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Firm Characteristics, Uncertainty and Research and Development (R&D) Investment: The Role of Size and Innovation Capacity

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Abstract: This paper examines the investment behavior of research and development (R&D) under uncertainty. We assume that there is a heterogeneous effect of uncertainty on R&D investment depending on characteristics of a firm. According to the results, the size and the innovation capacity of a firm are found to positively moderate the negative relationship between uncertainty and R&D investment. When the entire sample is divided into large and small-and-medium enterprises and high innovation capacity and low innovation capacity, it is found that the innovation capacity of a firm is a more crucial factor in positively moderating the negative relationship between R&D investment and uncertainty than the size of a firm. These findings provide policy implications, particularly for small-and-medium enterprises (SMEs), to promote R&D activities.

Keywords: R& D investment; firm size; firm innovation capacity; dynamic panel data analysis

1. Introduction

As the rapid technological advances, globalization and the convergence of industries have intensified the competition among firms, the duration of a competitive advantage of affirm has become gradually shorter. The average life span of the S&P (Standard & Poor's) 500 companies by 1928 was about 65 years, but it became 15 years by 2000 [1]. Therefore, to achieve sustainable growth, a firm should differentiate themselves from others by making a new product or process through constant innovation activities. Naturally, the literature on research and development (R&D) investment, which is an input of corporate innovation activities, is in the spotlight in both academia and policy makers.

Despite the importance of R&D investment, few companies continue to invest in R&D, except for a few large companies. The reason why continuous R&D investment cannot be achieved in most companies is due to the lack of funds to invest in R&D activities in the enterprise. The uncertainties that are inherent in the process and the results of R&D increase the information asymmetry between funders and investors in R&D activities [2]. Since information asymmetry requires funders to have high returns on R&D investments, the external funding costs for R&D investments will be much higher than the internal funding costs. Therefore, companies that do not have enough internal funds, especially small ones, have difficulties in making sustained R&D investments [3].

Besides financial constraint, the uncertainty that is inherent in R&D activities can also be a deterrent to continued R&D investment. According to real option theory, when there is uncertainty about the outcome of an investment, the company has the incentive to make a better decision by acquiring new information while delaying the decision [4,5]. Since the greater the uncertainty, the greater the value of the managerial flexibility, an increase in uncertainty is a factor that hinders investment. Predictions of real options theory on the relationship between investment and uncertainty are supported by many empirical studies. Koetse et al. [6], which conducted a meta-analysis of the relationship between investment and uncertainty, found that uncertainty has a negative effect on investment overall. Kellogg [7] analyzed the optimal investment decisions of firms in response to changes in future oil price uncertainty using oil drilling data in Texas, USA. According to the results, firms are less likely to invest if the uncertainty increases, as predicted by real option theory, and if a firm behaves differently from the real option theory, then it will be economically disadvantageous. Kang et al. [8] further confirmed the firm-level uncertainty and the economic policy uncertainty at macro level have a negative synergy in impending the investment of an enterprise. In other words, economic policy uncertainty is a factor that further enhances the negative impact of uncertainty on corporate investment.

However, recent studies suggest that a negative relationship between uncertainty and investment may not hold for R&D investment, which is of interest to this study. According to the Vo and Le [9], firms increase R&D investment when they faced with high idiosyncratic return volatility. In particular, it has been confirmed that uncertainty increases the positive effect of uncertainty on R&D investment when a firm belongs to the competitive industry or has low market dominance. Ross et al. [10] also identified a positive relationship between uncertainty and R&D investment. This relationship is mediated by factors affecting the learning effects that are created by R&D investments, such as corporate human capital and product lineup and industry maturity.

Extending the previous studies on the relationship between uncertainty and R&D investment, this study attempts to analyze the existence of heterogeneity in the effect of uncertainty on R&D investment. Folta and O'Brien [11] argued that corporate investment decisions are determined as a conflict between the two options that are inherent in the investment opportunity. In general, if there is uncertainty, irreversibility, and discretion over investment, the investment opportunity can have two options: a deferral option and a growth option. Both two options have an option-like characteristic that their value are an increasing function of uncertainty. A growth option, however, refers to an option for opportunities that are created in the future through current investments, so it can only be retained by enforcing a given investment opportunity. Thus, a firm cannot have both deferral and growth options for a given investment opportunity at the same time. In other words, a firm can hold a deferral option through delaying investment or have a growth option through executing investment. Thus, the impact of uncertainty on a firm's investment decisions is determined by comparing the value of the growth option, which is the return earned through the investment, and the value of the deferral option, which is the cost that is lost through the investment. If the value of both two options is affected by the characteristics of a firm, in addition to the uncertainty, the characteristics of the firm ultimately determine the relationship between the uncertainty and the investment.

The characteristics of the firms to be considered in this study are firm size and innovation capacity, and this study ultimately examines how these characteristics moderate the relationship between uncertainty and R&D investment. In particular, in measuring the innovation capacity of a firm, this study uses the number of patents owned by a company. Since the output of innovation activities contributes to the accumulation of innovation capacity, the patent, which is an output of innovation activities, is good proxy for innovation capacity of a firm [12]. According to the theoretical discussions of this study, the growth option is more important than the deferral in determining the value of given R&D investment as the firm size and innovation capacity grow. Thus, the negative impact of uncertainty on R&D investment is likely to be reversed into positive impacts as firm size and innovation capacity increase. The results of this study support this empirically. In addition, the findings of the sub-sample analysis further confirm that the influence of innovation capacity is greater than that of firm size in determining the value of growth options that are inherent in R&D

investment. Since this study utilizes a dynamic panel model, so we tried to improve the efficiency of the estimator by adopting the system Generalized Methods of Moments (GMM) method.

The remainder of the study consists as follows. In Section 2, we try to derive the hypotheses to be examined in this study with reference to previous studies. Section 3 discusses the data, variables, and estimation methodologies that are used in this study. In Section 4, we perform regression analysis based on the discussion in Section 3 to verify the research hypotheses that is presented in Section 2. Finally, Section 5 presents the policy implications that are based on the results.

