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# The Determinants of Korean Manufacturing Firms' Innovative Activity : Do Firm Size and Appropriabilities Matter?

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# 한국 제조업체의 혁신활동 결정요인 : 기업규모와 전유성의 역할

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**Abstract** This study empirically examined how a firm size affects the determinants of innovative activities using the data of the Korean Innovation Survey (KIS) 2016. With data from 2,003 firms in the manufacturing sector, we performed logistic regression analysis and zero-inflated negative binomial regression analysis. R&D expenditure and patent applications were used as proxies for innovative activity. The independent variables included the firm's characteristics variables such as the firm's age, tech-level industry, RDemp (R&D employee ratio), venture, export, and industrial characteristics variables such as networking, appropriability, and spillovers. The empirical findings are that there are some differences in firms' innovative activity determinants among the firms' size groups. Next, strategic appropriability has negative impacts on small firms' R&D expenditure and medium-firms' patents. Networking is an important determinant of innovative activity for all firms, except for large firms. Furthermore, in deciding R&D activities, small and medium-sized firms were significantly influenced by industrial characteristics as compared to that of large firms. Our findings suggest some R&D promotion policies. Policies fostering firms' technological interaction would allow firms to take advantage of technological spillovers and thus raise the probability of investing in R&D.

**요 약** 본 연구는 기업규모와 전유성 등의 기술전략이 기업 혁신활동을 결정짓는 데 대한 영향을 실증적으로 분석해보았다. 한국기술혁신조사(KIS)의 2016년 2,003개 제조업체의 자료로 로짓회귀모형과 영과잉음이항회귀를 활용하였다. R&D 지출과 특허출원이 혁신활동의 성과를 나타내는 변수로서 이용되었다. 설명변수로서는 기업의 특성을 나타내는 기업 나이, 기술수준별 산업구분, R&D 종사자수, 벤처기업여부, 수출여부, 그리고 산업 전유 특성을 타나내는 네트워크, 전유방법, Spillover를 설정하였다. 우선, 실증적인 분석결과는 전반적으로 기업의 규모에 따라 혁신활동 결정요인이 다르게 나타남을 보여주고 있다. 더욱이 혁신활동을 결정짓는 데에, 중소기업은 대기업보다 산업의 특성에 의해 유의미하게 영향을 받았다. 규모가 작은 신생기업, 벤처기업, 혹은 수도권 소재기업일 때 혁신활동에 긍정적인 것으로 나타났다. 반면, 전략적 전유는 소기업 R&D 지출과 중기업의 특허출원 성과에 부정적인 영향을 미치고 있다. 다른 기업 또는 산업 간의 네트워크는 대기업을 제외한 기업들에서 혁신활동을 결정짓는 중요한 결정요인으로 나타나고 있다. 기업간의 기술적 상호작용은 기술 spillover과 혁신활동의 가능성을 높일 수 있으나, 이 성과는 기업 규모와 산업 특성에 따라 다르게 나타날 수 있음을 보여준다.

**Keywords** : Manufacturing, Appropriability, Patent, R&D, Zero-Inflated Negative Binomial

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# 1. Introduction

## 1.1 Background

Given the importance of R&D as a major factor driving economic growth, understanding the determinants of firms' R&D investments has received much attention among researchers and policy makers. R&D investment is the most sensitive part of corporate activities depending on economic conditions at home and abroad [1]. According to the OECD definition, research and development is defined as 'creative work' undertaken on a systematic basis in order to increase the stock of knowledge (including knowledge of man, culture and society) and the use of this knowledge to devise new applications.

Analyzing the corporate characteristics and motivations for determining R&D activities is essential in establishing policy grounds and measures. The firms' ability to make appropriate R&D investment decisions will determine the innovativeness and competitiveness of the firm.

Schumpeter [2] claims 1) monopolistic firms and innovation have a positive relationship, and 2) large firms are more innovative than small and medium sized firms. The reason why the opinions of Schumpeter are supported is that 1) the R&D project has to have a large fixed cost and large enough sales to exist in a wide range of economies 2) Large firms have stronger cash flows and greater financial capability to fund innovation 3) The more diversified large firms are in a position to realize potential innovation. And large firms can push for multiple projects at the same time and spread R&D risk. 4) Larger firms may have access to a wider range of knowledge and human capital skills than small firms, allowing higher rates of innovation. 5) The larger the size of firms, the easier it is to attribute the results of innovation, and the resulting region (rent) is an incentive to innovate. On the contrary, Scherer & Ross [3] said, "As the size of firm increases, the efficiency of R&D decreases, so the smaller firms, the more innovation they make". Namely, the larger the size, the faster it is to respond to new changes in the environment, the more layers and structured procedures tend to cause bureaucratic tendencies, which can impair the incentives to innovate. As well as theoretical arguments, research on the size of firms and their relationship to R&D activities has been accumulating in empirical studies.

Some studies analyzed that the R&D activities (investment and R&D level) were active as firms' size grew [4-7]. Meanwhile, some report that the relationship between the two is not clear [8, 9]. Scherer [10] found reverse- U-shaped relations between the size of the firm and R&D, as well as reverse-U shape in studies by Sung, Song and Oh [11, 12]. On the other hand, there are studies on U-shaped relations. They found that firms employed by less than 100 employees or 2,000 employees were employed is more innovative with an U shape [13]. As such, existing studies of firm size and innovation in manufacturing industries show conflicting results, not supporting consistent assumptions. Although a basic firm size - innovation relationship is not apparent, it does appear that the determinants of innovation may vary between small and large firms.

Winter [14] suggested that the innovation activity of small and large firms responds to considerably different technological and economic environment. Acs and Audretsch also found that innovation activity for small firms responds to a different technological and economic environment than does innovation activity for large firms [8].

