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Strength of the association between R&D volatility and firm growth: The roles of corporate governance and tangible asset volatility☆

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ABSTRACT

We investigate the complementary roles of corporate governance; property, plant, and equipment (PPE) volatility; and intangible asset volatility in improving the returns from R&D volatility. With increasing R&D volatility, corporate governance can help align divergent goals and heterogeneous resources both internally and externally. PPE volatility or intangible asset volatility could help synchronize asset turnover with R&D volatility. The findings show that corporate governance and PPE volatility complement R&D volatility in improving a firm's performance.

1. Introduction

The literature on innovation views increasing R&D investments as beneficial to the long-term performance of a firm (Saunila & Ukko, 2014). Some recent works challenge this long-standing view by calling for proactive R&D management through greater R&D volatility (Mudambi & Swift, 2011; Mudambi & Swift, 2014; Swift, 2013). The volatility of R&D induces discipline by discontinuing less valuable R&D projects, increasing internal competition for the R&D budget, and allowing firms to change their foci from exploration to exploitation (Mudambi & Swift, 2014). Indeed, Mudambi and Swift (2014:127) conclude that "persistent, relatively routine changes in R&D expenditure are associated with higher firm growth."

In this paper, we investigate two research questions: (i) Can returns from R&D volatility be improved through better corporate governance? (ii) Does R&D volatility need to be complemented with volatility in property, plant, and equipment (PPE) or intangible asset investments? Both questions are salient in developing an understanding of how firms can further improve their returns from R&D volatility. Related to the first research question, we ask whether the quality of corporate governance could improve the returns from R&D volatility. Board members fulfilling both monitoring and resource provision roles could complement both internal and external resource realignments that result from R&D volatility. Related to the second research question, volatility in R&D investments must also be accompanied by a corresponding volatility in assets. As such, we posit that tangible and intangible asset volatilities could also complement the association between R&D volatility and a firm's performance.

Corporate governance can help improve the returns from R&D volatility for the following reasons. First, corporate governance allows for a smoother internal alignment of goals and resources in managing the effects of R&D volatility. Second, changing R&D volatility also means ensuring the availability of resources to meet varying R&D investments. While corporate governance helps improve internal resource stocks for investments (Zahra & Pearce, 1989), it also plays a critical boundary spanning role in managing relationships in the capital markets (Healy & Palepu, 2001). Third, corporate governance plays a pivotal role in innovation and technological change by priming efforts toward punctuated equilibrium (Mudambi & Swift, 2011) and can help manage competing innovation goals (Mudambi & Swift, 2014), both of which are outcomes related to R&D volatility.

PPE volatility can help improve the returns from R&D volatility. The products that result from R&D volatility might require retooling to manage costs, adapt quality, and tailor delivery criteria (Almeida & Campello, 2007). Lower PPE volatility could constrain the gains from R&D volatility as operations might not have the requisite

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complementary resources to meet the production needs of new products. The innovation that results from R&D volatility might also require firms to proactively manage their intangible assets, such as brand equity, goodwill, and intellectual property (Villalonga, 2004). Complementing R&D volatility with intangible asset volatility could further improve performance.

This paper's findings make the following contributions to the literature. First, the paper complements the literature on R&D volatility because we explain how firms can manage R&D volatility to improve their performance. Second, the paper highlights the salient role of corporate governance in facilitating growth by increasing R&D volatility. Third, we find that PPE volatility is an important complement to R&D volatility. This finding indicates that firms that aim to leverage R&D volatility could increase PPE volatility in tandem. Overall, our research contributes toward explaining how firms can improve the returns from R&D volatility. Managing R&D volatility is important as it may be a double-edged sword, and by providing a more comprehensive picture of moderators that enhance the returns from R&D volatility, we aim to complement the research on R&D volatility in the accounting and management literature.

We organize the paper as follows. We start by reviewing the relevant literature on R&D volatility. We then propose our moderation hypotheses for corporate governance, PPE volatility, and intangible asset volatility. Following this, we introduce our model and discuss our data and methods. We then present our results. We close with the discussion of theoretical and managerial implications of our findings, along with the limitations of our study and provide directions for future research.