2. Literature Reviews

2.1. Uncertainty and R&D Investment: A Conflict between Deferral Options and Growth Options

In real option theory, it is argued that there is an option to defer investment when uncertainty in investment, irreversibility of investment costs, and the discretion of investment decision makers exist [4,5]. The deferral option creates value when the investment cost is irreversible and uncertainty increases, by deferring the investment opportunity, allowing for the investor to invest in a better future investment environment. Therefore, the greater the uncertainty, the greater the value of the option to defer investment. However, once a company makes investment decisions at some point, this option is no longer present. Therefore, the deferral option that is embedded in the investment opportunity serves as the opportunity cost of the investment opportunity. Uncertainty, therefore, is an impediment to investment by increasing the opportunity cost of the investment. The prediction of real option theory has been verified by empirical studies on the relationship between uncertainty and investment, and it has been confirmed that there is a negative relationship between uncertainty and investment in general, as is consistent with the theory [6,13,14].

However, some empirical studies examining the impact of uncertainty on investment confirm that there is a positive relationship between the two. Vo and Le [9] found that uncertainty increases a firm's R&D investment by using the measurement of uncertainty calculated by an idiosyncratic error of stock returns. In addition, the positive effect of uncertainty on R&D investment is intensified when the competition is fierce and a firm's market power is low. Ross, Fisch, and Varga [10] also shows that the increase in uncertainty stimulates R&D investment, and this relationship is positively moderated by factors that increase corporate learning capacity, such as human capital, scope of innovation activities of firms, and industry maturity. In these studies, the rationale for uncertainty to have a positive impact on R&D investment is the strategic growth option that is inherent in R&D investment. Strategic growth option is created when early investment can create a position where a company can better utilize future growth opportunities [11]. In other words, if a leading firm can have first-mover advantage [15], such as achieving technological superiority and building brand awareness, there are strategic growth options that are embedded in an investment opportunity. The value of strategic growth options is an increasing function of market uncertainty for the following reason. If market uncertainty is so high that future markets are likely to explode, retaining strategic growth options through early investment will provide a competitive advantage in leveraging the given market opportunities relative to other latecomers. On the contrary, if the uncertainty is resolved and the market fails to grow unexpectedly, the firm can limit the market's downside risk to the cost of early investment by giving up investment in growth opportunities.

When considering growth option in addition to deferral option, the effect of uncertainty on investment becomes complex. The uncertainty that is inherent in an investment opportunity increases both the value of growth option and the deferral option. However, while the deferral option disappears due to the execution of investments, the growth option is generated only through the execution of investments, so the two options are mutually exclusive. In other words, the deferral option is a (opportunity) cost factor of investment, while the growth option is the revenue factor of investment. Thus, uncertainty increases both the cost and the return of an investment, so the impact of uncertainty on the investment is ultimately determined by the trade-off between the two options. If the value of the growth option that is embedded in an investment opportunity is not so large, uncertainty will be a factor in delaying the investment, as the deferral option becomes more dominant in determining the value of the investment opportunity. Conversely, if the value of the growth option that is embedded in an investment opportunity is significant, uncertainty can be a factor in promoting investment, since the growth option become more dominant in determining the value of investment opportunity. From this point of view, it may not be surprising that most of the empirical studies showing that the uncertainty hinders investment have utilized facility investment as a dependent variable, while the majority of studies that confirm that uncertainty promotes investment have used R&D investment as a dependent variable. R&D investment tends to provide future investment opportunities for firms in general, as they have the purpose of developing products and services that do not exist in the market [16]. This suggests that the value of R&D investment is more dependent on the value of growth option than on deferral option [17].

2.2. Firm Characteristics, Uncertainty and R&D Investment

If the characteristics of a firm affect the value of the deferral option and the growth option that is involved in a given investment opportunity, then these characteristics determine the relationship between uncertainty and the investment activity of the firm. In this sub-section, we focus on the size and the innovation capability of a firm.

In relation to R&D investment, firms must make decisions under the total uncertainty of systematic and non-systemic factors [18]. Uncertainty due to systematic factors is naturally resolved by time, rather than being resolved by an action of a firm [19]. Therefore, it is difficult to expect that the characteristics of firms will affect the resolution of uncertainty due to systematic factors. Theoretically, the fact that the maximum value of the deferral option value is an irreversible cost of an investment suggests that firm characteristics, such as firm size and innovation capacity, are not likely to influence the value of the option. On the other hand, uncertainty due to non-systemic factors tends to be resolved as a result of certain actions of a firm [19]. When considering that R&D investment is a learning investment [20], we can look more specifically at the impact of firm characteristics on the value of deferral option. The value of the deferral option depends on the new information that is revealed through waiting. Therefore, if the information gained from waiting is not a new knowledge to the enterprise, the value of waiting is minimal. The value of deferral options is not significant for companies that are already at the forefront of the technological frontier since they do not have targets to imitate or refer to. Conversely, companies that are small in size and are lacking in innovation capacity may have a greater incentive to wait until technology uncertainty is reduced and through imitation strategy. This is consistent with the results of the previous study [21], which shows that the larger the firm size and innovation capacity, the more innovation is generated directly, and the smaller the firm size and innovation capacity, the more innovation is generated indirectly.