## 1.2 Purpose

The aim of this paper is to provide empirical evidence of the determinants of R&D investment decision of Korean manufacturing firms by firm size, estimating logistic model.

The association between R&D investment and firm size has attracted a lot of attention in the literature [2, 8, 15]. In general, literatures suggest that large firms that tend to be more innovative. The decision to invest in R&D will be also influenced by firm size. Similarly, the factors driving firms decision to invest in R&D activities are also different by firm size. In particular, we evaluate the relevance of technological factors, such as R&D spillovers, and appropriability conditions.

The difference between large and small companies in Korea is stark. The Korea Innovation Survey 2016: Manufacturing Sector (KIS 2016) has already shown that Korean companies are pursuing R&D in different ways depending on size and achieving innovation. The government support system is also applied by the size of the employed and legal type.

The paper is arranged as follows. Section 2 reviews the literature that considers the determinants of innovative activity. Section 3 presents the data collection methodology and some descriptive statistics. Section 4 illustrates the zero-inflated negative binomial regression model and logit model. Section 5 presents the results and conclusion of the study.

## 2. Literature Review

We briefly discuss the main factors that have been put toward by the related literature as key determinants of innovative activity.

### 2.1 Innovative activity

There are several important qualifications which should be made concerning the innovative activity data. Innovations such as process, service, product, and management innovations emanating from large firms has some bias to underestimate the number of them. Since larger firms tend to produce more process innovations than do their smaller counterparts. Patent are commonly used as a measure of innovation, constituting an intermediate output of R&D efforts. On the other hand, R&D investment is usually regarded as the input to the innovative process. The innovativeness of the firms is measured by their average patenting activity, as patents represent a standardised output measure and have detailed data [16].

Some studies use the R&D expenditure and the number of R&D employees as the R&D input variables. In particular, the studies analysing the relationship between corporate scale/market structure and innovation are using inputs rather than outputs of innovation [8]. R&D expenditure is an input of the innovation activity, and patent application reflects an output of the innovation activity, thus becoming complementary indicators [17].

### 2.2 Firms' Age

According to 'learning models', firm age is a signal of efficiency since only efficient firms are able to grow and survive in the market [18, 19]. However, Klepper found that older firms would face less technological opportunities and therefore have lower incentives to invest in R&D [20].

The results that probability of R&D decreases with firm age were obtained from other studies [11, 21, 22] in Korean manufacturing industry. It is predicted that less firm age will lead to innovation and development efforts for products. On the other hand, some studies shown that the non-linear coefficient between firm age and innovative propensity.

### 2.3 R&D Employees

R&D Employees refers to individual experience, knowledge, judgment, skill, risk-taking propensity and wisdom associated with a firm. Therefore, it is important to use a team of scientists and engineers with the know-how and qualifications for R&D activities among the resources necessary to induce innovation activities within the enterprise. Because these human resources bring highly functional and information into the enterprise organization, the higher the availability of these resources, the higher the level of innovative activity can be expected. According to Bartel and Lichtenberg [23], a high degree of labour qualification may facilitate the implementation and development of innovation activities. Quevedo, Pellegrino, and Vivarelli [24] found that firms with more high-skilled workers are more likely both to engage in R&D activities and to increase their amount of R&D investment. Also in Korea, R&D-related human resource is the determinants of firm's innovative activities(patent applications) [25, 26].

## 2.4 Venture

It was expected that there would be a difference between the strength and form of the innovation between the venture and the general entity. Empirical studies in Korea show that when a dependent variable(technology innovation activity) is regarded as an investment in R&D, venture firms are more active than non-venture firms. However, Yoo and Jung [27] showed the results vary depending on the variable(or R&D investment or R&D concentration) or the method of analysis. On the other hand, they showed that the levels of both R&D intensity and R&D investment per worker of venture firms are higher than those of non-venture firms. Plus, Sung [11] found that venture firms are more innovative than non-ventures, for both product innovation and product improvement.

## 2.5 Export Ratio

Unlike in the process of technological innovation in modern economic society, the role of R&D organization or inter-enterprise network has become more important than individual inventors or individual firms [28, 29]. Small and medium-sized firms, especially those with lower technological capabilities and less R&D resources, are more likely to rely on external knowledge networks as a source of innovation activities. Most existing empirical studies confirm this. The export ratio is an important determinant of R&D activities of firms [11, 22, 30]. Related to this idea, Cohen and Levinthal [31] argue that international markets are channels for technology transfer that increase firms technology and stimulate R&D.

## 2.6 Technology Level

In general, R&D activities are more likely for high-tech industries. Some studies have shown that firms in high -technology level have more incentives to perform R&D activities. Mun, Chun and Lee [32] presented that  the decision of co-operative R&D is influenced by tech-level.

## 2.7 Region

The firms in non-capital regions were expected to be at a disadvantage in innovative activity compared to those in the capital regions. Mun, Chun and Lee [32] included the dummy variable indicating whether the firms' main office is located in the capital region of Korea. Results presented that firms with main office in capital region are disadvantageous to joint R&D, if the firms are in the non-ICT high tech firms. The result is same in case that firms which corporate with the university and research institute are. In addition, local-area-based firms and Chungcheong province-based firms are more innovative activity than municipal-area-based firms and non-Chungcheong province-based, for process innovation and product improvement, respectively [11]. They interpreted that determinants of innovative activity depend on regional characteristics.

