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Determinants of Successful R&D Performance in Korean Electricity Industry

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Dohyoung Kim

Determinants of Successful R&D Performance in Korean Electricity Industry

지도교수 황 준 석

이 논문을 공학석사학위 논문으로 제출함

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서울대학교 대학원
협동과정 기술경영경제정책전공
김 도 형

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위 원 장 ____________________(인)

부위원장 _____________________(인)

위 원 _____________________(인)

Abstract

Throughout the history of public policy, liberalization has been recognized as the hallmark of transition in the electricity industry sector. Before liberalization, the private sector was responsible for pursuing efficiency in the markets. However, an increasing number of governments inclined to introduce competition by liberalizing the sector. Soon thereafter, the effectiveness of liberalization policy was called into question: does liberalization really improve efficiency in the electricity market? Liberalization has brought many changes with it, but one in particular is the change in the role of public Energy-related R&D (ER&D). Since liberalization, public ER&D has focused on short-term projects which led to an increase of in-house research projects. But, in the case of Korea, R&D alliances seemed to have grown over the years. This unique quality in the Korean electricity industry and public ER&D behavior led to a further study on this matter. Therefore, the main objective of this study is to inspect two hypotheses: (1) whether liberalization has positively influenced the public ER&D performance of Korea, (2) whether R&D alliances have positively influenced the public ER&D performance of Korea. The result shows that R&D alliances positively influenced the ER&D performance of the Korean electricity sector; while liberalization did not significantly affect the ER&D performance of Korea.

Keywords: *Public ER&D Performance, Liberalization, Alliance, Electricity Industry*

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Contents

List of Tables

List of Figures

1. Introduction

1.1 Research Background

Throughout the history of public policy, liberalization was recognized as a hallmark of transition in the public sector. Before liberalization, pursuing the concept of efficiency was put into the hands of the private sector, so public utilities such as water, transport, telecommunication, postal services, and energy were not as open to competition as they are today. However, an increasing number of governments have been inclined to introduce competition in these markets through the act of liberalization so that their consumers could choose from a number of alternative products and services. These were plausible strategies by governments to build more competitiveness into their economy by allowing the public to benefit from lower prices and new services which were expected to be more efficient than before.

However, it is not clear whether liberalization had brought efficiency in the public sector. Some studies conclude that market liberalization did improve efficiency as it was intended (Bowonder and Richardson, 2000; Zaim, 2006). However, others argue that liberalization failed to significantly affect targeted industries in terms of efficiency. For instance, Rodrik (1988) argues that trade liberalization has not shown to enhance technological efficiency, nor has it been empirically demonstrated to do so. Similar results can be seen in the banking industry as well. An empirical study of the Pakistani banking system shows that liberalization in the financial sector did little to make privatized banks efficient compared to the remaining state-owned banks. (Bonaccorsi di Patti, 2005) Therefore, the argument over the effectiveness of liberalization in the public sector is still debated and requires further academic attention.

Out of the many liberalized public sectors, the energy sector is becoming more important as it directly impacts our daily lives and economy. From households to industry, our daily lives are enormously dependent on energy services as they become a major power source for our economy. The impact resulting from energy extraction, conversion, and use are major components of most environmental problems at every scale from the local to the global and international energy flows are both a significant ingredient in world trade and a potential source of tension and conflict. For these reasons and more, the character of national and global energy systems is crucial to the human condition and to the prospects for improving it (Sagar, 2002).

However, the current energy system is under immense stress and requires technological advancement. According to “World Energy Outlook 2014”, the global energy system is in danger of falling short of the hopes and expectations placed upon it; the Middle East still remains as the only large source of low-cost oil, while nuclear power faces an uncertain future; and electricity remains inaccessible to many people, while global greenhouse-gas emissions and air pollution in many of the world’s fast growing cities are continuously rising (OECD & IEA, 2014). Many studies sympathized that major challenges confront the energy system – ensuring adequate supply of energy services at low cost while mitigating adverse local and global environmental impacts will require further innovation in energy technologies. (Anadón, 2012; IEA, 2012; Nakicenovic & Nordhaus, 2011; Sagar & Holdren, 2002; Zhi, Su, Ru, & Anadon, 2013). Energy technology innovation is central to meeting those challenges by transforming its system through deploying advanced and cost-effective technologies. (IEA, 2015)

ER&D is an instrument to help achieve technological policy targets by sharing tasks between the public and private sector. Historically, the government R&D investment usually targeted areas with high-risk and long-term perspectives, whereas investment from the private sector targeted on the pre-competitive, short-term demonstration, and commercialization of energy technologies (IEA, 2007).

While the role of private ER&D has not changed much, the role of public ER&D has changed a great deal due to liberalization. The main reason for sector reform was to improve efficiency by introducing competition to the industry. Governments assumed that profit incentives would encourage and improve R&D and innovation once the reform took place (IEA, 1999). This structural change of the electricity industry had also brought change in the public R&D behavior. Previously, the most important role of public ER&D was considered to be laying the groundwork for major technological breakthroughs until enough incentives were induced for private investors to participate. This is still deemed as a valid role of public ER&D, however, the priority of public ER&D has moved toward the development and early commercialization of low-carbon technologies (GPPI, 2009).

Consequences followed once the priority of public ER&D had shifted. One of the first effects of liberalization is a decrease in R&D intensity. Reduction in R&D intensity affected many of the world's leading utilities in markets that were in the process of deregulation (GAO, 1996; Dooley, 1998). In addition, focus of R&D efforts had shifted from long-term to short-term projects. The United States and many of European countries show a trend of avoiding long-term and high-risk research and moving toward near-term business units (Dooley, 1998; Walker & Riley, 1996). Moreover, as the focus of projects moved from long-term to short-term, cooperative/collaborative researches are replaced with "in-house" research projects (The Netherland's Economic Ministry, 1996). In another word, liberalization had brought decrease in R&D alliances by relying more onto in-house research projects.

However, as a growing number of competitive research environments are being promoted, R&D alliancebecomes indispensable strategy for survival. Lai & Chang (2010) assert the importance of utilizing external resources to complement limited internal resources and capabilities in today's competitive and turbulent environment. Strategic alliances have become a vital strategy for many corporations to achieve competitive advantage by gaining market access, scale economies, and competence building through collaborations (Muthusamy & White, 2005; Dyer and Singh, 1998; Gulati, Nohria, & Zaheer, 2000; Yoshinol & Rangan, 1995). From the perspective of organizational learning, strategic alliances are indispensable because organizationally embedded knowledge cannot be easily blueprinted and inherited through market transactions (Doz, 1996; Inkpen, 1998). Also, strategic alliances can increase efficiency of the members of these alliances. Several strategic benefits can be obtained faster, at less cost, with greater flexibility and with much less risk through alliances than operating independently (Dyer and Singh 1998; Sako, 2000). For instance, many organizations enter into business alliances to overcome the inherent risks associated with new product development because alliances quicken the speed of innovation, overcome budgetary constraints, and help gain access to resources not otherwise available to them (Bleeke & Ernst, 1993). Therefore, more alliance should be expected to be occur under the circumstance of liberalization since both R&D alliance and liberalization are targeting on improving efficiency. This leads to the curiosity of whether empirical study can show that both liberalization and R&D alliance positively influence public ER&D performance.

In the case of public ER&D in Korea, alliance R&D projects have continued to increase. In 2001, less than 10% of public electricity R&D was devoted to alliance projects, whereas all projects in 2014 were composed of alliance projects. The shift toward increasing alliances indicates that the trend of Korea's public electricity R&D is heading toward a different direction compared to those of other countries. Therefore, analyzing this phenomenon – how such a difference affects the public ER&D performance – could have a significant impact on the understanding of Korea's electricity industry.

1.2 Research Objective

The liberalization in the electricity sector changed its public ER&D behavior. After the liberalization of the electricity, trends of ER&D were aimed at short-term commercialization performances. As competition was introduced to the sector, many changes were made which included a decrease in cooperative research programs. However, in the Korean electricity industry, R&D alliance seemed to be growing after the industry was liberalized. Such uniqueness in the Korean electricity industry and public ER&D behavior leads to a further study on this matter.

The main objective of this study is to inspect two hypotheses: *(1) whether liberalization has positively influenced the public ER&D performance of Korea, (2) whether R&D alliances have positively influenced the public ER&D performance of Korea.*

In this study, the term *successful ER&D performance* refers to the effective innovation output and outcome created by ER&D projects in terms of technological advances for a given expenditure. Since Sagar & Holdren (2002) pointed out that input-output relationship need to be studied further, several studies have delved into this issue (Costa-campi, Duch-brown, & García-quevedo, 2014; Salies, 2013), but those empirical studies were either focusing on the European private sector or analyzed the energy sector in general. Therefore, this research used data from Korea’s national electricity R&D program to empirically analyze determinants that led to a successful ER&D performance.

Although many previous studies pointed toward different directions, it is axiomatic that the purpose of liberalization in the Korean electricity industry was to induce efficiency by promoting a more competitive environment. Therefore, it is plausible to think that such a purpose would be positively reflected in the industry if they work ideally. Therefore, if liberalization only occurred in Power Generation sector of Korea, R&D performance in that sector would be better than Power Distribution sector. Also, if R&D alliances in the Korean electricity industry had increased, then it is due to R&D alliances having a positive relationship with R&D performance.

To conduct this study, first, the innovation system in the energy sector and performance metrics were reviewed through the literature review. Then, several influential factors (e.g. R&D input, alliance type, characteristics of electricity sector) were selected from previous literatures. After that, models and hypotheses were drawn, and econometric analyses were conducted. Finally, the conclusion and future study are discussed at the end of this dissertation.

2. Literature Review

2.1 Liberalization and Public ER&D

One of the biggest issues of the electricity industry is *liberalization*, also referred to as *deregulation*. The process of liberalization might include *privatization* depending on the degree of reform. Through the 1990s, numerous developed countries liberalized their electricity sectors through restructuring, competition, regulatory reform, and privatization (Jamasb & Pollitt, 2008). These reforms caused a paradigm shift from state ownership and centralized management of infrastructure industries to one that favors decentralized structures, competition, independent regulatory oversight, and private ownership (OECD, 2000).