Next, the size and the innovation capacity of a firm has the following effects on the value of strategic growth options created by R&D investments. Generally, strategic growth options created by R&D investment refer to future commercialization opportunities of new products or new technologies through that. Therefore, it can be expected that the degree of competitive advantage of the firm relative to competitors at the time of commercialization determines the value of the strategic growth option of R&D investment [22]. In this respect, the value creation mechanism of strategic growth options through R&D investment can be explained in terms of Lieberman and Montgomery [15]'s first mover advantage. Boulding and Christen [23] argued that the emergence of a first mover advantage requires the presence of an isolating mechanism, such as technology leadership, lack of resources, and consumer switching costs, a strong market dominance, or a strong IPR (Intellectual Property Right) protection system. A subsequent study, Boulding and Christen [24], regarded the preemption of scarce resources and learning effects through early entry as a source of first-mover advantage. Therefore, it can be easily confirmed through previous studies that the size and innovation capacity of a firm have a positive effect in achieving the first mover advantage [25]. Other things being equal, the importance of strategic growth options is even more emphasized for large and innovative companies that are beneficial in creating a first mover advantage, which is the source of value of strategic growth options through R&D investment. In addition, as in the case of the deferral option, if the R&D investment is considered as a learning investment, the magnitude of the value of the strategic growth option is positively correlated with a firm's learning capacity [26]. In large enterprises, the proportion of skilled workers is generally high, and they contribute to the selection of perceived opportunities by linking product markets and labs in the learning process [27,28]. Learning is cumulative and path-dependent. From this point of view, it can be seen empirically that the learning rate of firms in the sectors that are already known is higher than the learning rate of new ones [29]. Therefore, it is highly possible that innovative companies that have already done a lot of innovation activities will have higher learning rates. Therefore, it is possible to predict that, as the size and innovation capacity of a firm increases, the value of the strategic growth option in the R&D investment increases.

To sum up, it can be inferred that the size and the innovation capacity of a firm determines the relationship between uncertainty and R&D investment, as follows. First, companies with smaller size and less innovative capacity are more likely to put more emphasis on the deferral option than strategic growth option in R&D investment, so uncertainty in these companies is likely to hinder R&D investment. On the other hand, firms with large size and high innovation capacity are more likely to put more stress on the strategic growth option than the deferral option in R&D investment, so uncertainty in these firms is likely to accelerate R&D investment. Therefore, this study examines the hypothesis that firms' size and innovation capacity moderate the relationship between uncertainty and R&D investment, as the following Figure 1.

Hypothesis 1. *The size of a firm has a positive moderating effect on the negative relationship between uncertainty and R&D investment.*

Hypothesis 2. *The innovation capacity of a firm has a positive moderating effect on the negative relationship between uncertainty and R&D investment.*

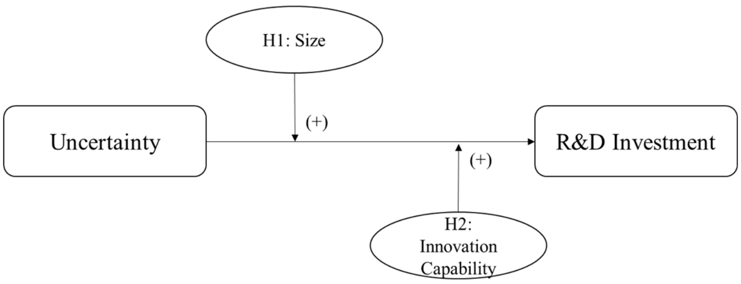

Figure 1. Research Framework.

3. Data and Methods

3.1. Data

The purpose of this study is to analyze the heterogeneous effects of uncertainty on R&D investment depending on the characteristics of a firm. To this end, this study seeks to utilize the "Corporate Activity Survey" that is provided by the Korea National Statistical Office. As a complete enumeration survey, the Corporate Activity Survey is aimed at surveying companies with more than 50 employees and 300 million won in capital. It provides a comprehensive overview of various business activities of a company (e.g., management performance, diversification, sequencing, e-business system, performance management system, etc.). The reason for choosing the Corporate Activity Survey rather than other databases is as follows. In general, studies attempting to identify the relationship between uncertainty and firms' investment activities have sampled listed companies to use stock returns data that are widely used to build uncertainty measures. However, the sample selection problem is likely to occur only when listed companies are used to test the heterogeneous effects of the uncertainty on R&D investment, which is one of the research questions that is to be addressed in this study. This is because most of the listed companies are larger than a certain size. Therefore, this study sought to avoid the above problems by choosing a Corporate Activity Survey that sampled as wide a range of companies as possible.

Specifically, this study uses sample data of Corporate Activity Survey from 2006 to 2014. Because of the time lag in the construction of the variables and the econometric models that are described below, the data used in the actual estimation are five years from 2010 to 2014. In addition, since it is necessary to create the proxy variable for uncertainty through estimating the equation, only the companies that are always present during the sample period are selected to construct the balanced panel data. Therefore, this study ultimately utilizes 30,420 observations consisting 6084 companies over five years.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.2. Variables

The variables to be used in this study can be divided into three types: dependent variable, explanatory variables, and control variables.

For the purpose of this study, the R&D intensity, which represents the amount of R&D investment relative to sales, is used as the dependent variable, as in previous studies. This normalization process contributes to the control of scale effect and dispersion effect in corporate R&D investment.

The main explanatory variable in this study is uncertainty related to corporate R&D investment decision. As pointed out as a major reason for hindering the activation of empirical studies on real option theory [30], it is very difficult to make a complete operational definition of uncertainty. Previous studies [14,31,32] have focused mainly on defining the uncertainty that is faced by firms through stock price volatility. However, this study is not able to measure uncertainty through stock price volatility because many SMEs, not listed companies, are included in the sample. Thus, this study seeks to measure the uncertainty faced by a firm in the following way, based on the fact that corporate R&D investment decision is ultimately the act of maximizing profits and that it is affected by firm-specific factors. According to Ghosal and Ye [33], first, a prediction model for profit of a firm is defined, as following Equation (1).

$$Z_t = \beta_0 + \beta_1 Z_{t-1} + \beta_2 Z_{t-2} + \varepsilon_t. \quad (1)$$

In Equation (1), the variable Z is not a simple profit but a ratio of profit to sales. Once the regression Equation (1) is estimated, the residuals of the prediction model can be derived as follows. Since residuals are an unstructured and unpredictable factor in determining the profit of a firm, it is appropriate to measure the uncertainty that is associated with a firm's profit margins.

$$\hat{\varepsilon}_t = Z_t - \left(\hat{\beta}_0 + \hat{\beta}_1 Z_{t-1} + \hat{\beta}_2 Z_{t-2}\right) \quad (2)$$

Since the residuals that are derived from Equation (2) have positive or negative values, it is squared to make them similar to the concept of variance that is the mathematical definition of uncertainty. Finally, the uncertainty that is faced by a firm i in year t is defined, as follows: $\sigma^2_{profit,it} = (\hat{\varepsilon}_{it})^2$.