2. Enablers of R&D volatility and performance relationship

R&D investments are associated with sales, profitability, and employment growth, but studies have also showed that this association is also contingent on industry, country, and period effects (Brynjolfsson & Yang, 1996). While Coad and Rao (2008) find that the association between growth and innovation is industry-specific, they also find that growth is generally related to innovation. Studies with samples from the US (Hall, 1987), Italy (Del Monte & Papagni, 2003), UK (Geroski & Machin, 1992), European countries (García-Manjón & Romero-Merino, 2012), and Japan (Yasuda, 2005) find a positive association between R&D related innovation and growth.

The proposition of R&D volatility is counter to the generally accepted idea of increasing R&D investments. Mudambi and Swift (2011: 431) define R&D volatility as "an indication that the firm is pursuing both exploration and exploitation; however, successful firms pursue these dissimilar processes sequentially over time," and R&D volatility is "positively related to firm growth." The volatility in R&D expenditure allows firms to overcome bureaucratic inertia to motivate R&D scientists who are difficult to monitor due to high information asymmetry (Mudambi & Swift, 2011). This volatility is also central to inducing the necessary discipline in innovation efforts by discontinuing projects, limiting slack available for R&D activities, and revitalizing R&D efforts (Mudambi & Swift, 2011). Continuing from Mudambi and Swift (2011), we use a firm's performance as the outcome variable.

Stronger corporate governance could be salient to improving the returns from R&D volatility for the following reasons. First, strong corporate governance ensures that the firm upholds the shareholders' interests. The monitoring, in turn, increases the pressure on managers to be proactive in meeting earnings expectations (Cheng, 2004; Chung, Wright, & Kedia, 2003). Mudambi and Swift (2011) propose that R&D investment volatility sequentially induces exploration and exploitation efforts to improve performance. Indeed, stronger corporate governance could increase the pressure to maximize value under increasing R&D volatility.

Second, R&D investments have uncertain returns, and scientists that pursue innovation focus on secrecy and primacy that might not fully help firms improve the efficiency of R&D (Mudambi & Swift, 2011). Boards allow firms to manage these competing foci in investments (Adams, Hermalin, & Weisbach, 2010). Therefore, stronger corporate governance could help manage the search scope of innovation under increasing R&D volatility. Monitoring helps acquire information about innovation activities and further helps incentivize managers to improve the returns from R&D volatility.

Third, under varying R&D expenditures, stronger corporate governance could improve internal capital allocation (Heidenberger, Schillinger, & Stummer, 2003) which further increases managerial discipline. The better budgeting from corporate governance (Dalziel, Gentry, & Bowerman, 2011; Osma, 2008) causes less valuable R&D projects to be discontinued and primes the pursuit of newer projects. Corporate governance reduces "real earnings manipulation," which refers to the "purposeful intervention in the external financial reporting process with the intent of obtaining some personal gain" (Schipper, 1989: 92). The resulting budgetary discipline helps allocate managerial attention toward viable innovation projects that improve performance. Although R&D volatility is generally beneficial, managers can take a short-term view and cut R&D expenditures to artificially increase R&D volatility. However, effective corporate governance reduces such myopic investment behavior (Bushee, 1998; Stein, 1989), and aligns managers' interests toward leveraging R&D volatility to improve long-term performance.

Fourth, corporate governance plays an important role in varying R&D investments (Driver & Guedes, 2012). Good governance reduces information asymmetry and increases the supply of funds when the returns from R&D increase that result in increasing R&D investment. Conversely, as the returns for the per unit cost of R&D funds decline, poor corporate governance reduces the supply of R&D funds. We posit that corporate governance better induces these oscillations because the board plays an important role in allocating investments. The proposed hypothesis is motivated by the question—who governs R&D volatility?:

H1. The relation between R&D volatility and a firm's growth is stronger with a higher level of corporate governance.

2.1. PPE volatility and R&D volatility

The theory behind PPE volatility has a basis in the concept of temporal orientation in asset investments (Souder & Bromiley, 2012). Similar to R&D volatility, PPE volatility induces the changes in the temporal orientations of tangible asset investments. Managers must consider both short-term and long-term operational needs and maintain a flexible temporal orientation to meet changing production needs that result from R&D volatility. They can do so by maintaining operating assets with varying time horizons. Complementing PPE variability is desirable, because uncertainty in R&D returns is three times higher than that of capital expenditures (Kothari, Laguerre, & Leone, 2002). As such, complementing the gains from R&D with varying capital expenditures could further improve performance. The mismatch between R&D volatility and PPE volatility could lead to lower gains from R&D volatility as the resource profiles of these two types of investments might not be fully compatible. Higher R&D and PPE volatilities could help fill strategic gaps that would improve performance. The reasoning behind R&D volatility is the renewal of knowledge, whereas the reasoning behind PPE volatility is that the firms have a commitment to reducing the erosion of tangible assets.