The degree of liberalization varied depending on the political and indsutry environment of each country. Liberalization in the electricity sector generally involves one or more of the following steps: sector restructuring, introduction of competitive electricity markets for wholesale generation and retail supply, regulation of transmission and distribution networks, establishment of an independent regulator, and privatization (Jamasb, 2002; Joskow, 1998; Newbery., 2002). Table 1 outlines a generic liberalization model for transforming a vertically integrated publicly owned monopoly into a privately owned competitive sector. (Jamasb & Pollitt, 2008)

Table 1. Main steps in electricity reform

Restructuring
Vertical unbundling of generation, transmission, distribution, and supply activities
Horizontal splitting of generation and supply activities
Competition and markets
Wholesale market and retail competition
Allowing new entry into generation and supply
Regulation
Establishing an independent regulator
Provision of third-party network access
Incentive regulation of transmission and distribution networks
Ownership
Allowing new private actors
Privatizing the existing publicly owned businesses

Source: Jamasb & Pollitt, 2008

The main reason for sector reform was to improve “efficiency” by introducing competition to the industry. It was assumed that profit incentives would also encourage and improve R&D and innovation in the sector once the reform was completed (IEA, 1999). This structural change of the electricity industry had also brought change in the public R&D behavior. Previously, the most important role of public ER&D was considered to be laying the groundwork for major technological breakthroughs until enough incentives were induced for private investors to participate. This is still deemed as a valid role of public ER&D. However, the priority of public ER&D had moved toward the development and early commercialization of low-carbon technologies. (GPPI, 2009)

Consequences followed once the priority of public ER&D had shifted. One of the initial effects of liberalization is decrease in R&D intensity. Many of the world's leading utilities in markets that are being deregulated were affected by a reduction in R&D intensity (GAO, 1996; Dooley, 1998). Also, focus of R&D efforts had shifted from long-term to short-term projects. The United States and many of European countries show a trend of avoiding long-term and high-risk research and moving toward near-term business units (Dooley, 1998; Walker & Riley, 1996). Moreover, as the focus of projects moved from long-term to short-term, cooperative/collaborative researches were replaced with "in-house" research projects (The Netherland's Economic Ministry, 1996).

Within liberalization, public ER&D quickly moves away from long-term, public focused research to short-term, proprietary R&D that is competitive and product oriented. Therefore, interpreting the performance of public ER&D in the electricity industry should be differentiated from the previous method of measuring R&D performance.

2.2 Electricity Industry of Korea and Public ER&D

Following the liberalization of the electricity sector by many other countries, Korea joined in on this reformation stream as well. Since 1961, Korea Electric Power Corporation (KEPCO) led the growth in the Korean electric industry while monopolizing on the supply of electric energy. In 1993, the Korean government started to develop an innovation strategy for reengineering public enterprises. As a result, the national government proposed restructuring of the industry, which included privatization. In 2001, the process of reengineering was started, and the competition in the industry came into view; the power generation segment of KEPCO was separated to six different subsidiary companies (5 thermal and 1 nuclear power companies), the Korea Power Exchange (KPX) and Korea Electricity Commission (KOREC) were established to operate and regulate the electric power exchange market (KEA, 2012).

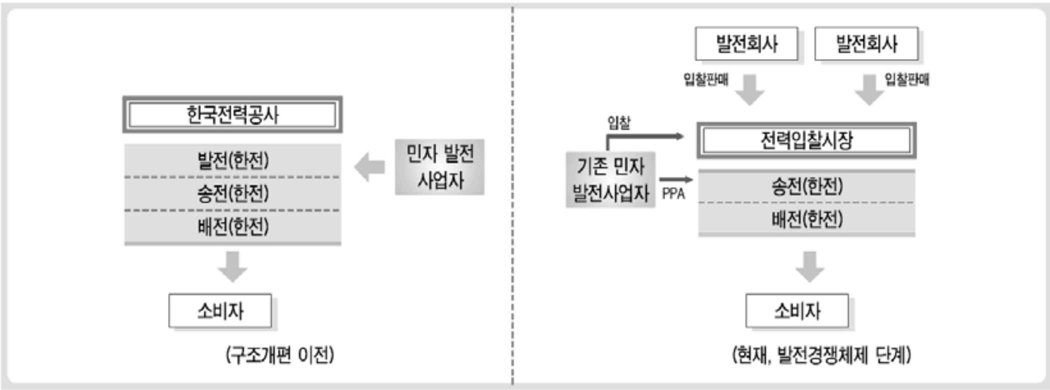
However, the reengineering process must be carried out in four independent stages: These stages, aligned with the models in Table 2, are: Stage 1, preparing the level (Model 1); Stage 2, power generation (Model 2); Stage 3, wholesales market (Model 3); and Stage 4, retail market sales (Model 4). But, after Stage 2 was introduced in 2001, the restructuring process was halted due to opposition from the Economic and Social Development Commission (ESDC), the national labor union consisting of laborers from KEPCO (Lee, 2013). In May 2004, ESDC reported their research and asked for a suspension of the electricity structure reform. The Korean government accepted their request and suspended the reform. However, the electricity reform, which should have been temporarily on hold for up to three to four years, has remained suspended for eleven years. Figure 1 shows the difference between the industry structure before liberalization and the current electricity structure of Korea.

Table 2. Structural reform model of the electricity industry

Model 1	Model 2	Model 3	Model 4
Monopoly	Purchasing Agency	Wholesale Competition	Retail Competition
No competition	Competition in PG	PG*, PD*	PG, PD, Retail

* PG = Power Generation / PD = Power Distribution

Source: Hunt & Shuttleworth (1996), Lee (2013)



Source: KEA, 2012

Figure 1. Electricity industry structure of Korea before 2001 (left) and after 2001 (right)

Partial implementation of the liberalization process in Korea's electricity industry left the question on the effectiveness of the competition policy. The current status of Korea's electricity is quite unstable. One evidence that supports this instability is the frequent amendments that are made in the price decision model. Since the reform was put on hold, there were six amendments made, and the recent amendment introduced in 2008 with compensating factor incentives already went through three major adjustments as well (Nam, 2012). However, the real problem is that KEPCO cannot maintain its current business model since the company has a deficit of more than $2 billion (Koh, 2011). This deficiency cannot be solved with an increase in the price of electricity but with a change in the entire business structure. Therfore, it is necessary to review the effectiveness of the liberalization policy in Korea's electricity industry.

The Electricity Industrial R&D Program was initiated as part of the reengineering plan in 2001, as the function of public benefit had shifted from KEPCO to the government, and in response, the government executed the Electricity Industrial Foundation Plan. The aim of the Electricity Industrial R&D Program was sustainable development of the industry and stability of the electricity supply. Resources for the program have been supplied by the Electricity Industrial Foundation Fund, established by the Electric Utility Law. The fund reached $180 million in 2013, while it was only $22 million in 2001 (see Table 3 (MIR & ETEP, 2007).

Table 3. Electricity R&D program annual budget (2001~2013)

(Unit : $ billion)

Program	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Electricity	22.6	72.5	98.4	112	145	144.6	163.3	174.2	114.5	113.6	108.8	674	907	1427
Nuclear									770	799	1101	1084	963	4,717
Ratio	-	220.8%	35.7%	13.8%	29.5%	-0.3%	12.9%	6.7%	9.9%	1.0%	13.1%	-19.7%	6.4%	

Source: MIR & ETEP (2007) (Updated with KETEP (2014))

Korea's Electricity Industrial R&D Program went through several changes because of the political regime change and efficiency improvements (see Figure 2). From 2001 to 2002, the program was carried out with three sub-programs: New-Power Technology, Electricity-Infrastructure Utilization Technology, and Electricity Environment & Quality Technology. From 2003 to 2006, the program was reorganized into four sub-programs: Electric Power Supply Expansion Technology, Electric Power Equipment Development Technology, Innovative Electric IT Technology, and Eco-friendly Electric Technology. In 2007, the Electricity R&D Industrial Program went through another restructuring process that was based on 1st National Energy Technology R&D Plan (2006). As a result, Hydrothermal Power Technology, Nuclear Power Technology, and Electric Infrastructure Technology development programs were initiated to target a "high-commercialization rate." Commercialization can be measured in terms of R&D sales, cost reduction, technology transfer, and import substitution generated by newly developed products or knowledge. (MKE, 2008; MST & OSTI, 2008)

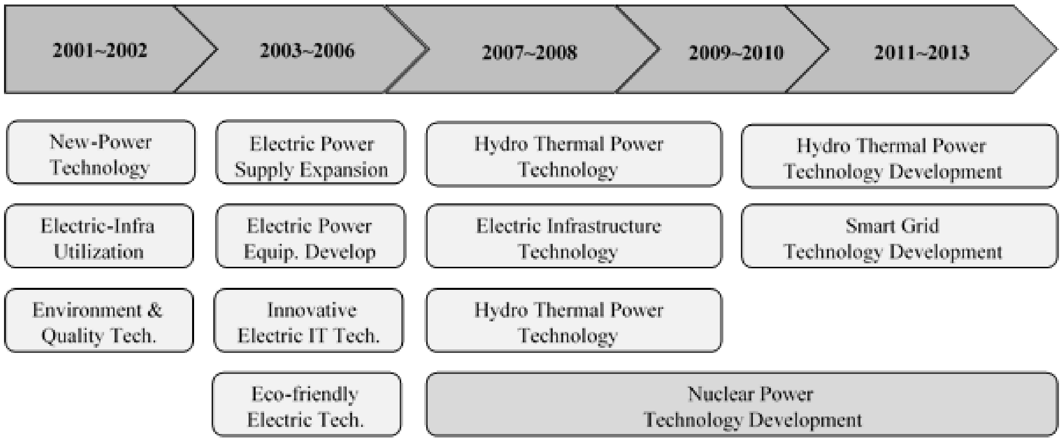


Figure 2. History of Korea's Electricity Industrial R&D Program

Among many sectors of Korea's ER&D program, the importance of the Electricity Industrial R&D Program has increased since the massive blackout in 2012. The incident was believed to have happened because of a failure in the electricity reserve margin plan. As a result, stabilizing power generation and distribution had become the central issue of Korea's energy policy (MKE, 2013). The Electricity Industrial R&D Program focuses on power generation, transmission, and distribution sectors which have been the cornerstones of the energy industry's infrastructure for the last few decades. Although interest in renewable energy is growing, these traditional sectors of the R&D program are still the most dominant field of study on the global decarbonization scenario (IEA, 2015).