In order to verify the moderating effects of firm size and innovation capacity on the impact of uncertainty on R&D investment, we define the firm size and the innovation capacity, as follows. First, the size of a firm is defined as logarithm of total assets of a firm. Second, the innovation capability of a firm can be represented by the number of patent which the firm has [34].

This study attempts to control other factors that are affecting dependent variables. The following control variables are confirmed with reference to the previous studies. First, R&D investment has a consistency because R&D investments has a high adjustment costs [35]. In other words, the R&D investment in period t is likely to be affected by the R&D investment in period $t - 1$. Therefore, this study uses the first-order lagged variable of the dependent variable, R&D investment intensity, as a control variable. In addition, corporate investment decisions are highly dependent on investment opportunities, and previous studies generally measure investment opportunities as Tobin's Q. However, since it is difficult to measure Tobin's Q in the limit of samples for the study, the past three year average sales growth rate as the proxy variable of the investment opportunity of the company [36]. In addition, since the capital structure of a firm affects the R&D investment in the previous study [37], the debt ratio of a firm is added as a control variable. Referring to Fazzari, Hubbard, Petersen, Blinder, and Poterba [3], which examined the effect of a financial constraint on investment decision, the cash flow of a firm is added as a control variable. Finally, the time dummies and the sectoral dummies are added to control the effects of macroeconomic non-observational factors and industry heterogeneity on corporate R&D investment. The sectoral dummies are based one first digit of Korean Standard Industry Classification (KSIC (It consists of five levels (five digits). First digit represents 'Section', second one represents 'Division', third one represents 'Group', fourth one represents 'Class', and fifth one represents 'Sub-class')).

Table 1 below briefly describes the definitions and measurement methods that are used in this study.

Table 1. Description of variables.

R&D Intensity (i,t)	Research and Development expenditure of the firm i including in-house, cooperation, and outsourcing for the period ending on t normalized by the sales for the period ending on t
Uncertainty (i,t)	The squared residuals derived from Equation (2) at the period ending on t for the firm i
Size (i,t)	Logarithm of the book value of assets for the firm i at the period ending on t
Innovation Capacity (i,t)	The number of patent owned by the firm i at the period ending on t
Cash flow (i,t)	Cash flow of the firm i during the period t divided by the beginning of the periods book value of total assets of the firm i where cash flow is defined as profit after tax plus depreciation and amortization plus R&D expense
Debt ratio (i,t)	The book value of debt for the firm i at the period ending on t divided by the beginning of the periods book value of total assets of the firm i
Investment Opportunity (i,t)	The average sales growth rate over the past three years based on the period ending on t

3.3. Econometric Model

The econometric model of this study is as the following Equation (3).

$$y_{i,t} = y_{i,t-1} + \beta_1\sigma_{i,t-1} + \beta_2 Interaction(= \sigma_{i,t-1} * (\text{Size or Inno. Capa.})) + \sum_j x_{j,t-1}\beta_j + \mu_i + \varepsilon_{it} \quad (3)$$

In Equation (3), y represents the R&D intensity of a firm that is the dependent variable of the study, σ is the square of the residuals of the profit prediction model, Equation (2), which is a proxy variable for uncertainty, x's are the control variables, μ is an individual effect, and ε is the idiosyncratic error.

To estimate the Equation (3), we adopt the System GMM method [38,39]. Under the assumption of mean stationarity, the System GMM method is more efficient than the difference GMM [40] if the shock on the dependent variable is persistent. Given that most of the firms in the sample are not venture firms that have just been created, but they are still in existence on the market, the assumption of mean stationarity for using the system GMM is reasonable. In general, the GMM estimation method has a one-step and two-step estimation procedures. In this study, we use two-step estimation method that is an asymptotically efficient estimator when there is no strong assumption about the error term. In addition, a cluster variance estimator is used to derive a robust estimate of variance for coefficients.

4. Results and Discussion

4.1. Descriptive Statistics

The descriptive statistics of the variables that are used in this study are shown in Table 2 below. Since the purpose of this study is to confirm the existence of heterogeneity, according to the characteristics of firms in the effect of uncertainty on R&D investment, we focus on comparing the differences in descriptive statistics by the type of firms. The types of firms are classified according to the size and the innovation capacity of a firm through the following procedure. First, the size of the company is divided into large companies with more than 300 employees and small-and-medium enterprises (SMEs) with less than 300 employees. Next, the innovation capacity of a company is divided into the high innovation capacity group and the low innovation capacity group, which is based on the median of patents that the company has.

The results of the analysis are shown in Table 2 below. First, there is no big difference in R&D intensity between large enterprises and SMEs. On the basis of innovation capacity, however, the R&D intensity of the high innovation capacity groups is only 2.6%, while that of the low innovation capacity groups is only 0.6%. Next, looking at the uncertainty that is faced by a firm, it can be seen that SMEs are in a higher level of uncertainty than large enterprises. Based on the innovation capability, the uncertainty that is faced by the low innovation capacity groups is more than double that of the innovation capacity groups. For cash flow, although the difference is small, larger enterprises and high innovation capacity groups are found to have higher values than SMEs and low innovation capacity groups. As for debt ratio, the large enterprises and the high innovation capacity groups have a lower value than the SMEs and the low innovation capacity groups. Finally, in terms of the average sales growth rate over the past three years, which is the proxy variable for an investment opportunity, it is found that the large enterprises and high innovation capacity groups have a higher value than the SMEs and low innovation capacity groups.

Table 2. Descriptive statistics.