### 2.8 R&D Spillover

The literature on innovation has stressed the importance of spillovers in the decision to participate in innovative activity. Interaction with suppliers, customers, public assistance agencies, industry associations, universities and the like, can provide missing external inputs into the firm learning process, such as staff training or consulting services [33-35]. There is also a number of papers suggesting that geographical proximity generates positive externalities, market linkages and possibilities for collaboration that in turn foster technological improvements and innovations. Caniels [36] stresses the importance of local knowledge spillovers, including quick diffusion of new technologies and knowledge through close interaction with other firms. According to Griliches [16], true spillovers may be understood as ideas borrowed by research teams of firm/industry *i* from the research results obtained by firm/industry *j*. In this line, we consider three separate forms of R&D spillovers: industry specific, region-specific and local. Industry specific spillovers are captures by R&D activities undertaken by firms within the same industry but outside the region where the firm operates. Region-specific spillovers are captured by R&D activities performed by firms in the same region but within different industries, and local spillovers are captured by the R&D activities undertaken by firms in the same industry and region in which firms operate. "Incoming spillovers" variable that represents the source of information have strong positive influence on the decision of co-operative R&D in all industries [32]. Several studies have been conducted on this issue, but the results show mixed results rather than supporting the innovation of firms.

### 2.9 Appropriability Condition

Appropriability conditions refer to the extent to which the results from innovative activities can be appropriated by the firm or easily diffused within or across industries. In short, appropriability is the capacity of the firm to retain the added value it creates for its own benefit. The higher the degree of appropriability of the returns to innovation the higher will be the incentives to invest in R&D. Mun, Chun and Lee [32] divided appropriability into strategic and legal appropriability. For all manufacturing industries, analysis results of two appropriabilities are inconsistent. In cooperation with universities and research institutes, legal appropriability has a significant relationship with co-operative R&D.

### 2.10 Network

Unlike in the process of technological innovation in modern economic society, the role of R&D organization or inter-enterprise network is important rather than individual inventors or individual firms[11, 28, 29]. Likewise, the external networks have a strong positive effect on innovation outputs, both patent application and patent-based sales [37, 38]. According to Hong and Kim [30] and Yoon [39], through technical cooperation small- or medium-sized firms seem to experience an increase in the efficiency related with their R&D performance measured by the number of successful R&D projects and innovative activity-induced sales. Especially, cooperation with large firms creates a greater effect than that with universities or public institutes. In contrast, Karlsson and Olsson [40] analyzed the absorption process of new technologies in Sweden's machinery, electronics and precision instruments industry, showing that small and medium-sized businesses do not rely more on regional infrastructure than large firms.

## 3. Model and Data

### 3.1 Model

$$Prob.(RD\,activities) = 1/\left[1+e^{-Z}\right]$$

$$\begin{aligned} Z = \alpha + \Sigma\beta_1 X_i = \ & \alpha + \beta_1 Age + \beta_2 Age^2 + \beta_3 RDemp \\ & + \beta_4 d\_Venture + \beta_5 d\_\mathrm{Export} + \beta_6 d\_size\_Large \\ & + \beta_7 d\_size\_Middle + \beta_8 d\_ind\_high + \beta_9 d\_ind\_highlow \\ & + \beta_{10} d\_ind\_lowhigh + \beta_{11} d\_region + \beta_{12} spill \\ & + \beta_{13} StrApp + \beta_{14} LegalApp + \beta_{15} Network \end{aligned}$$

where *RD activities* is the probability of patenting, *Age* indicates the age of the firm, *RD emp* is the percentage of R&D employees to total employees. *d_Venture* and *d_Export* are dummy variables equal to one if the firm belongs to venture enterprise and exported in the corresponding periods, d_*size_Large* and *d_size_Middle* are dummy variables that indicate whether the firm is large or small-sized. *d_ind_Highlow, d_ind_highlow,* and *d_ind_lowhigh* are dummy variables that represent the technology level of the industry group to which the business belongs. *d_region* is a dummy variable equal to one if the firm located in the capital region. Finally, *StrApp, LegalApp, Spill* and *Network* are variables that represent how the firm is monopolized, showing whether it is only strategic or legal as a proxy of appropriability conditions, and whether it is exclusively through the network and spillover, respectively (refer to Table 1).

Logistic regressions were run separately by firm size. The innovation variables such as R&D expenditure ratios and patent applications have values of 0 and 1, and Prob.(RD activities) represents the probability of performing the R&D activities. $X_i$ is an explanatory variable that can be estimated by mixing static and continuous variables. R&D expenditure ratios and patent applications, i.e. the innovation variables have values of 0 and 1, and A represents the probability of performing the innovation activities. $\beta$ is an explanatory variable that can be estimated by mixing static and continuous variables. $\alpha$ is the constant term, and $\beta$ is the value of the estimated coefficient.

We also analysed the negative binomial regression model instead of the Poisson regression model when the data under consideration are over-dispersed. If the data are divided into zero and non-zero subsets so that a probit or logit model could be fitted, the unconditional probability of zero would be sizable, larger than that arising in a Poisson or negative binomial distribution.

## 3.2 Data

The data used in this paper are drawn from the Korean Innovation Survey 2016(henceforth KIS 2016) which has been conducted yearly since 1997 by the Science and Technology Policy Institute(STEPI) based on the OECD Oslo Community Innovation Survey(CIS) manual. This dataset which comprises data about innovation activity at the firm level in Korea covers 21 industrial sectors based on the Hankyung Database(DB) industrial classification. This CIS 2002 used in current study contains detailed questions on various innovation activities at the firm level. The survey is based on the manufacturing firms who employ at least 10 people or greater and who were founded before year 2013. For the investigation, the survey questionnaire includes categories of survey parameters, such as general information about business operation, purposes of innovation, R&D cost, total sales, and information sources of innovation etc.

In this paper, we consider survey data for the period 2013 to 2015. The original sample comprised 4,000 observations, but because of missing variables and the fact that some firms have below 10 employees, we ended up with an cross section data of 2,003 observations. The firm size groups are based on the number of full time employees with small(1-100), medium(101-300),and large(300+). Study variables are derived into two groups according to Shin

[17]: firm and industrial characteristics. In this paper, characteristics are firm size, Age, RDemp, d_Venture, Exportratio, and d_Region. Industrial characteristics are tech levels, appropriability conditions, spillovers, and network.