PPE volatility helps upgrade the operational infrastructure to further improve the gains from R&D volatility. Despite higher R&D volatility, lower PPE volatility could limit the operational renewal of the capabilities that the firm needs to manage its materials, manufacturing, planning, and supply chain. Higher PPE volatility enhances the knowledge from R&D and the operations' ability to meet quality, cost, and reliability standards. Lower PPE volatility also reflects lower manufacturing flexibility because firms do not retire operational assets

Table 1
Variable operationalization.

Variable	Operationalization	Data source
Firm growth	$(Sales_{i,t}/Sales_{i,t-1}) - 1$	Worldscope
Tobin's Q	(Market Value$_{i,t}$ + Total Liabilities$_{i,t}$)/Total Liabilities and Shareholders' Equity$_{i,t}$	Worldscope
ROA	Net Income$_{i,t}$/Total Assets$_{i,t}$	Worldscope
Firm size	Total Assets$_{i,t}$	Worldscope
Altman's Z	$1.2 * Z_1 + 1.4 * Z_2 + 3.3 * Z_3 + 0.6 * Z_4 + 0.999 * Z_5$, where Z_1 is Working Capital$_{i,t}$ to Total Assets$_{i,t}$, Z_2 is Retained Earnings$_{i,t}$ to Total Assets$_{i,t}$, Z_3 is Operating Income$_{i,t}$ to Total Assets$_{i,t}$, Z_4 is Market Value$_{i,t}$ to Total Liabilities$_{i,t}$, and Z_5 is Sales$_{i,t}$ to Total Assets$_{i,t}$	Worldscope
Earnings per share	Net Income$_{i,t}$/Number of Shares$_{i,t}$	Worldscope
Firm debt	Ln (Total Debt$_{i,t}$/Total Assets$_{i,t}$ + 1)	Worldscope
Industry concentration	Herfindahl–Hirschman Index = $\Sigma_{i=1}^{N} s_{i,t}^{2}$, where s_i is the market share of firm i, and N is the number of firms in the 2-digit SIC code for each year t	Worldscope
Corporate governance (CG) Index	$\Sigma_{k=1}^{6} CGd_{k,i,t}$, where CGd are dummy variables for a set of six different corporate governance characteristics, namely, board size < 12 (CGd_1), at least 50% of non-executive directors (CGd_2), > 50% of directors are independent (CGd_3), > 20% of bonus component in total compensation (CGd_4), > 30% of stock and options component in total compensation ($CGd5$), and the CEO and chair of board are not the same person (CGd_6).	BoardEx
Property, plant & equipment (PPE) volatility	$PPE_{i,t}/PPEM_{i,t}$, where $PPE_{i,t}$ is the standard deviation of the errors of the trend model of Property, Plant & Equipment, and $PPEM_{i,t}$ is mean Property, Plant & Equipment for the estimation period of the trend model (five-year rolling windows)	Worldscope
Intangible asset (IA) volatility	$IA_{i,t}/IAM_{i,t}$, where $IA_{i,t}$ is the standard deviation of the errors of the trend model of Intangible Assets, and $IAM_{i,t}$ is mean Intangible Assets for the estimation period of the trend model (five-year rolling windows)	Worldscope
R&D volatility	$\frac{S_i}{x_i}$, where S_i is the standard deviation of residuals from regression R & $D_{it} = \alpha_{0i} + \beta_{1i}t + \varepsilon_i$ from t to $t-4$, and x_i is firm i's mean R&D expenditure over the 5-year rolling windows	Worldscope

despite the increasing R&D volatility. Against this background, the second hypothesis is:

H2. The relation between R&D volatility and a firm's growth is stronger with a higher level of PPE volatility.

2.2. Intangible asset volatility and R&D volatility

Itami (1987: 1) states that "…intangible assets, such as a particular technology, accumulated consumer information, brand name, reputation and corporate culture, are invaluable to the firm's competitive power. In fact, these invisible assets are often the only real source of competitive edge that can be sustained over time." Firms that are able to proactively revitalize their stock of intangible assets could further improve the gains from R&D volatility. Examples of intangible assets on a firm's balance sheet include the value of the knowledge capital from patents, trademarks, and logos; brand value; and customer goodwill (Hall, 1992; Villalonga, 2004). Firms have to expense and revalue intangible assets every year; therefore, firms proactively manage intangible assets (Powell, 2003).