Variables	All Firms		Split by Size				Split by Innovation Capacity			
			SME		Large		Low		High	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
R&D Intensity	0.02	0.05	0.02	0.05	0.01	0.03	0.01	0.03	0.03	0.06
Uncertainty	0.31	33.06	0.40	37.54	0.02	0.31	0.40	42.95	0.20	11.03
Innovation Capacity	45.48	865.71	6.56	23.75	179.90	1820.19	0.13	0.33	104.08	1308.34
Size	10.69	1.57	10.29	1.23	12.07	1.84	10.30	1.49	11.19	1.54
Cash Flow	0.09	0.15	0.09	0.16	0.10	0.13	0.10	0.15	0.09	0.15
Debt Ratio	0.58	0.45	0.59	0.47	0.55	0.36	0.61	0.48	0.54	0.40
Investment Opportunity	0.10	0.41	0.09	0.44	0.12	0.27	0.09	0.44	0.11	0.36
Number Obs.	30,420		23,920		6500		17,148		13,272	

4.2. Estimation Results

The purpose of this study is to verify the existence of heterogeneity by firm characteristics in the relationship between uncertainty and R&D investment through estimating Equation (3). Table 3 below shows the results of the system GMM estimation for the models extended from the baseline model to various models by including explanatory variables that are to be verified in the study.

Before the analysis, the following two preconditions are necessary for the system GMM estimation that is used in this study to be appropriate. The first specification test is for over-identifying restrictions in order to examine that the instrument variables that are used in the estimation are not correlated with the error of the model. With the analysis of the Hansen test, the null hypothesis that the population moment conditions are correct is not rejected; so, over-identifying restrictions are valid. The second specification tests is to validate that there is no serial correlation in the error of the model. If it is violated, the system GMM estimator is not consistent estimator. The results of the tests that are proposed by Arellano and Bond [40] suggest that we do not need to worry about the serial correlation of the error in the model. Additionally, we also perform a check on the consistency of system GMM estimates. According to the Bond [41], the point estimates of system GMM on the lagged dependent variable is expected to lie below the corresponding OLS estimate and above the corresponding fixed effects (FE) estimate. Although we do not report specific results here, our results support the consistency of estimates.

Table 3. Estimation results.

Dependent Variable: R&D (*i,t*)				
	(1)	**(2)**	**(3)**	**(4)**
Independent variables				
Uncertainty ($i,t-1$)		−0.0000295 *** (0.0000032)	−0.0000237 *** (0.0000032)	−0.0016142 *** (0.0000448)
Moderating variables				
Size ($i,t-1$)			−0.0061088 *** (0.0010542)	−0.0058439 *** (0.0009902)
Innovation capacity ($i,t-1$)			0.0000004 (0.0000005)	0.0000004 (0.0000004)
Interactions				
Uncertainty ($i,t-1$) × Size ($i,t-1$)				0.0001231 *** (0.0000036)
Uncertainty ($i,t-1$) × Innovation capacity ($i,t-1$)				0.0000143 *** (0.0000003)
Control variables				
R&D ($i,t-1$)	0.1297011 *** (0.0268878)	0.1023748 *** (0.0053720)	0.0974904 *** (0.0064912)	0.1115833 *** (0.0142919)
CF/TA ($i,t-1$)	0.0048161 (0.0028163)	0.0005311 (0.0006141)	0.0006259 (0.0006960)	0.0040521 *** (0.0010450)
Debt/TA ($i,t-1$)	−0.0001069 (0.0023763)	−0.0039237 *** (0.0009854)	−0.0037472 *** (0.0010011)	−0.0006862 (0.0012463)
Investment Opportunity ($i,t-1$)	0.0008500 * (0.0004318)	0.0010351 *** (0.0002811)	0.0009043 *** (0.0002733)	0.0007000 * (0.0002925)
Time dummies	Included	Included	Included	Included
Sector dummies	Included	Included	Included	Included
Wald test	85.65 ***	562.09 ***	542.34 ***	7477.87 ***
Hansen test (*p*-value)	0.110	0.186	0.246	0.233
AR (1) (*p*-value)	0.012	0.017	0.017	0.016
AR (2) (*p*-value)	0.297	0.495	0.540	0.480
Number of instruments	50	74	76	78
N obs.	30,420	30,420	30,420	30,420

Note. Significance level: * 10%, ** 5%, *** 1%. The value in parentheses is standard error.

It can be confirmed that there is a strong persistence in R&D investment, given that the lagged R&D intensity variable has a significant positive value in all of the model specifications of Table 3. Previous studies [35,42] argued that R&D is characterized by a high level of adjustment costs and an accumulation process. Therefore, it is pointed out that doing R&D consistently is advantageous in creating more innovation performance when compared to doing it sporadically. Second, according to the column (3) and (4) in Table 3, as the size of the firm increases, the degree of R&D investment decreases. It is not consistent with the late version of Schumpeterian Hypothesis (Schumpeter Mark II), but it is consistent with the early version of Schumpeterian Hypothesis (Schumpeter Mark I). That is, our results support the concept of "Creative destruction", and not a "Creative accumulation". As the knowledge economy is activated by a number of innovative start-ups, a number of studies have also been presented in which small firms are more active in innovation activities [43]. In addition, as companies' investment opportunities measured by sales growth rates in the past three years have been confirmed to have a positive impact on R&D investment in all of the model specifications of Table 3, the importance of recognized investment opportunities in R&D investment decisions has been proven. The debt-ratio which represents the financial soundness of a firm has a negative effect on R&D investment in column (2) and (3) of Table 3. It means that a financially table company is more active in R&D investment. The cash flow variable is only statistically significant in column (4) of Table 3. Since its sign is positive, the financial constraints affect R&D investment to some extent. The remaining variable, innovation capacity, fails to present statistically significant results, irrespective of model specifications.

Next, the moderation effects of the size and innovation capacity of a firm on the relationship between uncertainty and R&D investment are as follows. In column (4) in the Table 3, the coefficients of two interaction terms have a statistically significant and positive values. Therefore, all the research hypotheses in the study are strongly supported. It suggest that there is a heterogeneity in the effects of uncertainty on R&D investment. Uncertainty is the driving force of R&D investment as the size is large and the innovation capacity is high. On the other hand, Uncertainty is a deterrent of R&D investment when the size is small and the innovation capacity is low. Since it is widely known that R&D activities is a fundamental driver of productivity and economic growth, these results can provide implications for policy-makers to promote R&D activities. Specifically, it provides implications in how to promote private R&D investment that the uncertainty that has been recognized as a factor impeding R&D activities in the past may be a factor in promoting R&D activities depending on the nature of the firm.

