns. R&D volatility decreases firm returns more in larger firms, consistent with the high adjustment costs argument. That is, large and medium firms exhibit a negative relation between volatility and fund return because of the disruptive costs associated with changing investment in R&D. The relation is positive for small firms across all measures, which is consistent with hypothesis H2, in which volatility is valued by investors to control overinvestment in R&D.

5. Conclusion

This study provides empirical evidence of the impact of R&D expenditure volatility on stock return using a sample of 5,178 publicly listed US firms in 1980–2018. By measuring the R&D volatility, we directly test Li's (2011) conclusion that the positive R&D-return relation is due to the risk of financially constrained firms having to suspend or disrupt their R&D projects. Using R&D volatility to directly measure this risk, we find a negative relation between R&D volatility and return, which is consistent with variable R&D expenditure imposing disruption costs. Li's (2011) positive relation between expenditure and return persists, indicating that R&D expenditure is genuinely value-adding.

An alternative explanation for the negative R&D volatility-return relation may be that the market disapproves of the manager changing R&D expenditure by engaging in earnings management, which leads to suboptimal levels of investment in R&D. When the R&D expenditure is increased to smooth earnings, overinvestment occurs. However, we find that the market responds favorably when R&D expenditure is increased, contrary to the overinvestment rationale, thus attributing the negative relation between R&D volatility and return, to disruption costs.

The same proportionate change in R&D spending may cause greater disruption in larger firms because it affects more projects. We find that the negative relation between R&D volatility and return is moderated by firm size. The negative R&D volatility and return relation is most pronounced for larger firms, whereas it becomes positive for smaller firms. We attribute the positive R&D volatility-return relation that emerges for smaller firms to a governance mechanism where volatile R&D expenditure restricts technocrats and researchers from overinvesting in R&D.

Accordingly, the relation between R&D volatility and firm return is more complex than a simple linear relation. The overall picture is one where investors react negatively to the disruptive effect of changes to R&D expenditure, except where this effect concerns small firms in which investors regard R&D volatility as a governance mechanism that controls spending on R&D projects.

We provide empirical evidence of the impact of R&D expenditure volatility on stock return by testing two hypotheses, but acknowledge that the R&D expenditure volatility-return relation is complex and may be driven by other factors. Such factors include whether the R&D undertaken by a firm is long- or short-term, the skill set required for R&D is specialized, and whether the R&D of a firm is transferred across countries. Future research on the impact of R&D expenditure volatility on stock return may address these complexities when richer datasets become available.

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Appendix A

See

Table A1
Sample selection process.

Process	Number of firms/firm-month observations
Firms listed in the US between 1980 and 2018	35,318 firms
Selecting firms with the ratios of R&D expense to Sales (R&D) that are less than unity and firms for which we can calculate standard deviations of R&D during the sample period	5,178 firms
Matching with monthly stock return data	886,601 firm-month observations (unbalanced sample)
Considering the main variable of interest R&D expenditure volatility	435,624 firm-month observations (unbalanced sample)

Table B1
Variable definitions.

Variable	Definition
Dependent Variable	
R	R is the monthly return calculated using the Return Index from Datastream
Independent Variables	
$RD_{Intensity}$	R&D intensity ($RD_{Intensity}$) is the ratio of R&D expense to sales
$RD_{Volatility}$	R&D expenditure volatility ($RD_{Volatility}$) is measured as the standard deviation of the residuals from the firm's R&D expenditure trend over the past five years divided by the five-year mean expenditure
KZ	The Kaplan Zingales (KZ) measures financial constraints and is defined as: $KZ = -1.001909 \times \frac{CashFlow}{K} + 0.2826389 \times Tobin'sQ + 3.139193 \times \frac{Debt}{TotalCapital} -39.3678 \times \frac{Dividends}{K} - 1.314759 \times \frac{Cash}{K}$ where the 10 (90) percentiles of financially constrained firms correspond to -14.4 (10.1)
Change	Change is a dummy variable with '1' denoting an increase in R&D expenditure
ROA	Return on assets (ROA) is net income divided by total assets at the end of year t-1.
ln(ME)	We use the log of market capitalization (ME) at the end of year t-1.
ln(BE/ME)	We use the log of the ratio of book value (BE) to market capitalization (ME), both at the end of year t-1
Momentum	Momentum is the return over the previous six-months (with one-month gap to the current month)
Industry	Industry variables are defined by Fama-French Siccodes5 definitions. These are: Consumer, Manufacturing, High Technology, Health, and Other
RD_{VolStd}	R&D expenditure volatility (RD_{VolStd}) is the three-year rolling standard deviation of a firm's R&D expenditure divided by its three-year mean
RD_{VolAbs}	R&D expenditure volatility (RD_{VolAbs}) is the absolute value of the proportionate change in R&D expense

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