One of major trends in Korea's Electricity Industrial R&D Program is increasing the number of R&D project alliances. In 2001, less than 10% of the public electricity industry R&D was devoted to alliance projects, whereas all projects in 2014 were composed of alliance projects. This clearly shows that the R&D trend of public electricity industry of Korea is following a different direction compared to others (see Figure 3).

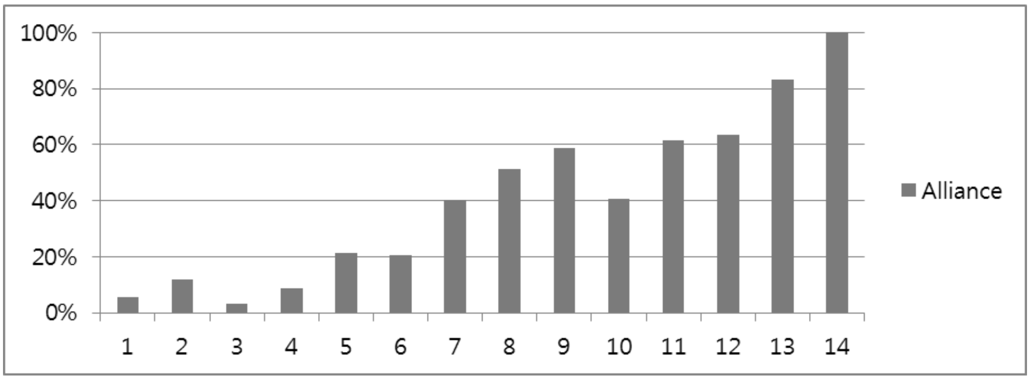


Figure 3. Trend of R&D alliances in Korea's public electricity industry

2.3 Innovation Process

The innovation process is a complex process in which a new technology evolves from a laboratory into the market. The key to the innovation process is the innovation system. This system has been studied by many researchers, and this dissertation introduces two of those major studies: Freeman (1987) defined innovation as an activity that involves the creation, application, modification, and diffusion of new technology. Nelson & Winter (1982) saw it as an outcome of technological change and development.

Innovative activities of the system are carried out by an innovation process. This process is often described as a simple model with several phases (see Figure 4): basic R&D, applied R&D, commercialization, demonstration, and widespread diffusion (Foxon, 2003; Kimura, 2010). The most important issue of this model is that each phase can receive various feedbacks so that the performance of each phase can be enhanced or diminished depending on the policy tool used.

R&D stages in the innovation process involve two main criterions: innovation and commercialization. According to Kelm, Narayanan, & Pinches (1995) there is a general agreement that early phases of R&D focus on innovation to find a technical solution to a problem, while later phases focus on commercialization. Although theoretical models of R&D projects can differ with respect to specifics, events prior to new product launches – project initiation, progress, and other events that imply a project has not yet reached a successful outcome – represent an innovation stage, and new product introduction marks the beginning of the commercialization stage of an R&D project.

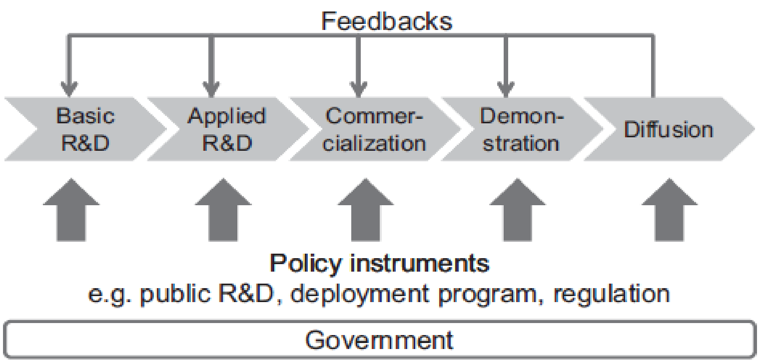


Figure 4. A simplified model of an innovation process (Kimura, 2010)

Out of all the characteristics of the ER&D innovation process, “uncertainty” might be the most significant characteristic (Kimura, 2010). It is difficult to predict market behavior, cost for development, or performance of a new. Many projects failed because of them, and only a few became successful. In the case of Japanese study (Kimura, 2010), only 3 technologies reached the commercialization level, out of 34 technologies that invested $134 million between 1974 and 2002. High failure rates in commercialization is detracting private sectors to lead the innovation process, so unlike other fields, investment from the government in the early stage of ER&D is more encouraging than in any other sector (IEA, 2007).

2.4 Measuring the Effectiveness of R&D Performance

Several steps were taken in this study in order to quantify and measure the effectiveness of R&D. Unlike sales or manufacturing which usually aims for a single purpose, the purpose of R&D tends to be multi-faceted and more subjective. Depending on the case, the goal of R&D could be focused on developing new products, cost savings, customer support, competitive evaluation, or IP protection (Schwartz, Miller, Plummer, & Fusfeld, 2011).

To achieve diverse goals, the R&D process is broken down into several stages so that they can be described in a more palpable measure. Brown & Svenson (1998) regarded R&D as a lab system and defined “input” as raw materials or stimuli a system receives and processes. An R&D lab's inputs are people, information, ideas, equipment, facilities, specific requests, and the funds needed to complete various R&D activities. "Output" includes patents, new products, new processes, publications, or simply facts, principles, or knowledge that were unknown before. "Outcomes" are the accomplishments that have value for the organization. This includes cost reduction, sales increases, product amelioration, etc. Table 4 shows each stage of R&D from input to impact.

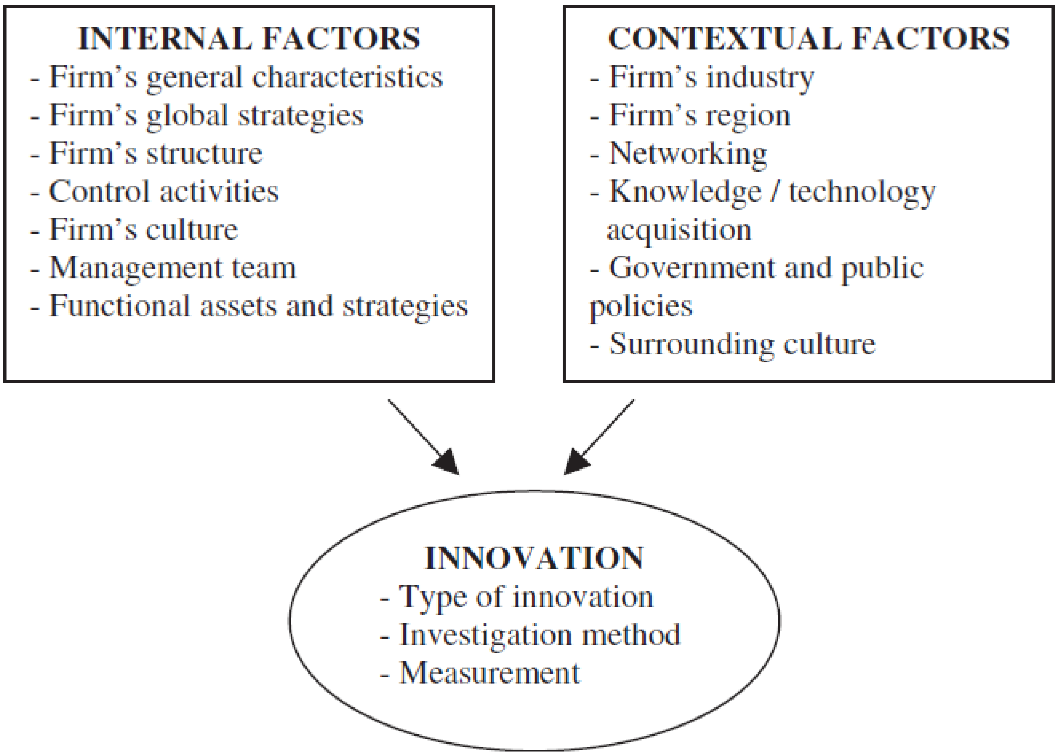
Table 4. Index for each stage of R&D

Input	Performance		Impact
	Output (1st Result)	Outcome (2nd Result)	
people, ideas, info, equipment, facilities, funds, specific request	patents, new products, new processes, facts, principles, knowledge publications	cost reduction, product amelioration, increase in sales, technology transfer	technology, society, science, economy,

Source: Measuring R&D Productivity (Brown & Svenson, 1998; Koh, 2014)

Becheikh, Landry, & Amara (2006) conducted systematic review on the literature of innovation empirical studies in the manufacturing sector from 1993 to 2003. Based on their approach, innovation findings can be divided into two categories: internal and contextual (see Table 5). The definition of internal factor is similar to what we have viewed in Brown & Svenson's (1998) studies, while the framework of Becheikh et al. (2006) considers more contextual factors into it. The contextual factors focus on the environment that has determining impact on a firm's strategies, structuring, and behavior. Sectors (Evangelista et al., 1997; Kam et al., 2003), government policies (Coombs and Tomlinson, 1998; Lanjouw and Mody, 1996), or interaction with universities/research centers/competitors (Fritsch and Meschede, 2001; Keizer et al., 2002) could be useful variables to measure these factors.

Table 5. A framework for integrating innovation findings



2.4.1 Funding

Out of many inputs, a fund is one of variables that could be most easily quantifiable. Although the relation between R&D investment and performance may seem plausible to quantify, the relation between the two is not quite determinative. Therefore, several studies have attempted to define this relationship through empirical studies to find whether they are positive, negative, or not significant (Jang, Shin, & Jung, 2009).

To determine whether a positive relationship exists between R&D investment and performance, Lee & Cho (2012) analyzed 118 private Korean firms that invested in R&D research. Their study concluded that R&D investment increases the technology commercialization rate of R&D sales, and business profit. A similar study was conducted by Shin & Ha (2012), who defined R&D investment as the main criteria of technology management. Their empirical study also concluded that R&D management capability has a positive relationship with R&D commercialization. The Morvey & Dugal (1992) study found that firms with increasing R&D investment generated a higher increase in R&D sales during the period of recession between 1982 and 1991. Foster (2003) studied 1,200 global companies that have increased their R&D investment despite the recession in the 1990s, and the investments of these companies returned much better management performances compared to their rival companies. W. Kim (2013) argued that one of the barriers to commercializing R&D outcomes is insufficient funding in the budget for commercialization; in 2010, only 1.3% of the national R&D budget was allocated to scale up and commercialize outcomes of research projects. Also, a lack of follow-up support or guidance to refine and enhance technologies could lead to the difficulty of turning R&D outcomes into a profitable business.