Additionally, we divide the entire sample into two sub-samples: large enterprises-SMEs and high innovation capacity-low innovation capability groups. The purpose of it is to examine how innovation capacity moderate the effect of uncertainty on R&D investment depending on the size of a firm and vice versa. The criteria for dividing the sample are as follows. First, the distinction between large enterprises and SMEs is based on the legal standards of the Republic of Korea, which is the subject of this study. To be specific, if the number of regular employees is 300 or more, it is regarded as a large enterprise, and if it is less than 300, then it is regarded as a SME. In the case of innovation capability, a firm with the top 50% of the number of patents held is classified as a high innovation capacity firm and a bottom 50% firm as low innovation capacity one.

According to the columns (1) and (2) of Table 4, the innovation capacity only positively moderates the relationship between uncertainty and R&D investment for SMEs. Therefore, SMEs can offset the negative effects of uncertainty on R&D activities derived from the small size, by strengthening innovation capabilities. On the other hand, for large enterprises, the moderating effect of innovation capacity is not only statistically insignificant, but it also has a negative sign. Therefore, it is only effective for SMEs to offset the negative impact of uncertainty on R&D through the enhancement of innovation capacity.

Table 4. Sub-samples estimation results.

Dependent Variable: R&D (*i*,*t*)				
	In Terms of Size		In Terms of Innovation Capacity	
	SME-(1)	**Large-(2)**	**Low-(3)**	**High-(4)**
Independent variables				
Uncertainty ($i,t-1$)	-0.0000946 *** (0.0000053)	−0.0008410 * (0.0004234)	−0.0001014 *** (0.0000234)	0.0130490 *** (0.0001012)
Moderating variables				
Size ($i,t-1$)	−0.0071006 *** (0.0011148)	−0.0028495 *** (0.0007914)	−0.0025405 *** (0.0006918)	−0.0153991 *** (0.0015077)
Innovation capacity ($i,t-1$)	−0.0000057 (0.0000334)	0.0000002 (0.0000004)	0.0000182 * (0.0000080)	0.0000001 (0.0000008)
Interactions				
Uncertainty ($i,t-1$) × Size ($i,t-1$)			−0.0000033 (0.0000070)	−0.0010137 *** (0.0000080)
Uncertainty ($i,t-1$) × Innovation capacity ($i,t-1$)	0.0000151 *** (0.0000004)	−0.0000006 (0.0000013)		
Control variables				
R&D ($i,t-1$)	0.1029980 *** (0.0165153)	0.1202661 *** (0.0071433)	0.0876473 *** (0.0129354)	0.0615282 *** (0.0053999)
CF/TA ($i,t-1$)	0.0055755 *** (0.0010977)	−0.0111500 *** (0.0024052)	0.0015803 * (0.0007928)	−0.0024100 (0.0038932)
Debt/TA ($i,t-1$)	−0.0017819 * (0.0007271)	−0.0040433 * (0.0016599)	−0.0003751 (0.0002135)	−0.0034162 * (0.0016927)
Investment Opportunity ($i,t-1$)	0.0004926 (0.0002676)	0.0021145 (0.0015284)	−0.0000831 (0.0005039)	0.0021776 * (0.0011101)
Time dummies	Included	Included	Included	Included
Sector dummies	Included	Included	Included	Included
Wald test	15168.12 ***	4353.30 ***	19519.01 ***	54490.62 ***
Hansen test (*p*-value)	0.228	0.395	0.743	0.333
AR (1) (*p*-value)	0.025	0.007	0.001	0.001
AR (2) (*p*-value)	0.453	0.374	0.117	0.724
Number of instruments	76	76	76	76
N obs.	23,920	6500	17,148	13,272

Note. Significance level: * 10%, ** 5%, *** 1%. The value in parentheses is standard error.

Looking at the columns (3) and (4) of Table 4, the moderation effect of the size of a firm is not statistically significant for firms with low innovation capacity, and it has a negative value for firms with high innovation capacity. If we look more closely at the results of the high innovation capacity group, based on the logarithm of total assets of 12.87, which is derived from the marginal effect of uncertainty on R&D investment, uncertainty has a positive impact on R&D investment for companies below this value. On the other hand, uncertainty affects R&D investment negatively for companies above this value. As shown in the descriptive statistics in Table 2, this figure is higher than the average total assets of large enterprises. It implies that the value of the growth option that is inherent in R&D investment is largely determined by the innovation capacity, and not the size of a firm. In the case of high innovation capacity firms, the negative moderating effect of firm size can be interpreted as follows. Since the absorptive capacity of a firm is an increasing function of the size of the firm [44,45], large firms with high innovation capacity has a great level of the absorptive capacity. Firms with high absorptive capacity can easily and quickly mimic the outcomes of competitors' innovations, which can increase the incentive to defer R&D investment under uncertainty. Therefore, if the size of high innovation capacity firms exceeds a certain level, it can be predicted that the uncertainty will be a factor that hinders R&D investment.

5. Conclusions and Implications

R&D activities are a source of innovation that leads to productivity and economic growth. Therefore, the literature on R&D investment decisions has an important academic and policy implication. This study focuses on growth options, which is one of the differentiating factors that R&D investment has over other types of investment of a firm. The existence of growth option is a key factor that makes the effect of uncertainty on R&D investment different from other investment types. This study empirically verifies that the effect of uncertainty on R&D investment differs from firm to firm under the theoretical argument that the growth options that are inherent in R&D investment are affected by the characteristics of the firm. The results of the analysis are briefly summarized, as follows.