### 3.2.1 Innovative activity

To measure R&D activities that are dependence variables, we use the R&D expenditure ratio to total sales, and the number of patents. The big advantage of this source of data is that considerable effort has been put in to making it comparable across firms. Data is available for the period 2013-15. To examine the determinants of innovative activity decision, we use the data on both R&D expenditure as the input (R&D) and the number of patents as the output of innovative activity. d_RDratio is the dummy variable for whether the firm spent the R&D expenditure more than 2 percent of total sales. The number of patent applications is considered a calculation proxy of innovative output. We use a question from a survey of firms which asks how many patents have been applied for the past three years. This question is used to classify firms into 'innovator' and 'non-innovator' categories. d_Patent is the dummy variable for whether the firm was an innovator for corresponding time periods.

### 3.2.2 Spillovers

Technology inflows as variables related to information flow within an enterprise are variables that show the importance of public information used in the innovation activities of the company, showing how much information flow through general media such as patent information, expert meetings, seminars, and trade fair. The Innovation Survey includes surveys on the importance of information from other companies, universities and research institutes as a source of information for innovation.

### 3.2.3 Appropriability Condition

In this study, we used strategic and legal protection to identify the reasons for corporate R&D cooperation in accordance with the protection methods. This measure measures the efficiency of methods used to protect product innovation or process innovation that occurred in the process of corporate innovation. Methods for protecting an entity's innovative activities can be divided into strategic and legal appropriability.

We measure appropriability conditions by dividing it into strategic and legal appropriability [32]. Strategic appropriability is maintained as an confidentiality within the firm, being first to the market, and complexity. Legal appropriability is the case when an entity's innovative activities are protected using intellectual property rights by using patent registration, utility rights, chair rights, trademarks, etc. As in the case of technology inflows, appropriability condition is required to give 0 to 5 points depending on the preference of the protection method.

### 3.2.4 Network

1 if an official partnership with another firms or organizations was established within the survey period, otherwise 0. Partnering include affiliates of parent firms or major firms, demanders, materials and parts suppliers, machinery and equipment suppliers, competitors, joint venture companies, external consulting firms, universities, government-funded research institutes, and national testing institutes. The network is expected to have a positive impact on determining R&D.

### 3.2.5 Firms Characteristics

Venture is the dummy variable for whether firm is the venture. 1 if the firm belongs to venture in 2015, otherwise 0. As a proxy of the firm's reputation and operating activities, the ratio of export to total sales in 2015 was used. Firm age, measured as the number of years elapsed since the firm was founded, captures firm' experience and knowledge accumulation, and it usually proxies for firms efficiency differences.

We divided manufacturing industries in the Korean Standard Industry Classification(KSIC) according to OECD standards. The OECD presents knowledge-based manufacturing industries by dividing them into high-tech, medium-high-tech, medium-low-tech, and low-tech categories according to their technical intensity. We classify the manufacturing industries into two groups, such as high(high-tech, medium-high-tech) and low (medium-low-tech, and low-tech) technology industries by the level of technology level.

We include a regional dummy, d_Region indicating that the firm is located in capital region such as Gyeonggi-do, In-cheon and Seoul.

## 4. Results

### 4.1 Summary Statistics

Table 2. presents summary statistics of the dependent and control variables(refer to Table 1.) in the final data set. The sample used in this study is thus made of the remaining 2,003 firms. Means and standard deviations of firm size, age, and key control variables are listed. The average firms' age is 17.9 years with about 7.7% of them being large-sized firm. Of them, the firms that are in the high-tech industry, 18%, in medium-high-tech industry are 30.5%, in the medium-low-tech industry, 21.9%, and in the low-tech industry, 16.2%. Dependent variables, both d_RDratio and d_patent are the highest in large-sized firms than in other sized firm groups. Control variables include firm size, tech-level industries, region, venture, and other firm statistics. Age, RDemp, d_ind_mid (medium-low-tech, d_region, Spill, AtrApp, LawApp, and Network are the highest in large-sized firms than in other sized firm groups.

Table 1. Explanatory Variables

| Variable | | Description | |
|---|---|---|---|
| d_RDratio | | Dummy variables : equal 1 if the firm had R&D expenditure ratio to sales over 2 percent in 2015, otherwise 0 | |
| d_Patent | | Dummy variables : equal 1 if the firm had an patent application in 2015, otherwise 0 | |
| Firm Size | Large | Dummy variables : equal 1 if firm is in corresponding firm size, otherwise 0 (reference : d_size (Small)) | |
| | Medium | | |
| | Small | | |
| Age | | Age of firm (years) in 2015 | |
| RDemp | | R&D-related employee / all employees * 100 (%) | |
| d_Venture | | Dummy variables : equal 1 if the firm belongs to a venture in 2015, otherwise 0 | |
| Exportratio | | Export profit / total sales *100 (%) | |
| d_region | | Dummy variables : equal 1 if firm has the head office in capital region(Gyeonggi-do, In-cheon and Seoul), otherwise 0 | |
| Spill | | importance of knowledge spillover to the firm | |
| Appropriability | StrApp | Score from firms that have used innovative protection methods in the past three years (2013 - 2015) assessed preference of each protection method (0 - 3) | intellectual property rights |
| | LegalApp | | confidentiality<br>being first to market<br>complexity |
| d_Network | | Dummy variables : equal 1 if the firm uses 'formal networking with other firms and institutes, otherwise 0 | |
| Technology Level | d_ind_high | Dummy variables : equal 1 if firm is in corresponding tech-level industry, otherwise 0 (reference : low tech industry) | |
| | d_ind_high-low | | |
| | d_ind_low-high | | |
| | d_ind_low | | |