According to the knowledge-based view of the firm, the volatility of intangible assets could, according to Dierickx and Cool (1989), reduce the liabilities of time compression diseconomies, because the routines to renew intangibles allow for better asset stocks. By managing intangible asset volatility with R&D volatility, firms can improve resource management across levels. The R&D expenditures and intangible asset values in flux create unique possibilities for interconnectedness in intangible assets and increase causal ambiguity (Knott, Bryce, & Posen, 2003; Kothari et al., 2002; Pike, Roos, & Marr, 2005). The tacit, complex, and complementary nature of intangible resources are a source of competitive advantage; however, if a firm fails to renew its stock of intangible assets, threat-rigidity and possible obsolescence could result (cf. Galbreath & Galvin, 2006).

While intangible resources are stickier than tangible resources (Ghemawat, EI, & Costa, 1993), both exploratory and exploitative innovations from R&D volatility erode architectural knowledge (Henderson & Clark, 1990). Lower volatility in intangible assets could result in core rigidities (Leonard-Barton, 1992) that result in the reduction in the efficacy of gains from R&D volatility. Examples of these consequences range from firms that produce hard-disk drives (Christensen, 1993) to firms that produce film photography (Lucas & Goh, 2009). In these cases, the firms' stocks of intangible assets faced significant declines.

R&D volatility and intangible asset volatility can thus be complementary in improving a firm's performance. Hence, to appropriate gains from R&D volatility, renewing intangible assets could be essential. Renewing intangible assets such as human resources, brand value, and processes could complement the gains from R&D volatility. This leads to the third hypothesis:

H3. The relation between R&D volatility and a firm's growth is stronger with a higher level of intangible asset volatility.

3. Research methods

The sample in this paper comprises all nonfinancial firms listed on the London Stock Exchange for the period from 2000 to 2013. The financial data for the firms comes from Worldscope, and the corporate governance data comes from BoardEx. We use three filters: to calculate the volatility measures we require at least five continuous firm-year observations; at least ten firms must be present in the two-digit industry codes for each year; and we drop any observations with negative sales. The final sample, after merging both financial and corporate governance databases and case-wise deletions, comprises 2511 firm-year observations that are reduced to 1590 firm-year observations from 325 publicly traded firms when using the lag values of the variables in the regression model. All continuous variables are winsorized at 1% (top and bottom) to minimize the effect of outliers. Table 1 lists the data sources and the operationalization of each variable.

3.1. Dependent variable – firm growth

Growth is the primary goal of publicly traded firms and is also a proximal outcome of proactively managed R&D expenditures (Coad & Rao, 2010; Klette & Griliches, 2000). Similar to Mudambi and Swift (2011), we also use sales growth as the outcome variable. The firms' growth is the annual percentage growth in sales from the previous year.

3.2. R&D volatility

The treatment of accounting R&D in the UK follows the SSAP 13. This guideline allows firms to write off their R&D expenses in the year they occur or to capitalize them in certain circumstances, such as when the reliable measurement of future benefits is possible. However, Nixon (1997) provides evidence that accountants in the UK prefer to expense R&D costs due to the uncertainty in estimating future benefits, with a large majority of the accountants (81%) writing-off these expenses immediately. Following Kumar and Li (2016), we estimate the R&D volatility measure with the available information on a firm's annual R&D expense in the income statement.

Mudambi and Swift (2014) measure R&D volatility as unexpected and extreme changes in R&D in a GARCH specification over a ten-year window. Although this approach is feasible in OLS-based tests where long-term R&D changes can be included in the regression as a variable, it bears disadvantages in a panel setting. Indeed, ten-year rolling windows for measuring R&D volatility might lead to lower statistical variance over a period of observation. More importantly, the effects of R&D decisions are less likely to persist over a long period of time.

Therefore, we rely on a simpler measure of R&D volatility, which Mudambi and Swift (2011) also propose. Further, we use the coefficient of variation, that is, the standard deviation of residuals in the trend of R&D expenditures over the past five years:

$$\text{R\&D Volatility} = \frac{S_i}{x_i}$$

where S_i is the standard deviation of the residuals from regression $R \& D_{it} = \alpha_{0i} + \beta_{1i}t + \varepsilon_i$ from t to $t-4$, and x_i is firm i's mean R&D expenditure over the five-year rolling windows.