To analyze the relationships that were either negative or not significant between R&D

investment and performance, Jaruzelski, Dehoff, & Bordia (2005) conducted a study on the investment in R&D of 1,000 global companies for a period of six years. Their study concluded that there are no signs of a positive relationship between R&D investment and performance. Furthermore, after comparing the R&D investments of top global companies such as Toyota and Google with their rivals, the results showed that R&D intensities of the top global companies were relatively low while the performance was much higher. A similar study was conducted by Jang, Shin, & Jung (2009). They studied 175 companies with R&D research institution and concluded that R&D investment and performance had a negative relationship. These studies provide support for why the effectiveness of R&D funding should be considered more than the total amount of investment itself.

However, when it comes to energy R&D, it is still unclear what effect the funding has on the R&D performance because analysis of the trends in ER&D efforts have tended to be based mostly on analysis of the spending pattern, which measures inputs, not outputs, and hobbled by inadequacies in the available data (Sagar & Holdren, 2002). For this reason, many of the recent studies in the energy field aim to define the relationship between input and output (Balachandra, Kristle Nathan, & Reddy, 2010; Costa-campi et al., 2014; Kimura, 2010; Walsh, 2012). However, econometric approach on the electricity R&D of Korea is still a new concept in the industry.

2.4.2 Alliance

The importance of external factors is continuously emphasized in recent literatures. One of main focus is alliances. Lai & Chang (2010) asserted that utilizing external resources to complement limited internal resources and capabilities are important in today's competitive and turbulent environment. Utilizable resources could be enhanced by forming strategic alliances with others. Forming strategic alliances have become a vital strategy for many corporations to achieve competitive advantage by gaining market access, scale economies, and competence building through collaborations (Muthusamy & White, 2005; Dyer and Singh, 1998; Gulati, Nohria, & Zaheer, 2000; Yoshinol & Rangan, 1995). R&D alliance is a type of strategic alliance that happens to form in fast-changing technological fields (Todeva & Knoke, 2005). Many terms are used to indicate R&D alliance, such as "R&D cooperation", "technology innovation network", "open innovation", or "industry-university-government research institution" (Bae, Oh, & Kim, 2014). Basically, these terms indicate that two, or sometimes more, companies in the same field form a R&D alliance to constitute a new entity for R&D activities or technology development. While forming an alliance, many companies also continue to compete with each other in the existing market (Lai & Chang, 2010). However, this isn't just a phenomenon; it is rather a system of exchanging knowledge between researchers. For researchers wanting to share knowledge and access new technologies, R&D alliances function as a platform (Browning & Beyer, 1995; Sakakibara, 2002; Teece, 1992). Some collaborative mechanisms, such as building central laboratories and setting up funding pools to outsource R&D activities, can support R&D alliances. The Government–University-Industry (GUI) linkage (the Triple Helix) also plays an important role in R&D alliances (Lai & Chang, 2010).

In previous researches, many types of R&D alliances were considered. Some researches categorized those types into cooperative and non-cooperative research (Chang, 2010; Park, 2014). In other studies, participant subject, such as university-university, university-industry, university-research institution, and so on was considered (Chung, Chung, & Kim, 2014). Differentiated alliance types to competitor, supplier, and customer had been attempted (Belderbos, Carree, & Lokshin, 2004), while some studies concentrated on cooperative structures, company size, or affiliated district (Veugelers & Cassiman, 2005; Coursey & Bozeman, 1989; Onida & Malerba, 1988). Coursey & Bozeman (1989) analyzed cooperative researches that involved government laboratories and categorized participant subjects by involvement of university, international research, federal and local government research, and involvement of private firms. Onida & Malerba (1988) categorized European university-industry-government laboratory by time-period and target of the relationship. Some researchers focus on cooperative R&D projects as well (Schwartz, 2012). Schwartz concluded that type, size, and number of participant institution are successful factors of cooperative researches. Also, it was found in previous research that multiple R&D alliance portfolios are most likely to succeed in jointly creating innovative outcomes in the high-tech manufacturing industries such as semiconductor, electronics, computer manufacturing, and telecommunication (S. J. Kim, 2014).

2.4.3 Competition

All previous studies made great contributions to the academic study on cooperative researches. However, these studies focused on broad industries, which mean there is still a need for detailed empirical studies on specific industries, in this case, electricity industry. The electricity industry is a complex industry that requires high-tech manufacturing for supervision and control purposes and deals with energy resources, manufacturing, turbine technology, etc. Therefore, due to the complexity of the electricity industry, the impact that an alliance has on it could be different from other previous studies.

Another significant external factor is the level of the competition of the industry, which is a traditional and important research topic for business and economics (Cohen & Levin, 1989; Sutton, 1997; Castellacci, 2011). Classical works in this field were originally motivated by the empirical investigation of the effects that the degree of competition and concentration of an industry may have on firms' R&D and innovative activities (Castellacci, 2011). One of the key hypotheses, corroborated in several empirical studies, is that industry-level competition may decrease the monopoly rents of prospective innovative firms, thus reducing their incentives to engage in R&D activities (Geroski, 1990; Nickell, 1996; Scherer, 1967). This is an argument traditionally known as *the Schumpeterian effect*, which postulates the existence of a negative relationship between the degree of competition in an industry and the R&D intensity of firms (Griffith, Harrison, & Simpson, 2010; Nicoletti & Scarpetta, 2003). However, more recent research has also pointed out the possibility that product market competition may also turn out to boost R&D investments, since it may increase the incremental profits that firms obtain by investing in R&D activities (P. Aghion, Harris, Howitt, & Vickers, 2001). This argument is known as *the escape-competition effect*, and it points out that the relationship between the degree of market competition and innovation may hence be positive, and even more so in industries where competition between rival firms is fierce. Considering these two contrasting forces, Philippe Aghion, Bloom, Blundell, Griffith, & Howiltt (2002) have also pointed out the existence of an inverted U-shaped relationship between market competition and innovation.

Focusing on the measurable outcomes and outputs may provide a more effective measurement of performance (Brown & Svenson, 1998). However, focusing too much on the behavior or subjective matter would lead to the failure of measurement because many of these terms are difficult to measure. For instance, ideas or specific information are difficult to compare their impact unless a quantified value is given. As Brown & Svenson (1998) indicate, the typical measurable outputs are the number of papers published, designs produced, products designed, patents received, etc. These tendencies could be found in many other empirical studies, where quantity index is used – often reflecting quality factors as well. Koh (2014) used patents as innovation output and R&D sales as innovation outcome to measure the project performance of government R&D programs in IT and CT. McLaughlin & Jordan (1999) and Ruegg & Feller (2003) used papers, patents, and new employees to construct the logic models for the R&D performance. Kim (2012) used patents to measure intangible innovation of the value-based innovation system of the Korean smart media industry. However, Brown & Svenson (1998) acknowledged that external measures should be considered to improve the R&D lab system.

Evidence suggests that the electricity sector reforms can achieve (short-term) operating efficiency through cost savings and the spread of best practices. The logical extension of the argument is that liberalization will also lead to improved (mid-term) investment efficiency and adoption of best available technologies. A further extension of this logic suggests that firms will have an incentive to engage in R&D to gain competitive advantage. Indeed, the main source of efficiency improvement in the sector and its contribution to sustainable development lies in long-term technological progress (Jamasb & Pollitt, 2008).

Also, an effective measurement system requires specific consideration on the targeted industry; however, most previous researches were too general on this matter. Another problem is that many of explanatory variables are differently operationalized by the authors. Therefore, relative internal and external variables are considered based on the targeted purpose of the study.

3. Methodology

3.1 Data

The data used for this empirical analysis was obtained from "Energy R&D Result Analysis Reports of 2013”, reported by Korea institute of Energy Technology Evaluation and Planning (KETEP) (KETEP, 2014). KETEP is the government’s funding agency that undertakes planning, evaluation, and management of national energy R&D projects in Korea. The “Result Analysis Report” is issued annually to update statistical data on the performance of the national energy R&D program. The annual report includes data such as economic results, new employment, patents, papers, etc. The report also contains projects that have completed all technical objectives within the last five years. In other words, for each annual analysis report, project samples may have different time periods from their project completion to provide their outcome. So, there could be additional performance results for projects completed in recent years. The analysis contains each individual report on the subcategories of national energy R&D programs: Power Generation & Electricity Delivery, Nuclear Power, Energy & Resource Recycling, New & Renewable Energy, Radioactive Waste Management, Energy Experts Development Program, and Energy Technology Policy Analysis.

Among those programs, Power Generation & Electricity Delivery and Nuclear Power programs were selected because this study focuses on the traditional electricity industry.

For these two programs, over $1 billion was invested since 2001, specially targeted for developing the infrastructure of the electricity power industry.

From 2008 to 2013, 565 projects were completed; among them, 439 projects were verified for the purpose of econometric analysis. 309 projects were completed in the Electricity Delivery Program, 72 projects were for the Power Generation (Thermal) program, and 58 projects were from the Nuclear Power program.

3.2 Crepon, Duguet, and Mairesse (CDM) Model

One of the common econometric models for analyzing R&D performance is the CDM model. The standard version of the CDM model is used to argue the importance of analyzing four stages of the innovation–productivity link in order to investigate the impact of innovation on the productivity performance of firms (Crépon, Duguet, & Mairessec, 1998; Hall & Mairesse, 2008; Heshmati & Lööf, 2005). (1) First, the firm decides whether to engage in innovative activities. If the enterprise decides to engage in innovation, (2) it then allocates resources for investment in R&D activities. (3) Subsequently, the innovative input leads to an innovative output (e.g. new products); and (4) finally, the innovative output leads to an improvement in the labor productivity of the firm (Castellacci, 2011).