Table 2. Descriptive Statistics of the Variables

| Variables | Total | | Large firms | | Medium firms | | Small firms | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Dev | Mean | Std. Dev | Mean | Std. Dev | Mean | Std. Dev |
| d_RDratio | 0.599 | 0.490 | 0.753 | 0.433 | 0.453 | 0.498 | 0.651 | 0.477 |
| d_Patent | 0.392 | 0.488 | 0.513 | 0.501 | 0.412 | 0.493 | 0.366 | 0.482 |
| Age | 17.897 | 11.320 | 25.779 | 13.735 | 21.969 | 11.973 | 14.906 | 9.408 |
| RDemp | 7.555 | 9.498 | 2.081 | 2.244 | 3.257 | 3.380 | 10.357 | 10.911 |
| d_Venture | 0.216 | 0.412 | 0.058 | 0.235 | 0.209 | 0.407 | 0.240 | 0.427 |
| Exportratio | 0.118 | 0.251 | 0.081 | 0.190 | 0.161 | 0.249 | 0.101 | 0.256 |
| d_size_Small | 0.618 | 0.486 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 |
| d_size_Medium | 0.305 | 0.461 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| d_size_Large | 0.077 | 0.266 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| d_ind_high | 0.180 | 0.384 | 0.208 | 0.407 | 0.219 | 0.414 | 0.157 | 0.364 |
| d_ind_high-low | 0.439 | 0.496 | 0.403 | 0.492 | 0.441 | 0.497 | 0.442 | 0.497 |
| d_ind_low-high | 0.219 | 0.414 | 0.240 | 0.429 | 0.203 | 0.402 | 0.224 | 0.417 |
| d_ind_low | 0.163 | 0.369 | 0.149 | 0.358 | 0.137 | 0.344 | 0.177 | 0.382 |
| d_region | 0.484 | 0.500 | 0.584 | 0.494 | 0.410 | 0.492 | 0.508 | 0.500 |
| Spill | 20.048 | 6.978 | 22.071 | 7.882 | 20.667 | 6.429 | 19.492 | 7.051 |
| StrApp | 3.087 | 3.308 | 5.571 | 3.364 | 3.340 | 3.388 | 2.654 | 3.108 |
| LegalApp | 1.358 | 1.352 | 2.039 | 1.182 | 1.510 | 1.347 | 1.199 | 1.339 |
| Network1 | 0.200 | 0.400 | 0.325 | 0.470 | 0.185 | 0.388 | 0.193 | 0.395 |
| Sample size | 2,003 | | 154 | | 611 | | 1,238 | |

Table 3. Results of ZINB Regression Analysis: Patents

| Variables | All firms (1) | | Small firms (2) | | Mid-Large firms (3) | |
|---|---|---|---|---|---|---|
| | Count Model | Logit Model | Count Model | Logit Model | Count Model | Logit Model |
| Num of Obs. | 785 | 1,218 | 454 | 784 | 331 | 434 |
| Spill | 0.013$^{*}$ | 0.018 | 0.012 | 0.014 | 0.006 | 0.020 |
| | (0.008) | (0.015) | (0.008) | (0.018) | (0.016) | (0.031) |
| StrApp | -0.033$^{*}$ | 0.208$^{***}$ | 0.023 | 0.206$^{**}$ | -0.086$^{**}$ | 0.289$^{**}$ |
| | (0.019) | (0.072) | (0.022) | (0.085) | (0.036) | (0.141) |
| LegalApp | 0.140$^{**}$ | -1.792$^{***}$ | 0.155$^{**}$ | -1.813$^{***}$ | 0.146 | -1.895$^{***}$ |
| | (0.060) | (0.211) | (0.068) | (0.242) | (0.114) | (0.433) |
| d_Network | 0.502$^{***}$ | -0.372 | 0.291$^{**}$ | -0.673$^{**}$ | 0.652$^{***}$ | -0.137 |
| | (0.105) | (0.262) | (0.122) | (0.332) | (0.183) | (0.437) |
| Age | 0.011 | 0.034 | 0.016 | 0.068 | -0.011 | 0.004 |
| | (0.012) | (0.029) | (0.018) | (0.044) | (0.020) | (0.046) |
| Age2 | 0.0001 | 0.0001 | -0.001 | -0.001 | 0.0001 | 0.0001 |
| | (0.000) | (0.001) | (0.000) | (0.001) | (0.000) | (0.001) |
| RDemp | 0.015$^{***}$ | -0.026$^{**}$ | 0.005 | -0.040$^{*}$ | 0.082$^{***}$ | -0.051 |
| | (0.006) | (0.015) | (0.005) | (0.021) | (0.022) | (0.070) |
| d_Venture | 0.199$^{*}$ | -0.921$^{***}$ | 0.248$^{**}$ | -0.542$^{*}$ | 0.193 | -1.668$^{**}$ |
| | (0.107) | (0.268) | (0.121) | (0.306) | (0.182) | (0.699) |
| Exportratio | 0.142 | -1.090$^{**}$ | 1.038$^{***}$ | 0.134 | -0.550$^{*}$ | -1.405 |
| | (0.192) | (0.518) | (0.246) | (0.345) | (0.317) | (0.872) |
| d_size_Mid_Large | 0.649$^{***}$ | -0.357 | | | | |
| | (0.107) | (0.257) | | | | |
| d_ind_high | 0.006 | -1.224$^{**}$ | -0.075 | -1.365$^{**}$ | -0.116 | -1.109 |
| | (0.197) | (0.492) | (0.240) | (0.550) | (0.321) | (0.874) |
| d_ind_high-low | 0.450$^{**}$ | -0.968$^{***}$ | 0.070 | -1.268$^{***}$ | 0.531$^{*}$ | -0.968$^{*}$ |
| | (0.182) | (0.332) | (0.219) | (0.411) | (0.298) | (0.528) |
| d_ind_low-high | 0.318 | -1.234$^{***}$ | 0.196 | -1.715$^{***}$ | 0.257 | -1.042$^{*}$ |
| | (0.197) | (0.368) | (0.234) | (0.464) | (0.324) | (0.593) |
| d_Region | 0.080 | 0.219 | -0.063 | 0.128 | 0.136 | 0.237 |
| | (0.096) | (0.216) | (0.114) | (0.270) | (0.161) | (0.385) |
| _cons | -0.346 | 1.831$^{***}$ | -0.172 | 2.210$^{***}$ | 0.675 | 1.597 |
| | (0.279) | (0.541) | (0.328) | (0.652) | (0.502) | (0.990) |
| Sample size | 2,003 | | 1,238 | | 765 | |