3.3. Corporate governance index

In this paper, we use six indicators to construct a corporate governance index that is a replica of the one in Driver and Guedes (2012). The firms have significant heterogeneity in structures, processes, and the management of corporate governance; they also have varying disclosure preferences beyond basic reporting requirements. Using the approach in Gompers, Ishii, and Metrick (2003) as a basis, Driver and Guedes's (2012) approach comprises structures and procedures in governance practices and executive compensation practices.

Effective boards are generally smaller, do not have the CEO as the chairman, and can carry out their governance duties better when they are independent of significant executive influence. The index includes four board-related measures and two executive compensation-related measures. Table 2 presents the details of each indicator and each cutoff. The basis for the critical values for the measure comes from Driver and Guedes (2012). The corporate governance index is the sum of the six indicators.

3.4. PPE volatility and intangible asset volatility

The operationalization of PPE volatility and intangible asset volatility is similar to that of R&D volatility.

3.5. Control variables

We control for Tobin's Q and return on assets (ROA). Although R&D volatility most certainly influences Tobin's Q, the growth prospects are also based on complementary capabilities that are subsumed in Tobin's Q. To reduce such omitted variable bias from these effects, we include Tobin's Q as a control.

To control for the internal efficiency of a firm, we include ROA. Because higher ROA requires well-honed routines, unobservables of the ROA could affect both the PPE volatility and the intangible volatility. We include a firm's size as the operationalized total assets because larger firms are more likely to have greater entrenchment of R&D routines and consequently lower R&D volatility (Cohen, Levin, & Mowery, 1987).

Distance from bankruptcy is represented by Altman's Z (Altman, 1968). Altman's Z is related to omitted variable bias. A lower Z switches focus from growth to survival and could influence the nature of asset investments. We also control for earnings per share as it influences the level of asset investments and the pursuit of growth opportunities (Bushee, 1998). Firms with lower earnings per share in the previous period pursue more growth strategies. Because the debt-to-asset ratio influence R&D investments, this measure is also a control. Further, industry concentration represents the level of industry competition.

Table 2 also presents the sample descriptions.

4. Empirical analysis and results

We use the Arellano-Bond robust GMM estimator to test the hypotheses. Table 3 presents the results. H1 proposes that with increasing R&D volatility, a higher level of corporate governance will have a positive association with firm growth. As Column 2 of Table 3 shows that the interaction between the corporate governance index and R&D volatility has a statistically significant coefficient of 0.0735 ($p < 0.05$), H1 is supported. Fig. 1(a) shows that, under increasing R&D volatility, a firm's performance improves with a higher corporate governance index but declines with a lower index.

H2 proposes that PPE volatility strengthens the R&D volatility and performance association. Column 3 of Table 3 shows a statistically significant estimate of 0.4547 ($p < 0.001$) on the interaction between PPE volatility and R&D, which supports H2. Fig. 1(b) shows that with increasing R&D volatility, a higher level of PPE volatility improves performance. The estimates support the assertion that PPE volatility strengthens the association between R&D volatility and sales growth.

H3 proposes that intangible asset volatility strengthens the R&D volatility and performance association. However, this hypothesis is not supported (Table 3, column 4: $\beta = 0.1032$, $p > 0.10$). Finally, in the full model (Table 3, column 5), we find support for H1 and H2 but not for H3.

4.1. Robustness checks

For robustness, we use the return on assets (ROA) as an alternative outcome measure. Column 6 of Table 3 has the results for this specification. They are consistent with the main analysis and support H1 and H2 but not H3.

We also test the extent to which the individual governance items have different effects on the relation between a firm's R&D volatility and sales growth. Table 4 shows that the effects of individual governance items are consistent with the main effects for items 1 (board has fewer than 12 members), 2 (at least 50% of the board members are non-executive directors), and 5 (stock and options are > 30% of the compensation). However, for item 6 (CEO is not the board chair), the table shows that the effect is in the opposite direction at a marginal significance level. The findings indicate that smaller boards with a majority of independent directors and significant executive compensation in stocks and stock options improve the returns from R&D volatility.

5. Discussion and conclusion

This study explores the moderation effects of corporate governance and tangible and intangible asset volatilities in improving the returns from R&D volatility. The empirical results show that by increasing R&D volatility, firms with more effective corporate governance realize higher performance. Furthermore, the volatility of PPE improves the returns from R&D volatility, but the intangible asset volatility does not influence this association.