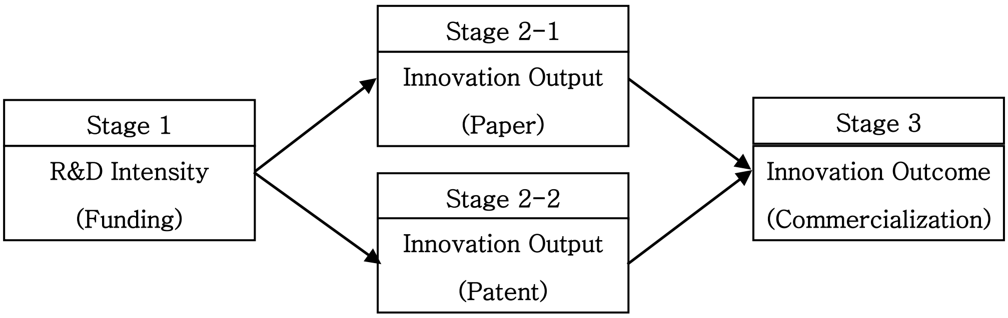


Figure 5. Variation of CDM model

The model proposed in this research (Figure 5) was made from a modification of the traditional CDM approach because this research focuses on the performance of R&D projects instead of firms. Therefore, Stage 1 was disregarded since all R&D projects target innovative activities. However, Stages 2 to 4 were slightly modified. For Stage 2, this research considers how the resources for R&D activities were distributed since the amounts of resources invested in R&D activities were already determined by the government or funding agencies. At Stage 3, all terms remain the same except innovative output was measured by the quantity of patents and research papers. For Stage 4, however, the commercialization of the project was considered instead of the labor productivity of the firm.

From hereafter, the first three stages will be referred to as (1) Stage 1: R&D Intensity, (2) Stage 2: Innovation Output, and (3) Stage 3: Commercialization (Outcome). This is aligned with the previous study of Brown & Svenson (1998) in their R&D lab process. For the econometric analysis, different explanatory and moderate variables are considered depending on the characteristics of each stage.

The advantage of using the CDM model is that this could unravel the relationship between innovation input and productivity by looking at the black box of innovation processes at the project level (Griffith, Huergo, Mairesse, & Peters, 2006). Each stage measures not only the effect that comes directly from the previous stage but also the effect generated from the stage before. Therefore, a collectively exhaustive effect could be reflected in the final stage. The modification of the CDM analysis is commonly practiced among numerous empirical studies for measuring the effect of R&D performance (Balachandra et al., 2010; Blanchard, Huiban, Musolesi, & Sevestre, 2013; Castellacci, 2011; Costa-campi et al., 2014; Griffith et al., 2006).

As previously introduced in the literature review section, there are three categories of variables used in the econometric analysis: (1) R&D input (e.g. funding, researcher, etc.), (2) alliance, and (3) industrial characteristics. The main idea of this research is *to observe what factors contribute to the successful R&D output and outcome.* For this purpose, the concept of intensity was considered in this analysis. Intensity is usually expressed as the output divided by the input, so the number of researchers is considered to calculate the intensity of the output. Also, quantity metric alone is not sophisticated enough to measure effectiveness. To adjust for the deficiency, quality factors are added to the variables. For instance, for the innovation output of papers, the SCI papers are weighted more (see Table 3.1). For the innovation output of patents, the applied and registered patents are weighted differently. The guideline for weighted variable was referenced from the electricity program evaluation of the electricity R&D program (MST & OSTI, 2008). Considering all those, three categories of variables were named for this study: (1) Characteristics of Projects (CoP), (2) Type of Alliance (ToA), and (3) Characteristics of Electricity Industry (CoE).

3.3 Characteristics of Projects (CoP)

Characteristics of Projects (CoP) is a set of variables that represents inputs and outputs of each individual projects. These variables are related to project funding, duration, researchers, innovation output, and commercialization. Since the research model of this dissertation is based on CDM, some of these inputs (e.g. amounts of funding and innovation output) are used as dependent variables as well as explanatory variables, depending on the stage. Most of these inputs were treated in several previous researches (Castellacci, 2011; Kim, 2014). However, few more terms such as stability and ratio are newly introduced to estimate the relationship between stages in a more drastic measure. For instance, one can expect that more funding leads to increased output. But, specifically, is this the result of more investment from the government or the private sector? The larger projects with more researchers would generate more innovation output, but what if we considered the intensity? One of the purposes of this dissertation is to consider such terms to measure the relationship more precisely between each stage by using variables that are more effective and efficient (see Table 6).

Table 6. CoP variables for econometric analysis

Variable	Description	Unit	N	Mean	Std. dev	Min	Max
funding.total.billion	Amount of funding includes gov. and private investment (in-kind included)	₩B	439	3.46	8.03	0.04	106.47
funding.gov.billion	Amount of gov. investment (in-kind included)	₩B	439	1.77	3.55	0.03	35.23
funding.private.billion	Amount of private funding (in-kind included)	₩B	439	1.69	5.69	0.00	96.48
inty.funding.total.billion	$\frac{funding.total.billion}{total.number.of.researchers}$	₩B/ppl	439	0.11	0.01	0.006	2.13
inty.funding.gov.billion	$\frac{funding.Gov.billion}{total.number.of.researchers}$	₩B/ppl	439	0.06	0.005	0,004	1.29
inty.funding.private.billion	$\frac{funding.private.billion}{total.number.of.researchers}$	₩B/ppl	439	0.05	0.005	0.00	1.44
funding.ratio	$\frac{Amount.of.Gov.funding}{Amount.of.total.funding}$	-	439	0.67	0.17	0.09	1.00
funding.stability	$\frac{\sum Change.of.annual.funding}{Amount.of.total.funding}$	-	439	0.91	1.50	0.00	12.78
researcher.total	Number of researchers	N	439	26.69	32.67	3.00	294.00
researcher.bs	Number of university degree holder or under.	N	439	14.60	19.73	0.00	165.00
researcher.ms	Number of master degree holder	N	439	7.78	12.55	0.00	111.00
researcher.ph.d	Number of Ph.D degree holder	N	439	4.30	5.38	0.00	69.00
duration.year	Duration for project development	Yr	439	3.07	1.39	1.00	7.83
size	Number of additional participants in consortium	N	439	1.94	3.57	0.00	41.00
innovation.quality.paper	0.5*regular papers + 1.0*SCI papers	N	439	3.16	4.91	0.00	50.50
innovation.quality.patent	0.4*patent application + 0.6* patent registration	N	439	1.62	2.58	0.00	26.80
innovation.intensity.paper	$\frac{innovation.quality.paper}{total.number.of.researchers}$	N/ppl	439	0.19	0.27	0.00	2.02
innovation.intensity.patent	$\frac{innovation.quality.patent}{total.number.of.researchers}$	N/ppl	439	0.19	0.44	0.00	5.00
comm.ox	Dummy=1 if project is commercialized (technology transfer, R&D sales, import substitution, and cost reduction)	-	439	0.16	0.37	0.00	1.00

3.4 Type of Alliance (ToA)

The main focus of this research is to conduct empirical studies on the R&D of electricity industry from the perspective of the type of alliance. In this specific research, Type of Alliance (ToA) is defined as a R&D project consortium that is convened by a government funded project to achieve technology innovation and commercialization in electricity R&D. Seven different types of alliances are considered in ToA. The first six types are mapped on a 3x3 table in Figure 6; they are: (1) industries (II), (2) universities (UU), (3) government research institutes (RR), (4) industry & university (IU), (5) industry & research institution (IR), and (6) university & research institute (UR). The seventh ToA is industry & university & research institute (IUG), which is depicted as a box in Figure 6.

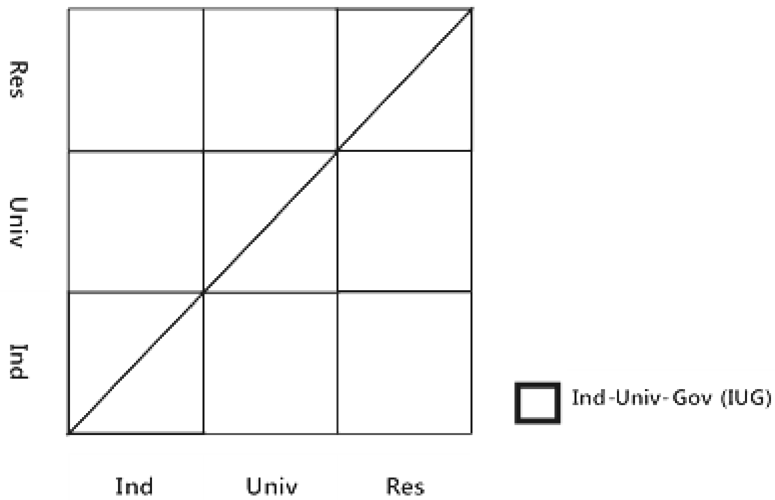


Figure 6. 3 x 3 Matrixes for ToA

To perform econometric analysis on all seven ToAs, certain limitations are placed due to the relatively small number of samples. Therefore, to complement the restrictions placed on ToA, two types of alliance strategies are added: (1) converged/diverged strategy, and (2) industry-included strategy. Converged/diverged strategy is used to differentiate ToA that are made between the two subcategories, converged alliance and diverged alliance. II, UU, and RR are considered converged alliance strategies, while IU, IR, UR, and IUR are considered diverged alliance strategies (see Figure 7). Industry-included alliance is used to observe specific categories related to commercialization. Because commercialization occurs among relationships within an industry, such categorization would be useful for differentiation.