| | Log Likelihood | LR x2(No.ofObs.)(p) | lnAlpha | Vuong test A (p) |
|---|---|---|---|---|
| (1) | -2,894.58 | 115.47(<.001) | 0.507(<.001) | 6.84(<.001) |
| (2) | -1.539.43 | 61.82(<.001) | 0.077(<.100) | 6.06(<.001) |
| (3) | -1,306.11 | 68.83(<.001) | 0.715(<.001) | 4.99(<.001) |

Standard errors in bracket : * significant at 10% level; ** significant at 5% level; *** significant at 1% level.

## 4.2 ZINB Regression Results

The ZINB regression results are summarised in Table 3. Based on these results, we can identify which factors influence firms' participation in patenting activities, and which ones do not.

First, 39.19% (785) of the firms in the sample applied for patents at least once, whereas 60.81% (1,218) of them show no patenting activity during study period. The Vuong statistic for testing the ZINB versus NBR (negative binominal regression) is in the lower quadrant of Table 4 suggests that the ZINB is the correct model. On Patent, strategic appropriability have a negative impact, but legal appropriability has a positive impact significantly. The appropriability variables are highly significant and confirms the relevance of using information on the share of inventions that are patented in order to better understand how an increase in R&D efforts would translate into more R&D expenditure and patenting activity. Remarkably, the effects of appropriabilities vary by firm size. Strategic appropriability has positive effects on small firms' patenting activity. However, strategic appropriability has a negative and significant impact on medium and large firms' patent. Legal appropriability have more patents overall, whereas have a lower probability of zero patents. Firms with many R&D related employees are more likely to patenting activities. Network improve the probability of patenting activity as like results of previous studies [30, 39]. d_venture variable for overall firms shown significant and positive coefficient like the findings of Sung [11] and Yoo and Jung [27]. High-tech firms have more patents overall, whereas low-high, and high-low tech industry firms have a lower probability of zero patents.

## 4.3 Logistic Regression Results

Logistic regressions for R&D expenditure ratio were run on the small and large firms separately. The logistic regression results are summarised in Table 4.

Table 4. Results of Logistic Regression Analysis

| Variables | All firms | Small firms | Mid-Large firms |
|---|---|---|---|
| Spill | 0.023*** (0.007) | 0.013 (0.009) | 0.045*** (0.013) |
| StrApp | -0.003 (0.023) | -0.052* (0.030) | 0.034 (0.037) |
| LegalApp | 0.060 (0.057) | 0.083 (0.072) | 0.084 (0.097) |
| d_Network | 0.617*** (0.130) | 0.309** (0.169) | 1.020*** (0.208) |
| Age | -0.058*** (0.014) | -0.075*** (0.020) | -0.025 (0.023) |
| Age2 | 0.001*** (0.000) | 0.001*** (0.000) | 0.001* (0.000) |
| RDemp | 0.034*** (0.007) | 0.033*** (0.007) | 0.057** (0.027) |
| d_Venture | 0.114 (0.124) | 0.161*** (0.155) | 0.051 (0.215) |
| Exportratio | -0.658*** (0.207) | -0.252 (0.237) | -1.308*** (0.345) |
| d_size_ Mid_Large | -0.337*** (0.112) | | |
| d_ind_ high | 0.062 (0.169) | -0.157 (0.218) | 0.414 (0.284) |
| d_ind_ high-low | 0.314** (0.141) | 0.188 (0.176) | 0.648*** (0.246) |
| d_ind_ low-high | 0.217 (0.156) | 0.269 (0.196) | 0.176 (0.273) |
| d_Region | 0.427*** (0.098) | 0.385*** (0.126) | 0.406** (0.163) |
| _cons | -0.160 (0.233) | 0.440 (0.291) | -1.835*** (0.442) |
| Sample size | 2,003 | 1,238 | 765 |
| loglikelihood | -1,258.487 | -761.292 | -475.325 |
| LRx2 | 182.160*** | 78.880** | 109.390*** |
| PseudoR2 | 0.068 | 0.049 | 0.103 |

Standard errors in bracket : * significant at 10% level; ** significant at 5% level; *** significant at 1% level

Age, Exportratio and d_Medium have a negative and significant impact only on d_RDratio. Age square, d_region, Spillover have a positive and significant impact only on d_RDratio. On the R&D expenditure, the firm age shows a significant negative impact, but the firm age square has a significant positive effect, showing that it has become the U-shape. Spillover have a positive and significant impact only on Medium and large firms' R&D expenditure ratio. Strategic appropriability have a negative and significant impact only on small firms' R&D expenditure ratio. The network requires firms to pay more for R&D and participate in innovative activity as like results of previous studies [30, 39]. In other words, firms that spend large R&D expenditures actively participate in innovation activities using spillover and network. Age2, R&Demp, d_Rigion have a positive and significant impact on R&D expenditure ratio. On the other hand, contrary to our expectation, Exportratio affects negatively on R&D expenditure ratio.