The literature shows that corporate governance plays an important

Table 2
Mean, SD, and correlations.

		Mean	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11
1	Firm growth	0.091	0.294	− 0.548	1.585	1										
2	Tobin Q	2.085	1.821	0.516	12.372	0.032	1									
3	ROA	− 0.048	0.263	− 1.418	0.277	0.066***	− 0.331***	1								
4	Firm size	1,690,000	6,100,000	1143	42,200,000	− 0.014	− 0.050**	0.118***	1							
5	Altman's Z	3.413	9.158	− 21.507	60.68	0.156***	0.379***	0.103***	− 0.035*	1						
6	Earnings per share	0.056	0.525	− 3.243	1.814	− 0.008	− 0.042**	0.459***	0.312***	0.054***	1					
7	Firm debt	0.137	0.147	0	0.835	− 0.076***	0.043**	− 0.097***	0.127***	− 0.350***	− 0.027	1				
8	Industry concentration	0.744	0.178	0.434	0.996	0.019	0.091***	− 0.049**	0.251***	0.124***	0.063***	0.049**	1			
9	CG index	3.324	0.887	1	5	0.049**	− 0.011	0.231***	0.032	0.013	0.159***	0.082***	0.055***	1		
10	PPE volatility	0.188	0.186	0.012	1.029	0.136***	0.174***	− 0.355***	− 0.146***	− 0.006	− 0.241***	− 0.050**	− 0.039**	− 0.160***	1	
11	IA volatility	0.367	0.378	0	1.581	0.084***	0.094***	− 0.210***	− 0.094***	− 0.083***	− 0.147***	− 0.03	− 0.124***	− 0.131***	0.293***	1
12	R&D volatility	0.357	0.424	0.021	2.092	0.085***	− 0.025	− 0.119***	− 0.111***	− 0.049**	− 0.137***	0.004	− 0.141***	− 0.149***	0.268***	0.125***

Notes
N = 1590 firm-year observations from year 2000 to 2013.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$ (two-tailed).

Table 3
Arellano–Bond robust GMM estimates.

	DV = firm growth					DV = ROA
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Controls	Moderation effect of corporate governance	Moderation effect of PPE volatility	Moderation effect of IA volatility	Full model	Full model
Lag firm growth	− 0.0046 (− 0.1643)	− 0.0039 (− 0.1386)	− 0.0152 (− 0.5434)	− 0.0146 (− 0.5190)	− 0.0209 (− 0.7489)	0.2067*** (7.3663)
Tobin's Q	− 0.0012 (− 0.1232)	− 0.0029 (− 0.2977)	− 0.0008 (− 0.0860)	0.0002 (0.0201)	0.0005 (0.0536)	− 0.0323*** (− 7.0964)
ROA	− 0.0462 (− 0.7630)	− 0.0627 (− 1.0289)	− 0.0632 (− 1.0482)	− 0.0477 (− 0.7895)	− 0.0698 (− 1.1553)	− 0.0360** (− 2.4745)
Firm size	0.0000 (0.6782)	0.0000 (0.6211)	0.0000 (0.6159)	0.0000 (0.5917)	0.0000 (0.5442)	− 0.0000 (− 0.8872)
Altman's Z	0.0028 (1.3744)	0.0030 (1.4859)	0.0028 (1.4192)	0.0026 (1.2728)	0.0028 (1.4051)	0.0105*** (11.1327)
Earnings per share	− 0.0052 (− 0.1592)	− 0.0052 (− 0.1595)	− 0.0012 (− 0.0379)	− 0.0076 (− 0.2337)	0.0012 (0.0358)	0.2627*** (18.2640)
Firm debt	0.1175 (0.8787)	0.1076 (0.8063)	0.0884 (0.6680)	0.0894 (0.6697)	0.0643 (0.4857)	− 0.1776*** (− 2.6638)
Industry concentration	− 0.3997 (− 1.5637)	− 0.3848 (− 1.5074)	− 0.3312 (− 1.3040)	− 0.3544 (− 1.3863)	− 0.3129 (− 1.2312)	− 0.0019 (− 0.0144)
PPE volatility			0.0478 (0.4574)		0.0214 (0.1996)	− 0.0491 (− 0.9245)
R&D volatility		− 0.1952 (− 1.6327)	− 0.0538 (− 0.9747)	0.0048 (0.0930)	− 0.2785** (− 2.2376)	− 0.2754*** (− 4.4760)
CG index		− 0.0008 (− 0.0525)	0.0153 (1.2623)	0.0168 (1.3791)	− 0.0021 (− 0.1427)	− 0.0034 (− 0.4616)
PPE volatility × R&D volatility			0.4547*** (2.5870)		0.4478** (2.3905)	0.2933*** (3.1405)
CG index × R&D volatility		0.0735** (2.1251)			0.0712** (2.0809)	0.0645*** (3.8131)
IA volatility				0.0439 (0.9050)	0.0523 (1.0514)	− 0.0308 (− 1.2367)
IA volatility × R&D volatility				0.1032 (1.0728)	0.0033 (0.0326)	0.0092 (0.1781)
Constant	0.3439* (1.7999)	0.3272* (1.6465)	0.2237 (1.1352)	0.2315 (1.1650)	0.2580 (1.2888)	0.0508 (0.4923)
Observations	1590	1590	1590	1590	1590	1590
Number of id	325	325	325	325	325	325