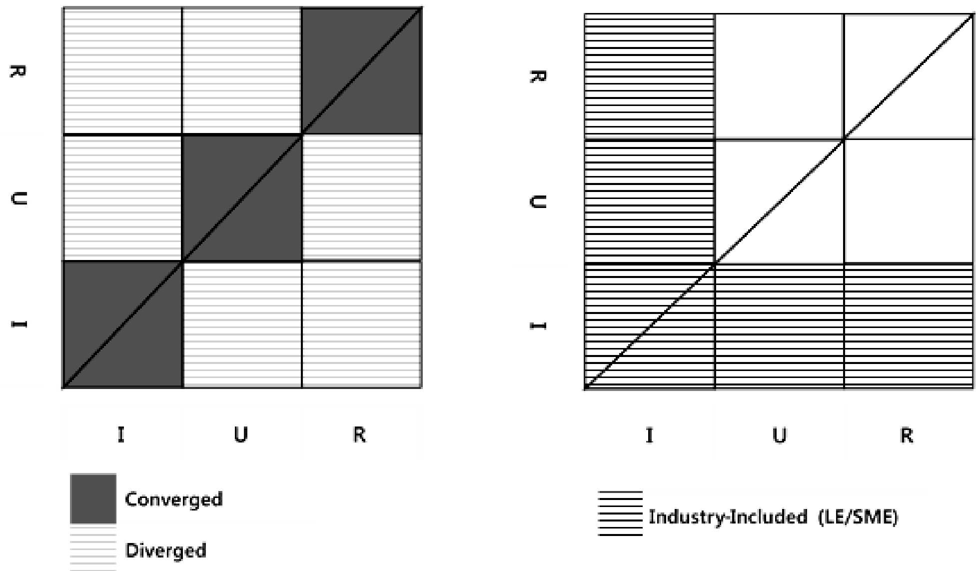


Figure 7. Converged/Diverged Matrix / Industry-Included Matrix

Table 7. ToA variables for econometric analysis

Variable	Description	Unit	N	Mean	Std. dev	Min	Max
toa.ox	Dummy=1 if project consortium includes participants	-	439	0.62	0.49	0.00	1.00
toa.strategy.conv.div	Dummy=1 if alliance type is divergent (ex. IU, IR, IUR)	-	439	0.43	0.50	0.00	1.00
toa.strategy.industry	Dummy=1 if alliance type includes industry (ex. IU, IR)	-	439	0.64	0.48	0.00	1.00
toa.leading.le	Dummy=1 if project leader is Large Enterprise	-	439	0.29	0.46	0.00	1.00
toa.leading.sme	Dummy=1 if project leader is SME	-	439	0.15	0.36	0.00	1.00
toa.leading.others	Dummy=1 if project leader is other than LE or SME	-	439	0.56	0.50	0.00	1.00
toa.type.i	Dummy=1 if project includes industry alone (no alliance)	-	439	0.08	0.26	0.00	1.00
toa.type.u	Dummy=1 if project includes university alone (no alliance)	-	439	0.10	0.30	0.00	1.00
toa.type.r	Dummy=1 if project includes government research institution alone (no alliance)	-	439	0.21	0.41	0.00	1.00
toa.type.ii	Dummy=1 if project alliance type is II.	-	439	0.15	0.36	0.00	1.00
toa.type.uu	Dummy=1 if project alliance type is UU	-	439	0.03	0.17	0.00	1.00
toa.type.rr	Dummy=1 if project alliance type is RR	-	439	0.00	0.05	0.00	1.00
toa.type.iu	Dummy=1 if project alliance type is IU	-	439	0.19	0.40	0.00	1.00
toa.type.ir	Dummy=1 if project alliance type is IR	-	439	0.12	0.32	0.00	1.00
toa.type.ur	Dummy=1 if project alliance type is UR	-	439	0.02	0.13	0.00	1.00
toa.type.iur	Dummy=1 if project alliance type is IUR	-	439	0.10	0.30	0.00	1.00

3.5 Characteristics of Electricity Industry (CoE)

Table 8. CoE variables for econometric analysis

Variable	Description	Unit	N	Mean	Std. dev	Min	Max
coe.public.enterprise	Dummy=1 if the project includes public enterprise	-	439	0.29	0.45	0.00	1.00
coe.gen.dis	Dummy=1 if project belongs to power distribution (smart-grid) (0 for thermal power and nuclear power generation)	-	439	0.70	0.46	0.00	1.00

The CoE variables are intended to identify whether certain characteristics of Korea's electricity industry are reflected in each stage. Two variables are considered: (1) participation of Public-Enterprise (PE), and (2) differences of technical-sector. Difference of technical-sector is consisting Power Generation (PG) and Power Distribution (PD) (Figure 8).

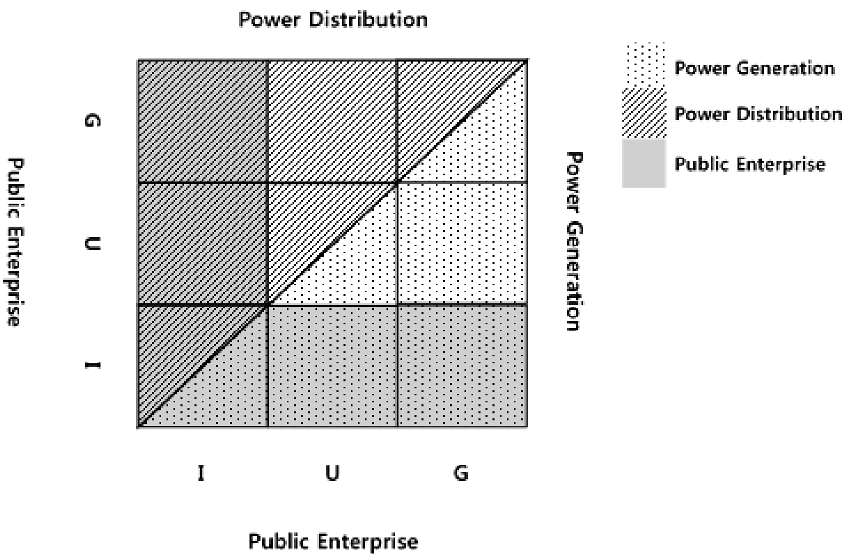


Figure 8. 3 x 3 Matrix for ToA within CoE

The participation of Public Enterprise is used to observe whether public enterprises that play a key role in Korean electricity industry also play a key role in electricity R&D as well. Most of public enterprises are subsidiary companies of KEPCO, which consists of KEPCO Plant Service & Engineering Co. (KPS), KEPCO Knowledge Data Network (KDN), KEPCO Nuclear Fuel Company (KNF), Korea Electric Power Research Institute

(KEPRI), Korea Hydro & Nuclear Power (KHNP), KEPCO Engineering and Construction (KEPCO-ENC), and five thermal power companies (East-West, South-East, South, West, and Middle), etc. Analyzing the impacts these firms have on the electricity R&D would provide meaningful implications.

Another variable for differences of technical sector divides the table in Figure 8 into two groups. They are power generation and power distribution. Power generation is thermal & nuclear power where privatization had occurred in 2001. On the other hand, power distribution is the power transmission and distribution sector which was left as a monopolized market structure since 2004 when the ESDC had halted the rest of liberalization process. The main purpose of this variable is to determine if any disparate effects appear between two sectors.

3.6 Econometric Analysis Model

Since this analysis is founded on the CDM model, regressions needs to be implemented on each stage based on the characteristics of the data. Previous studies show that several analysis techniques could be used for empirical studies on innovation (Becheikh et al., 2006). OLS was the most common technique. Descriptive statistics and Logit model were the next. Tobit, Probit, Negative Binomial, and Poisson models are also used from time to time depending on the way the dependent variables are measured. For the purpose of this study, three different models were selected, which are described in the following:

3.6.1 Stage 1: R&D Intensity

$$R\&D = \beta_1 \times CoP_i + \beta_2 \times ToA_i + \beta_3 \times CoE_i + \varepsilon_i \qquad \textbf{(1)}$$

The model for Stage 1 was constructed using the Ordinary Least Square (OLS) method (Eq 1). Characteristics of Projects (CoP), Type of Alliance (ToA), and Characteristics of Electricity Industry (CoE) were used as explanatory variables. For the dependent variable, intensity of total amount of funding represents the R&D intensity.

3.6.2 Stage 2-1: Paper Innovation Output

$$IO_{PAPER_i} = \beta_4 \times CoP_i + \beta_5 \times ToA_i + \beta_6 \times CoE_i + \beta_7 \times R\&D_i + \varepsilon_i \qquad \textbf{(2)}$$

The model for Stage 2-1 was constructed using Negative Binomial (NB) regression, due to over-dispersion problem (Eq 2). Over-dispersion problem can occurred when the standard deviation is greater than average. Such phenomenon could generate bias for error term, therefore, NB distribution, which is combined by Poisson and Gamma distribution, could be exploited to enhance the regression result instead of the Poisson regression where the mean has to be equal to the variance (Jong, 2008). Since the analysis uses CDM model, asymptotic value of R&D intensity from the previous stage is now used as an explanatory variable with CoP, ToA, and CoE.

3.6.3 Stage 2-2: Patent Innovation Output

$$IO_{PATENT_i} = \beta_8 \times CoP_i + \beta_9 \times ToA_i + \beta_{10} \times CoE_i + \beta_{11} \times R\,\&\,D_i + \varepsilon_i \qquad \textbf{(3)}$$

The model for Stage 2-2 is the same as Stage 2-1 since both are measurements of innovation output (Eq 3). Since the analysis uses the CDM model, asymptotic value of R&D intensity from the previous stage is used as the explanatory variable with CoP, ToA, and CoE.

3.6.4 Stage 3: Commercialization

$$COMM_i = \beta_{12} \times CoP_i + \beta_{13} \times ToA_i + \beta_{14} \times CoE_i + \beta_{15} \times R\,\&\,D_i + \beta_{16} \times IO_{PAPER_i} + \beta_{17} \times IO_{PATENT_i} + \varepsilon_i \quad \textbf{(4)}$$

The model for Stage 3 assumes the binary logistic regression model since the dependent variables consist either 0 or 1 (0 means not commercialized and 1 means commercialized) (Eq 4). Commercialization includes R&D sales, technology transfer, import substitution effect, and cost reduction effect. Since the analysis uses the CDM model, asymptotic value of R&D intensity from the previous stage and innovation output (both paper and patent) is now used as the explanatory variable with CoP, ToA, and CoE.