## 5. Conclusion

In this study, we analysed and compared the determinants of innovation activities by firm size using the data from KIS 2016. The econometric analysis conducted has used zero-inflated negative binomial regression for patents, and logit model for R&D expenditure rate. The size and method of investment in R&D varies across firm sizes, and the determinants of a firm's innovative activity is affected by its size. Our main results are the following. Our evidence suggests that the factors that determine R&D activities in large and small businesses were analyzed differently.

1) We obtained the results that the probability of undertaking R&D expenditure increases with age and decreases with age square only in small firms. It means that young and old firms spend more R&D expenditure than middle-age firms if they're small-sized. 2) It was analyzed that venture firms have a positive impact on patent activities only for large and small-sized firms. 3) Contrary to expectations, exports are negatively affecting R&D expenditure of large and medium sized firms. For these firms, being an exporter could reduce the R&D expenditure. 4) The level of technology was the determinant of R&D activities. Firms with higher technology levels were more likely to participate in R&D activities. High technology levels have a positive effect, especially on patents. 5) When the head offices are located in the metropolitan area, small firms are more likely to participate in R&D activities, but firms of other sizes have been affected non-significantly. 6) Spillover has a positive impact on R&D expenditure of medium-sized firms. Appropriability variables have positive impacts on two R&D activities of overall firms. However strategic appropriability has negative impacts on small firms' R&D expenditure and medium-firms' patent. 7) Network is an important determinant of innovative activity for overall firms, except for in large firm. It is interpreted that for small and medium-sized firms the cooperation is more important than competition in terms of technology strategy for the survival and growth of firms[29]. 8) In deciding R&D activities, small and medium-sized firms were significantly influenced by industrial characteristics compared to large firms. This study shows that there are significant differences in the determinants of R&D activities between the manufacturing firms size groups. Our findings make an important contribution to the understanding of the determinants of firms decision to undertake R&D activities and suggest possible R&D promotion policies. First, policies fostering firms technological interaction would allow firms to take advantage of technological spillovers and thus raise the probability of investing in R&D. Second, policies encouraging firms to participate in R&D activities should be differentiated and implemented according to the size of firm. Third, the wider study including qualitative and quantitative factors is needed to better understand the nature of innovative activities. There are a number of issues that remain for future research. The R&D expenditure ratios and patent applications as performances were selected by inputting variables for R&D activities, but there is still probability for doubt that these variables reflect the firm's true R&D activities.

## References


[1] F. Lichtenberg, "R&D investment and international productivity differences", in *Economic Growth in the World Economy*(Ed.), H. Siebert, J. C. B. Mohr, Tuebingen, pp.89-110, 1993.
DOI: https://doi.org/10.3386/w4161

[2] J. A. Schumpeter, *Capitalism, Socialism, and Democracy*, New York: Harper, 1942.
DOI: http://dx.doi.org/10.4324/9780203202050

[3] F. M. Scherer, D. Ross, *Industrial Market Structure and Economic Performance*, Houghton-Mifflinm, 1990.

[4] W. M. Cohen, S. Klepper, "Firm Size and the Nature of Innovation within Industries: The Case of Process and Product R&D", *Review of Economics and Statistics*, Vol.78, No.2, pp.232-243, May. 1996.
DOI: https://doi.org/10.2307/2109925

[5] T. K. Sung, "A Firm Size - Innovative Activity Relationship: An Empirical Study of the Korean Manufacturing Industry", *Journal of Small Business Studies*, Vol.25, No.2, pp.305-325, Jun. 2003.

[6] S. H. Yoo, "Analysing the Determinants of Company R&D Investment Using a Semi-parametric Estimation Method", *Journal of Korea Technology Innovation Society*, Vol.6, No.3, pp.279-297, Dec. 2003.

[7] S. H. Yoo, H. S. Moon, "Policies for Improving the Survey of Research and Development in Science and Technology: The Case of Industrial Sector", *Journal of Korea Technology Innovation Society*, Vol.5, No.2, pp.228-244, Jul. 2002.

[8] Z. J. Acs, D. B. Audretsch, "R&D, Firm Size, and Innovation Activity", in Z. J. Acs, D. B. Audretsch, eds., *Innovation and Technological Change: An International Comparison*, Basil Blackwell, 1991.

[9] F. M. Scherer, K. Huh., "R&D Reactions to High-Technology Import Competition", *Review of Economics and Statistics*, Vol.74, pp.202-212, May. 1992.
DOI: https://doi.org/10.2307/2109651

[10] F. M Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions", *American Economic Review*, Vol.55, No.5, pp.1097-1125, Dec. 1965.

[11] T. K. Sung, "Determinants of Firm's Innovative Activity: The Role of Regional Characteristics in Korea", *Journal of Korean Economy Studies*, Vol.13, pp.21-54, Dec. 2004.

[12] C. U. Song, W. K. Oh, "R&d Activities, Consumer-orientedness, and Innovation in Manufacturing Industries of Korea", *Journal of Korea Technology Innovation Society*, Vol.13, No.1, pp.124-140. Mar. 2010.
DOI: https://doi.org/10.1016/j.enpol.2015.02.022

[13] K. Pavitt, M. Robinson, J. Townsend, "The Size Distribution of Innovating Firms in the UK: 1945-1983", *The Journal of Industrial Economics*, Vol.35, No.3, pp.297-316, 1987.
DOI: https://doi.org/10.2307/2098636

[14] S. G. Winter, "Schumpeterian Competition in Alternative Technological Regimes", *Journal of Economic Behavior and Organization*, Vol.5, pp.287-320, 1984.
DOI: https://doi.org/10.1016/0167-2681(84)90004-0

[15] W. M. Cohen, R. C. Levin, "Empirical Studies of Innovation and Market Structure", in R. Schmalensee, R. D. Willig, eds. *Handbook of Industrial Organization*, North Holland. 1989.
DOI: https://doi.org/10.1016/S1573-448X(89)02006-6

[16] Z. Griliches, "The Search for R&D Spillovers", *The Scandinavian Journal of Economics*, Vol.94, pp. S29-S47, Jul. 1992.
DOI: https://doi.org/10.3386/w3768

[17] T. Y. Shin, *The Determinants of Technology Innovation: Firm Size, Industry Structure, and Innovation*, STEPI, 1999.