The size of a firm has a positive moderation effect on the relationship between uncertainty and R&D investment, and the innovation capacity of a firm also positively moderates the relationship between the two. In other words, the impact of uncertainty on R&D is negatively impacted when the size and innovation capacity of a firm is small, but when the size and innovation capacity of a firm above a certain level, the sign of the effect is reversed. Therefore, uncertainty in large or innovative firms can be seen as a factor in promoting R&D investment rather than as a deterrent. This implies that factors such as economies of scale and technological leadership can significantly increase the value of the growth options inherent in R&D investment. On the other hand, SMEs or firms with low innovation capacity tend to be reluctant to invest in R&D under uncertainty because they lack the capacity to internalize the value of growth options. An interesting fact that is evident in the sub-sample analysis is that innovation capacity is more important than firm size in maximizing the value of growth options that are inherent in R&D activities. It is supported by the results of research that the increase of innovation capacity is a factor that promotes R&D investment regardless of the size of a firm and that the size of a firm in high innovation capacity enterprise is rather a factor that hinders R&D investment.

The results of this study provide the following policy implications and strategic implications. There is an aggressive R&D promotion policy for SMEs globally that cannot perform given R&D opportunities by factors, such as financial constraints [46]. However, with the speed of remarkable technological advances, globalization, and industry-to-industry convergence, the uncertainty has become so severe that the efficiency of indiscriminate support for SMEs is being raised [47]. The efficiency of indiscriminate R&D support for SMEs can be greatly damaged, given that R&D investments are rational decisions that maximize the profit of an enterprise. According to the analysis of this study, even though firms belong to the same SME sector, their attitude to cope with uncertainty differs depending on the level of innovation capability. While SMEs with high innovation capacity are actively responding to uncertainties, SMEs with low innovation capacity are less willing to take uncertainty. Therefore, when uncertainty is considered to be an inevitable exogenous factor at the decision level of a single firm, it is reasonable for the SME R&D activity promotion policies to follow the following procedure. First, for SMEs with low innovation capacity, support should be provided to increase the innovation capacity before R&D funding. R&D funding for these SMEs is likely to be a one-time event without improvement in innovation capacity. However, if the innovation capacity is enhanced, the results of this study suggest that these SMEs can increase R&D investment under uncertainty by recognizing the value of the growth options inherent in R&D under the same circumstances in the future. Conversely, SMEs with innovative capabilities are more aggressive in their R&D activities under uncertainty, so it is effective to resolve these financial constraints of these enterprises through financing. These SMEs are able to invest more in R&D under uncertainty that is based on their earnings when they invest in R&D through government funding. Therefore, it is expected that the appropriate support for R&D activities of SMEs depending on their innovation capacity will contribute to the promotion of private R&D investment in the long term, rather than applying the comprehensive support package for SMEs.

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References

1. Cheng, J.T.S.; Jiang, I.-M.; Liu, Y.-H. Technological Innovation, Product Life Cycle and Market Power: A Real Options Approach. *Int. J. Inf. Technol. Decis. Mak.* **2015**, *14*, 93–113. [CrossRef]
2. Hall, B.H.; Lerner, J. Chapter 14—The Financing of R&D and Innovation. In *Handbook of the Economics of Innovation*; Hall, B.H., Rosenberg, N., Eds.; North-Holland: Amsterdam, The Netherlands, 2010; Volume 1, pp. 609–639.
3. Fazzari, S.M.; Hubbard, R.G.; Petersen, B.C.; Blinder, A.S.; Poterba, J.M. Financing Constraints and Corporate Investment. *Brook. Pap. Econ. Act.* **1988**, *1988*, 141–206. [CrossRef]
4. McDonald, R.; Siegel, D. The Value of Waiting to Invest. *Q. J. Econ.* **1986**, *101*, 707–727. [CrossRef]
5. Dixit, A.K.; Pindyck, R.S. *Investment under Uncertainty/Avinash K. Dixit and Robert S. Pindyck*; Princeton University Press: Princeton, NJ, USA, 1994.
6. Koetse, M.J.; Groot, H.L.F.D.; Florax, R.J.G.M. A Meta-Analysis of the Investment—Uncertainty Relationship. *South. Econ. J.* **2009**, *76*, 283–306. [CrossRef]
7. Kellogg, R. The Effect of Uncertainty on Investment: Evidence from Texas Oil Drilling. *Am. Econ. Rev.* **2014**, *104*, 1698–1734. [CrossRef]
8. Kang, W.; Lee, K.; Ratti, R.A. Economic policy uncertainty and firm-level investment. *J. Macroecon.* **2014**, *39*, 42–53. [CrossRef]
9. Vo, L.V.; Le, H.T.T. Strategic growth option, uncertainty, and R&D investment. *Int. Rev. Financ. Anal.* **2017**, *51*, 16–24.
10. Ross, J.M.; Fisch, J.H.; Varga, E. Unlocking the value of real options: How firm—Specific learning conditions affect R&D investments under uncertainty. *Strat. Entrep. J.* **2017**. [CrossRef]
11. Folta, T.B.; O'Brien, J.P. Entry in the presence of dueling options. *Strat. Manag. J.* **2004**, *25*, 121–138. [CrossRef]
12. Griliches, Z. Patent Statistics as Economic Indicators: A Survey. In *R&D and Productivity: The Econometric Evidence*; University of Chicago Press: Chicago, IL, USA, 1998; pp. 287–343.
13. Leahy, J.; Whited, T. The Effect of Uncertainty on Investment: Some Stylized Facts. *J. Money Crédit. Bank.* **1996**, *28*, 64–83. [CrossRef]
14. Bulan, L.T. Real options, irreversible investment and firm uncertainty: New evidence from U.S. firms. *Rev. Financ. Econ.* **2005**, *14*, 255–279. [CrossRef]
15. Lieberman, M.B.; Montgomery, D.B. First-mover advantages. *Strat. Manag. J.* **1988**, *9*, 41–58. [CrossRef]
16. Trigeorgis, L.; Reuer, J.J. Real options theory in strategic management. *Strat. Manag. J.* **2017**, *38*, 42–63. [CrossRef]
17. Kumar, P.; Li, D. Capital Investment, Innovative Capacity, and Stock Returns. *J. Financ.* **2016**, *71*, 2059–2094. [CrossRef]
18. Amram, M.; Kulatilaka, N. Uncertainty: The New Rules for strategy. *J. Bus. Strategy* **1999**, *20*, 25–29. [CrossRef]
19. Oriani, R.; Sobrero, M. Uncertainty and the market valuation of R&D within a real options logic. *Strateg. Manag. J.* **2008**, *29*, 343–361.
20. Magazzini, L.; Pammolli, F.; Riccaboni, M. Real Options and Incremental Search in Pharmaceutical R&D Project Portfolio Management. *Creat. Innov. Manag.* **2016**, *25*, 292–302.
21. Naranjo-Valencia, J.C.; Jiménez-Jiménez, D.; Sanz-Valle, R. Innovation or imitation? The role of organizational culture. *Manag. Decis.* **2011**, *49*, 55–72. [CrossRef]
22. Kulatilaka, N.; Perotti, E.C. Strategic Growth Options. *Manag. Sci.* **1998**, *44*, 1021–1031. [CrossRef]
23. Boulding, W.; Christen, M. Sustainable Pioneering Advantage? Profit Implications of Market Entry Order. *Mark. Sci.* **2003**, *22*, 371–392. [CrossRef]