Notes
z-statistics are in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

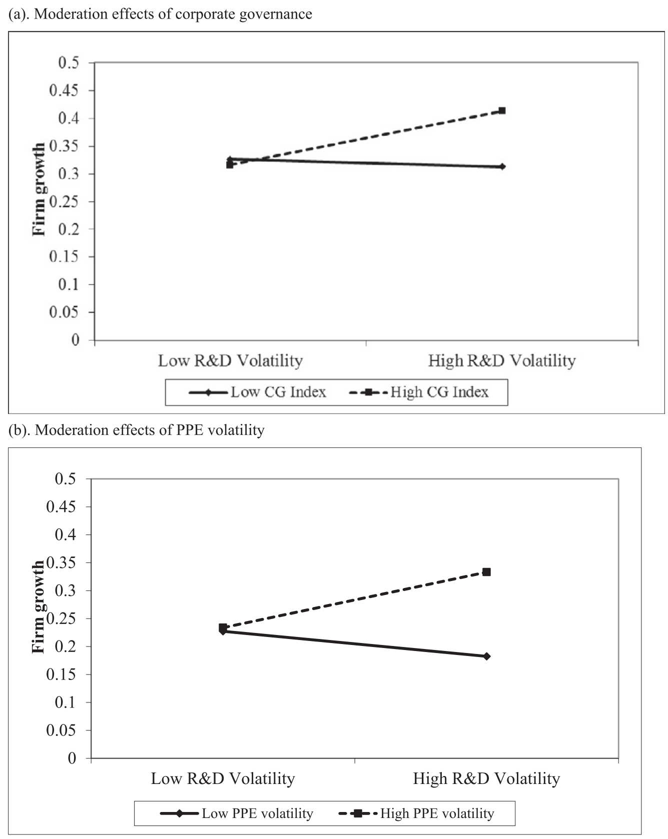

Fig. 1. Interaction graphs for firm growth.

role in influencing investments and facilitating access to resources and information (Baysinger, Kosnik, & Turk, 1991; Kose, Litov, & Yeung, 2008; Malmendier & Tate, 2005). Underscoring the important role of R&D volatility in managing innovation projects, corporate governance plays a salient role in helping monitor and manage activities related to R&D volatility. According to Table 4, the independence of the board, a smaller board, and executive compensation that promotes risk taking are salient in supporting this relation.

As for the second hypothesis, volatility in PPE assets is also salient. A variety of studies focus on the longevity, youth, or stability of PPE (Souder & Bromiley, 2012). The changing stock and flow of PPE complements the returns from R&D volatility. The R&D volatility results in the dynamic accumulation of knowledge assets through stocks "of available [tangible or intangible] factors that are owned or controlled by a firm" (Amit & Schoemaker, 1993: 33), and the flow of assets to maintain a bundle of competitive resources. The flow of new assets is the rate of replication of existing assets. Low PPE volatility could mean that the firm must leverage gains from the R&D volatility by using older tangible assets.

The finding regarding the lack of significance for volatility in intangible assets is equally important. The lack of support indicates that the historically path dependent and sticky intangible assets might not be in synchronization with the R&D volatility to improves performance. Socially complex, intangible resources built over years might be difficult to adapt in the short-term to complement the returns from R&D volatility. Volatility in investments is a potential area of interest that could contribute to the resource accumulation (Dierickx & Cool, 1989) and orchestration (Sirmon, Hitt, Ireland, & Gilbert, 2011) literature.