[18] R. Ericson, A. Pakes, "Markov-Perfect Industry Dynamics: A Frame for Empirical Work", *Review of Economic Studies*, Vol.62, No.1, pp.53-82, 1995.
DOI: https://doi.org/10.2307/2297841

[19] B. Jovanovic, "Selection and the Evolution of Industry", *Econometrica*, Vol.50, No.3, pp.649-670, May. 1982.
DOI: https://doi.org/10.2307/1912606

[20] S. Klepper, "Entry, Exit and Innovation over the Product Life cycle", *American Economic Review*, Vol.86 No.3, pp.562-583, Jun. 1996.
DOI: https://doi.org/10.1023/A:1025067906102

[21] H. J. Kim, "Dispersed Corporate Information Networks and Their Determinant Factors: Utilizing Technology Innovation Activity Survey", *The Korea Spatial Planning Review*, Vol.63, pp.205-223, Dec. 2009.
DOI: http://dx.doi.org/10.15793/kspr.2009.63..011

[22] J. P. Lee, *The Determinants of Innovative Activities in Korean SMEs*, Ph.D. Dissertation, Pukyong National University, 2017.

[23] A. Bartel, F. Lichtenberg, "The Comparative Advantage of Educated Workers in Implementing New Technology", *The Review of Economics and Statistics*, Vol.69, No.1, pp.1-11, 1987.
DOI: https://doi.org/10.2307/1937894

[24] Q. G. Quevedo, G. Pellegrino, M. Vivarelli, "The determinants of YIc's R&D activity," Working Papers XREAP2011-20, Xarxa de Referència en Economia Aplicada (XREAP), revised Dec. 2011.

[25] T. K. Sung, "The Determinants of the Firm's Decision to Carry Out Innovative Activities: in Terms of the Resource-Based View", *Journal of Technology Innovation*, Vol.10, No.2, pp.69-90, Dec. 2002.

[26] S. J. Choi, H. Park, "The effect of labor union presence on corporate technology development investment and performance : Focused on

manufacturing companies in the capital area", *Journal of Social Science*, Vol.44, No.2, pp.103-114, 2018. DOI: http://dx.doi.org/10.15820/khjss.2018.44.2.005

[27] S. H. Yoo, K. O. Jung, "Analyzing R&D Investment of Venture Companies in KOSDAQ", *Journal of Entrepreneurship and Venture Studies*, Vol.6, No.3, pp.3-26, Nov. 2003.

[28] G. Rosegger, *The Economics of Production and Innovation: An Industrial Perspective*, Butterworth-Heinemann, 1996.

[29] T. K. Sung, B. Carlsson, "The Evolution of a Technological System : The Case of CNC Machine Tools in Korea", *Journal of Evolutionary Economics*, Vol.13, pp.435-460, Oct. 2003.

[30] S. M. Yoon, "The Determinants of R&D Activities in Subcontracting Small Firms", *Journal of Small Business Studies*, Vol.25, No.1, pp.51-82, 2003.

[31] W. M. Cohen, D. A. Levinthal, "Innovation and Learning: the Two Faces of R&D", *The Economic Journal*, Vol.99, pp.569-596, Sep. 1989. DOI: http://dx.doi.org/10.2307/2233763

[32] S. B. Mun, H. B. Chun, E. M. Lee, The Determinants of Co-operative R&D among ICT firms, KISDI, 2007.

[33] B. Lundvall, "Innovation as an Interactive Process: from User-Producer Interaction to the National System of Innovation", in B. Lundvall, *The Learning Economy and the Economics of Hope*, pp.61-84, 2016.

[34] B. Lundvall, National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning. Anthem Press, 2015.

[35] R. Rothwell, M. Dodgson, "External Linkages and Innovation in Small and Medium-Size Enterprises", R&D Management, Vol.21, No.2, pp.125-137, Apr. 1991. DOI : https://doi.org/10.1111/j.1467-9310.1991.tb00742.x

[36] M. C. J. Caniels, Knowledge Spillovers and Economic Growth, Edward Elgar, Cheltenham, 2000.

[37] T. K. Sung, "The Determinants of Firm's Innovative Activity: A Comparison of Manufacturing and Service Firms in Korea", *Journal of Business Research*, Vol.21, No.4, pp.283-304, 2006.

[38] T. K. Sung, J. S. Kim, "Determinants of Firm's Innovation Performance: Evidence from Jeonbuk-based Firms in Korea", *Korean Journal of Business Administration*, Vol.22, No.4, pp.2017-2036, 2009.

[39] S. H. Hong, B. K. Kim, "An empirical analysis on the effect of technical cooperation between large and small-or medium-sized firms on R&D activities-related efficiency improvements", *Journal of Korean Official Statistics*, Vol.23, No.3, pp.24-38, 2018.

[40] C. Karlsson, O. Olsson, "Product Innovation in Small and Large Enterprises", *Small Business Economics*, Vol.10, pp.31-46, Feb. 1998. DOI : https://doi.org/10.1023/A:1007970416484

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〈Research Interests〉
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