24. Boulding, W.; Christen, M. Disentangling Pioneering Cost Advantages and Disadvantages. *Mark. Sci.* **2008**, *27*, 699–716. [CrossRef]
25. Zachary, M.A.; Gianiodis, P.T.; Payne, G.T.; Markman, G.D. Entry Timing:Enduring Lessons and Future Directions. *J. Manag.* **2015**, *41*, 1388–1415.
26. McGrath, R.G. Exploratory Learning, Innovative Capacity, and Managerial Oversight. *Acad. Manag. J.* **2001**, *44*, 118–131.
27. Arora, A.; Gambardella, A. The changing technology of technological change: General and abstract knowledge and the division of innovative labour. *Res. Policy* **1994**, *23*, 523–532. [CrossRef]
28. Kim, L. Crisis Construction and Organizational Learning: Capability Building in Catching-up at Hyundai Motor. *Organ. Sci.* **1998**, *9*, 506–521. [CrossRef]
29. Cohen, W.M.; Levinthal, D.A. Absorptive Capacity: A New Perspective on Learning and Innovation. *Adm. Sci. Q.* **1990**, *35*, 128–152. [CrossRef]
30. Li, Y. Duration analysis of venture capital staging: A real options perspective. *J. Bus. Ventur.* **2008**, *23*, 497–512. [CrossRef]
31. Bloom, N.; Bond, S.; Van Reenen, J. Uncertainty and Investment Dynamics. *Rev. Econ. Stud.* **2007**, *74*, 391–415. [CrossRef]
32. Baum, C.F.; Caglayan, M.; Talavera, O. On the investment sensitivity of debt under uncertainty. *Econ. Lett.* **2010**, *106*, 25–27. [CrossRef]
33. Ghosal, V.; Ye, Y. Uncertainty and the employment dynamics of small and large businesses. *Small Bus. Econ.* **2015**, *44*, 529–558. [CrossRef]
34. Dutta, S.; Weiss, A.M. The Relationship Between a Firm's Level of Technological Innovativeness and Its Pattern of Partnership Agreements. *Manag. Sci.* **1997**, *43*, 343–356. [CrossRef]
35. Coad, A.; Rao, R. Firm growth and R&D expenditure. *Econ. Innov. New Technol.* **2010**, *19*, 127–145.
36. Sasidharan, S.; Jijo Lukose, P.J.; Komera, S. Financing constraints and investments in R&D: Evidence from Indian manufacturing firms. *Q. Rev. Econ. Financ.* **2015**, *55*, 28–39.
37. Dalziel, T.; Gentry, R.J.; Bowerman, M. An Integrated Agency–Resource Dependence View of the Influence of Directors' Human and Relational Capital on Firms' R&D Spending. *J. Manag. Stud.* **2011**, *48*, 1217–1242.
38. Arellano, M.; Bover, O. Another look at the instrumental variable estimation of error-components models. *J. Econ.* **1995**, *68*, 29–51. [CrossRef]
39. Blundell, R.; Bond, S. Initial conditions and moment restrictions in dynamic panel data models. *J. Econ.* **1998**, *87*, 115–143. [CrossRef]
40. Arellano, M.; Bond, S. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Rev. Econ. Stud.* **1991**, *58*, 277–297. [CrossRef]
41. Bond, S.R. Dynamic panel data models: A guide to micro data methods and practice. *Port. Econ. J.* **2002**, *1*, 141–162. [CrossRef]
42. Máñez, J.A.; Rochina-Barrachina, M.E.; Sanchis-Llopis, A.; Sanchis-Llopis, J.A. The determinants of R&D persistence in SMEs. *Small Bus. Econ.* **2015**, *44*, 505–528.
43. Pederzoli, C.; Thoma, G.; Torricelli, C. Modelling Credit Risk for Innovative SMEs: The Role of Innovation Measures. *J. Financ. Serv. Res.* **2013**, *44*, 111–129. [CrossRef]
44. Greve, H.R. Interorganizational Learning and Heterogeneous Social Structure. *Organ. Stud.* **2005**, *26*, 1025–1047. [CrossRef]
45. Murro, P. The Determinants of Innovation: What Is The Role of Risk? *Manch. Sch.* **2013**, *81*, 293–323. [CrossRef]
46. Klette, T.J.; Møen, J.; Griliches, Z. Do subsidies to commercial R&D reduce market failures? Microeconometric evaluation studies1We have benefited from comments by Tore Nilssen, John van Reenen and participants at the NBER productivity meeting in December 1998. This project has received partial financial support from the Research Council of Norway.1. *Res. Policy* **2000**, *29*, 471–495.
47. Jun, S.-P.; Kim, S.-G.; Park, H.-W. The mismatch between demand and beneficiaries of R&D support programs for SMEs: Evidence from Korean R&D planning programs. *Technol. Forecast. Soc. Chang.* **2017**, *116*, 286–298.