The present study is not without limitations. First, we use a sample of publicly traded firms in the UK, and the findings cannot be generalized to private firms or non-UK firms. Second, we use archival data that is considered reliable and that prior studies of R&D volatility have used. However, similar to other works, we are unable to ascertain the rich micro-dynamics between R&D volatility and PPE volatility. Future studies using a qualitative approach could further explore such dynamics. Third, meetings and proceedings of corporate governance activities are confidential, and as such, we cannot assess the behavioral role of boards in managing R&D volatility.

Mudambi and Swift (2011: 439) propose that "proactive management of R&D expenditure introduces frequent and substantial disruptions." Likewise, the current framework shows that disruptions in PPE investments could complement R&D volatility. Corporate governance could be salient in managing diverging goals and heterogeneous resources that emerge under increasing R&D volatility. Corporate governance can also fill the boundary spanning role by improving access to capital and resources for managers (Letza, Sun, & Kirkbride, 2004; Rao & Sivakumar, 1999) and in helping manage diverging goals under increasing R&D volatility.

Table 4
Individual corporate governance items: regressions for DV = firm growth.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Moderator effect of R&D volatility in CGX1	Moderator effect of R&D volatility in CGX2	Moderator effect of R&D volatility in CGX3	Moderator effect of R&D volatility in CGX4	Moderator effect of R&D volatility in CGX5	Moderator effect of R&D volatility in CGX6
Lag firm growth	− 0.0055 (− 0.1965)	0.0004 (0.0151)	− 0.0046 (− 0.1623)	− 0.0087 (− 0.3103)	− 0.0090 (− 0.3247)	− 0.0045 (− 0.1599)
Tobins Q	− 0.0007 (− 0.0684)	− 0.0012 (− 0.1280)	− 0.0011 (− 0.1160)	− 0.0037 (− 0.3830)	− 0.0008 (− 0.0872)	− 0.0009 (− 0.0913)
ROA	− 0.0376 (− 0.6234)	− 0.0474 (− 0.7811)	− 0.0453 (− 0.7478)	− 0.0602 (− 0.9851)	− 0.0528 (− 0.8800)	− 0.0472 (− 0.7794)
Firm size	0.0000 (0.8007)	0.0000 (0.5931)	0.0000 (0.6482)	0.0000 (0.7495)	0.0000 (0.7507)	0.0000 (0.6596)
Altman's Z	0.0026 (1.2914)	0.0028 (1.4028)	0.0028 (1.3616)	0.0032 (1.5723)	0.0029 (1.4605)	0.0027 (1.3179)
Firm profitability	− 0.0046 (− 0.1413)	− 0.0064 (− 0.1959)	− 0.0064 (− 0.1971)	− 0.0088 (− 0.2713)	− 0.0052 (− 0.1601)	− 0.0060 (− 0.1848)
Firm debt	0.1131 (0.8492)	0.1195 (0.8914)	0.1154 (0.8625)	0.1345 (1.0094)	0.1094 (0.8268)	0.1061 (0.7928)
Industry concentration	− 0.3928 (− 1.5439)	− 0.4182 (− 1.6256)	− 0.4019 (− 1.5687)	− 0.4399* (− 1.7304)	− 0.4091 (− 1.6188)	− 0.3986 (− 1.5600)
R&D volatility	− 0.3045*** (− 2.7299)	− 0.1757 (− 1.5853)	0.0372 (0.4412)	0.0608 (1.2037)	− 0.0659 (− 1.3531)	0.1647* (1.9110)
CG_X	0.0011 (0.1032)	− 0.1923 (− 1.3066)	0.0382 (0.3084)	0.2086*** (2.5918)	− 0.0795* (− 1.7646)	0.0709 (1.1944)
R&D volatility × CG_X	0.0513*** (3.2581)	0.4547** (2.0583)	− 0.0137 (− 0.0749)	− 0.1725 (− 1.1031)	0.4125*** (4.5928)	− 0.1675* (− 1.8332)
Constant	0.3189 (1.5572)	0.4309** (2.0674)	0.3197 (1.6309)	0.3321* (1.7423)	0.3648* (1.9247)	0.2758 (1.3856)
Observations	1590	1590	1590	1590	1590	1590
Number of id	325	325	325	325	325	325

Notes
z-statistics are in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

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