4. Econometric Analysis of the CDM Model

4.1 Results of Econometric Analysis

Stage 1: R&D Intensity

The amount of resources that a project receives for R&D is, on average, higher when the ToA includes industry.	***Significant***
The amount of resources that a project receives for R&D is, on average, different among CoE characteristics.	***Significant***

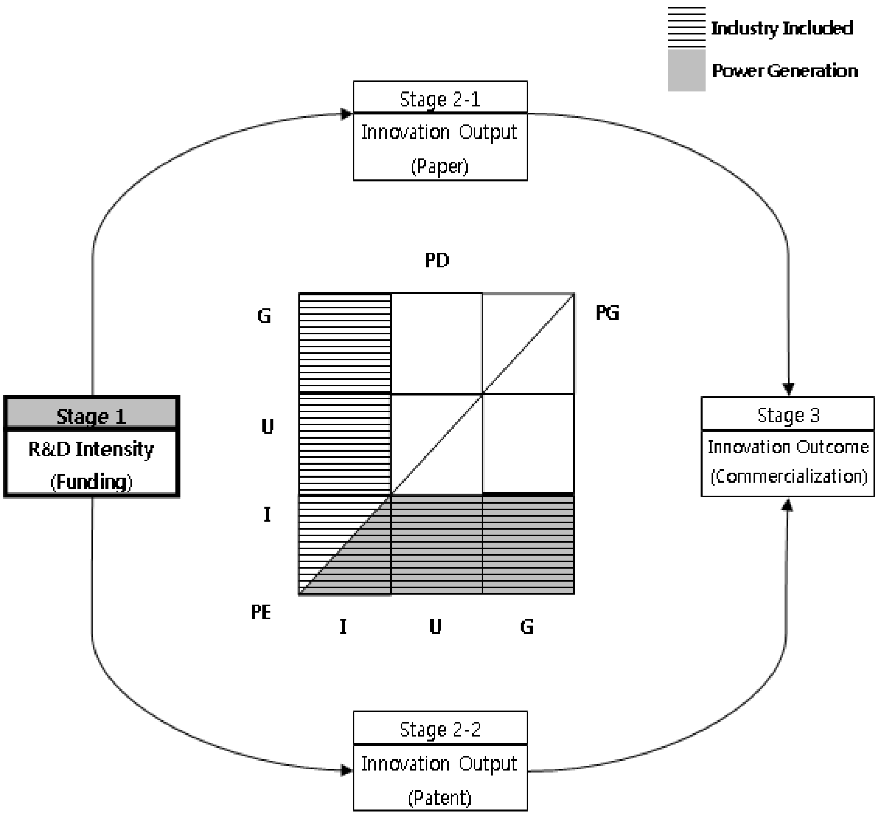


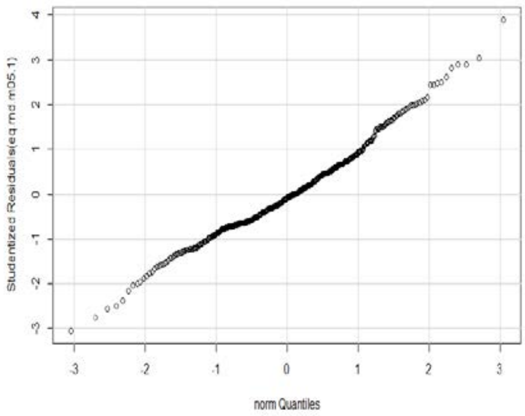
Figure 9. Diagram of Econometric Analysis on Stage 1

First, the correlation test was conducted to see whether certain variables cannot be used together for econometric analysis because of the endogeniety problem. The variables shown in Table 9 were avoided being used together for the econometric analysis.

Table 9. **Correlation test for Stage 1 R&D intensity**

funding.total.billion	funding.gov.billion	funding.private.billion	funding.stability
	0.78	0.92	0.64
researcher.total	researcher.bs	researcher.ms	researcher.ph.d
	0.91	0.88	0.65
size	researcher.total	researcher.bs	researcher.ms
	0.78	0.75	0.66

Next, the goodness of the fit test was conducted to see how well the constructed model for Stage 1 fits a set of observations. The Stage 1 model used OLS, therefore, the Goldfeld–Quandt test was used to check for homoscedasticity. The Goldfeld–Quandt test is one of two tests proposed in a 1965 paper by Stephen Goldfeld and Richard Quandt (Goldfeld & Quandt, 1965). The test checks for homoscedasticity by dividing the dataset into two parts or groups; hence the test is sometimes called a two-group test. According to the Goldfeld-Quandt test result for Stage 1, the null hypothesis was not rejected. Similar result was obtained with the Harrison-McCabe test, which is a similar test also used for checking heteroscedasticity of a model. The results are shown in the Figure 10.



Goldfeld-Quandt Test

- data: eq.rnd.m05.1
- GQ = 0.7093, df1 = 205, df2 = 204,
- p-value = 0.9928

Harrison-McCabe Test

- data: eq.rnd.m05.1
- HMC = 0.5761; p-value = 0.987

Figure 10. Goldfeld-Quandt & Harrison-McCabe Test

According to the econometric analysis shown in Table 10, which was completed by linear regression, “funding.ratio” and “ln.inty.funding.total.billion” has a negative relationship. This means that the logarithm value of the total amount of funding decreases when government funding takes a bigger portion for intensity of total funding. This could also be interpreted as the funding size of the project being affected by the amount of private funding. From the result Table 10, it is also found that “ln.researcher.bs”, “ln.researcher.ms”, and “ln.research.ms” has a significantly negative relationship with “ln.inty.funding.total.billion”. The result of this analysis means that the intensity of the total amount of funding decreases with more researchers involved in a project, however, the decrease return to scale (DRS) is BS (-0.03) > MS (-0.01) > Ph.D (-0.02) in order.

The funding intensity among the ToA is I (0.72) > IR (0.63) > IUR (0.51) > II (0.44) > IU (0.37) were in order for relationship with “ln.inty.funding.total.billion”. This is an interesting point because IUR projects averagely receive more funding, but it does not necessarily correlate with the intensity of the funding. It should be noted that the analysis did not compare projects between selected and non-selected due to the lack of data, so this analysis is limited to checking the tendency of projects that have received funding.

Table 10. Linear Regression Result for CoP + Type.ToA on ln.funding.total.billion

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-4.21183	0.221052	-19.054	< 2e-16	***
funding.ratio	-0.45135	0.207754	-2.173	0.03037	*
ln.researcher.bs	-0.03398	0.008616	-3.944	9.38E-05	***
ln.researcher.ms	-0.01119	0.004768	-2.347	0.019364	*
ln.researcher.ph.d	-0.02206	0.005951	-3.707	0.000237	***
duration.year	0.472609	0.025495	18.538	< 2e-16	***
toa.type.i1	0.720645	0.150502	4.788	2.33E-06	***
toa.type.r1	-0.25112	0.117559	-2.136	0.033245	*
toa.type.ii1	0.443253	0.132061	3.356	0.000861	***
toa.type.uu1	-0.24537	0.193464	-1.268	0.205395	
toa.type.rr1	-0.26397	0.628236	-0.42	0.674568	
toa.type.iu1	0.378482	0.120947	3.129	0.001873	**
toa.type.ir1	0.63478	0.132803	4.78	2.42E-06	***
toa.type.ur1	0.146108	0.235504	0.62	0.535323	
toa.type.iur1	0.511799	0.145223	3.524	0.000471	***

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

The study also found that including industry in ToA shows a tendency to receive more funding (Table 11). Including industry in R&D process means the level of R&D is shifting from basic research to the deployment level, where higher R&D cost is expected.

Table 11. Linear Regression Result for CoP + ToA.Strategy.Industry

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-4.47919	0.186486	-24.019	< 2e-16	***
funding.ratio	-0.35845	0.201854	-1.776	0.0765	.
ln.researcher.bs	-0.03647	0.008569	-4.256	2.55E-05	***
ln.researcher.ms	-0.00952	0.004745	-2.007	0.0454	*
ln.researcher.ph.d	-0.02443	0.005728	-4.264	2.47E-05	***
duration.year	0.490919	0.024275	20.223	< 2e-16	***
toa.strategy.industry1	0.653088	0.076543	8.532	2.45E-16	***

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

The participation of public enterprise (“coe.public.enterprise”) has a positive relationship with the intensity of the total amount of funding based on all three econometric analyses above. The amount of funding for a project is greater when the public enterprise is included.

Table 12. Linear Regression Result for CoP + CoE.public.enterprise

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-3.84652	0.186945	-20.576	< 2e-16	***
funding.ratio	-0.87305	0.217801	-4.008	7.20E-05	***
ln.researcher.bs	-0.02706	0.009151	-2.957	0.00327	**
ln.researcher.ms	-0.00174	0.004994	-0.348	0.72822	
ln.researcher.ph.d	-0.03413	0.006017	-5.672	2.59E-08	***
duration.year	0.510057	0.026399	19.321	< 2e-16	***
coe.public.enterprise1	0.204684	0.084662	2.418	0.01603	*

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Table 13 shows he result on comparison between the power generation and the distribution sector (“coe.gen.dis”). It shows a negative relationship with the logarithm value of total amount of funding, which means that project funding has been given slightly more to the power generation field.

Table 13. Linear Regression Result for CoP + CoE.gen.dis on ln.funding.total.billion

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-3.4547	0.175358	-19.701	< 2e-16	***
funding.ratio	-0.99666	0.192865	-5.168	3.63E-07	***
ln.researcher.bs	-0.02711	0.008969	-3.022	0.00266	**
ln.researcher.ms	-0.00207	0.004882	-0.423	0.67244	
ln.researcher.ph.d	-0.03247	0.005916	-5.488	6.95E-08	***
duration.year	0.506019	0.025521	19.828	< 2e-16	***
coe.gen.dis1	-0.338	0.070411	-4.8	2.19E-06	***

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Stage 2-1: Innovation Output (Paper)

The amount of innovation output of papers that a project produces for R&D is, on average, lower when ToA includes industry.	***Significant***
The amount of innovation output of papers that a project produces for R&D is, on average, different among CoE characteristics.	***Not Significant***

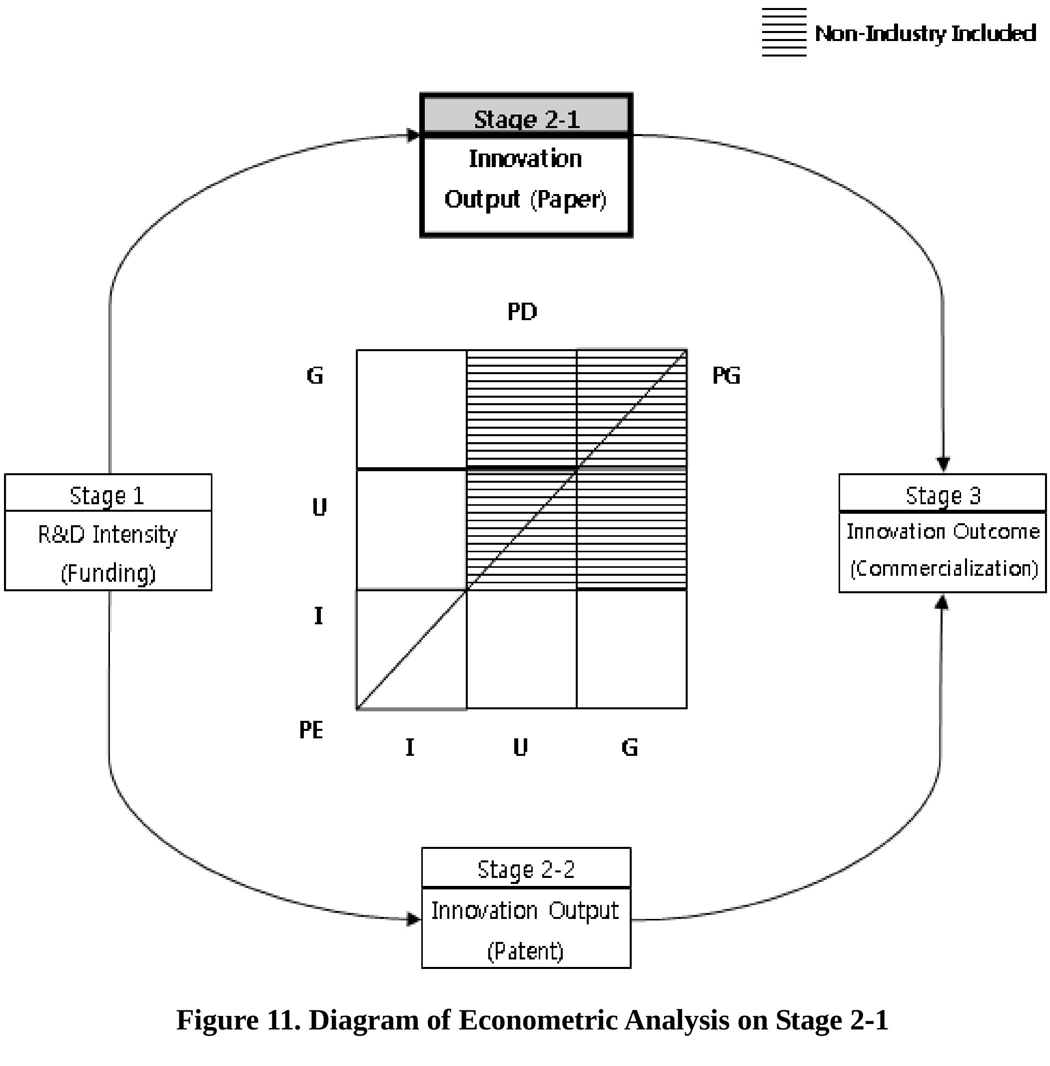


Figure 11. Diagram of Econometric Analysis on Stage 2-1

For Stage 2, few more correlations were found. The variables shown in Table 14 were avoided being used together for the econometric analysis.

Table 14. Correlation test for Stage 2 Innovation Output (paper and patent)

innovation.quality.paper	Innovation.total.paper	innovation.intensity.paper
	0.96	0.65
innovation.quality.patent	Innovation.total.patent	
	0.99	

In this stage, the negative binomial regression method was selected since dependent variables are count variables (patents and papers). Negative binomial regression is used instead of the Poisson model when the dispersion of data is wide. A Poisson variable can be used only when the mean is equal to the variance. The distribution of the data is shown in Figure 12

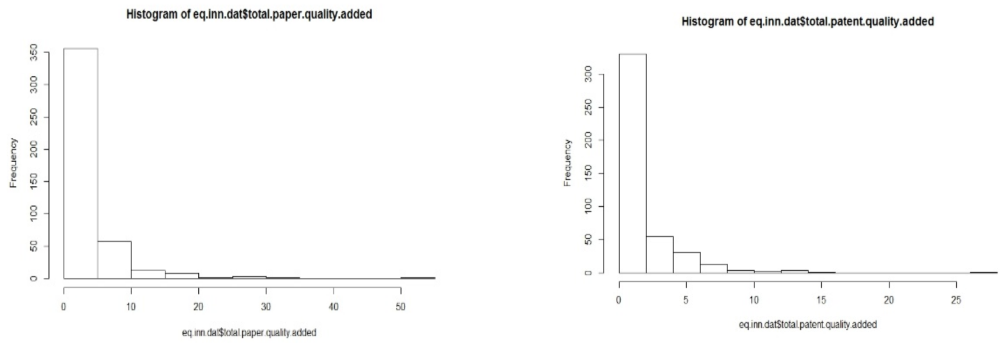


Figure 12. Distribution of Total Papers (left) and Patents (right)

The next step is finding what variables to use by comparing different models. For comparison purposes, Akaike Information Criterion (AIC) was used in this study. AIC is a measure of the relative quality of a statistical model for a given set of data. Suppose that we have a statistical model of some data. Let L be the maximized value of the likelihood function for the model and k be the number of estimated parameters in the model. Then the AIC value of the model is the following as Eq 5:

$$\mathrm{AIC} = 2\mathrm{k} - 2\ln(\mathrm{L}) \qquad \textbf{(5)}$$

Given a set of candidate models for the data, the preferred model is the one with the minimum AIC value (Akaike, 1974). Table 15 shows the comparison and that Poisson isn’t appropriate. Also, ToA and CoE must be analyzed separately for optimization. There could be an alternative approach for model comparison. For instance, Likelihood Ratio (LR) and Schwarz’s Bayesian Criterion (SBC) could be considered.

On Table 16, few of the CoPs used in this model appeared to have a significant relationship with quality considered paper (“innovation.quality.paper”) (. First of all, “funding.gov.billion” and “funding.stability” both showed a positive relationship with paper, while stability showed a negative relationship. In other words, government funding affects the total amount of paper, and if more funding is provided by the private sector compared to that of the government, then more papers can be generated.

Table 15. Negative binomial regression model comparison

Variable	Poisson.GLM		N.B.GLM		N.B.GLM	
	Estimate	Sig	Estimate	Sig	Estimate	Sig
(Intercept)	1.104312	***	0.761534	.	0.468556	
funding.gov.billion	0.024685	***	0.047369	**	0.04336	*
funding.private.billion	0.005542		0.001467		0.006238	
funding.ratio	-1.19222	***	-0.80156	.	-0.38499	
funding.stability	-0.2145	***	-0.22788	***	-0.23223	***
researcher.bs	-0.00218		-0.00132		-0.00116	
researcher.ms	-0.00806	*	-0.00704		-0.00484	
researcher.ph.d	0.026415	***	0.032935	*	0.025249	.
duration.year	0.433083	***	0.447968	***	0.428015	***
toa.type.i1	-1.58847	***	-1.72498	***	-1.75345	***
toa.type.r1	-0.29503	**	-0.32387		-0.32215	
toa.type.ii1	-1.1186	***	-1.18251	***	-1.2522	***
toa.type.uu1	-0.14771		-0.20345		-0.17828	
toa.type.rr1	-1.03368	**	-1.44622		-1.2791	
toa.type.iu1	-0.50951	***	-0.57458	**	-0.6084	**
toa.type.ir1	-0.7627	***	-0.6953	**	-0.72678	**
toa.type.ur1	-0.34371	.	-0.50119		-0.4597	
toa.type.iur1	-0.35629	**	-0.49784	.	-0.45774	.
coe.gen.dis1					0.02398	
coe.public.enterprise1					0.307237	*
AIC	INF		1894.993		1895.293	

※ Significant levels: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Another important factor in Table 16 is the number of Ph.D degree holders in a project ("researcher.ph.d") has a positively significant relationship with the innovation output of papers. It means that more qualified researchers would also generate more papers. Also, considering both funding effect and researcher effect, it could be speculated that the labor costs of researchers, both cash and in-kind, are important for generating more paper innovation output. Besides those two effects, project duration showed significance as well.

Table 16. Regression Result for CoP + ToA.type on innovation.quality.paper

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	0.761534	0.431423	1.765	0.07754	.
funding.gov.billion	0.047369	0.01808	2.62	0.00879	**
funding.private.billion	0.001467	0.01329	0.11	0.9121	
funding.ratio	-0.80156	0.434575	-1.844	0.06512	.
funding.stability	-0.22788	0.053708	-4.243	2.21E-05	***
researcher.bs	-0.00132	0.003578	-0.369	0.71208	
researcher.ms	-0.00704	0.006964	-1.011	0.31213	
researcher.ph.d	0.032935	0.01293	2.547	0.01086	*
duration.year	0.447968	0.05323	8.416	< 2e-16	***
toa.type.i1	-1.72498	0.301284	-5.725	1.03E-08	***
toa.type.r1	-0.32387	0.202124	-1.602	0.10908	
toa.type.ii1	-1.18251	0.234086	-5.052	4.38E-07	***
toa.type.uu1	-0.20345	0.326007	-0.624	0.53259	
toa.type.rr1	-1.44622	1.001797	-1.444	0.14885	
toa.type.iu1	-0.57458	0.207212	-2.773	0.00556	**
toa.type.ir1	-0.6953	0.227851	-3.052	0.00228	**
toa.type.ur1	-0.50119	0.405055	-1.237	0.21596	
toa.type.iur1	-0.49784	0.254598	-1.955	0.05053	

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Among the ToA, industry-included alliances showed a negative effect on the paper innovation output (Table 17). With the exception of IUR, all types involving industries showed a weak relationship compared to university alone (which is an omitted dummy variable of the analysis). The weakest relationship was built with the non-alliance industry project, which is understandable since the most important work for the industry does not focus on academic success. The negative relationship between industry-included alliance and paper innovation output can be found in the analysis below.

Table 17. Regression Result for CoP + ToA.strategy.industry

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	0.297047	0.37775	0.786	0.432	
funding.gov.billion	0.025567	0.018244	1.401	0.161	
funding.private.billion	0.001568	0.013307	0.118	0.906	
funding.ratio	-0.66855	0.434824	-1.538	0.124	
funding.stability	-0.24866	0.054194	-4.588	4.47E-06	***
researcher.bs	0.002049	0.003554	0.577	0.564	
researcher.ms	-0.00724	0.007138	-1.015	0.31	
researcher.ph.d	0.049353	0.012627	3.909	9.28E-05	***
duration.year	0.478264	0.051528	9.282	< 2e-16	***
toa.strategy.industry1	-0.58116	0.139713	-4.16	3.19E-05	***

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Furthermore, other regressions were performed based on trial-and-error approaches. However, no further meaningful results were found. This means that the convergent/divergent alliance strategy, participation of public enterprise, and sector difference between power generation and distribution did not make any obvious relationship with paper innovation output, as this research previously expected.

Stage 2-2: Innovation Output (Patent)

The amount of innovation output of patents that a project produces for R&D is, on average, higher when the ToA includes industry.	***Significant***
The amount of innovation output of patents that a project produces for R&D is, on average, higher when the ToA has divergent alliances.	***Significant***
The amount of innovation output of patents that a project produces for R&D is, on average, *different among CoE characteristics.*	***Not Significant***

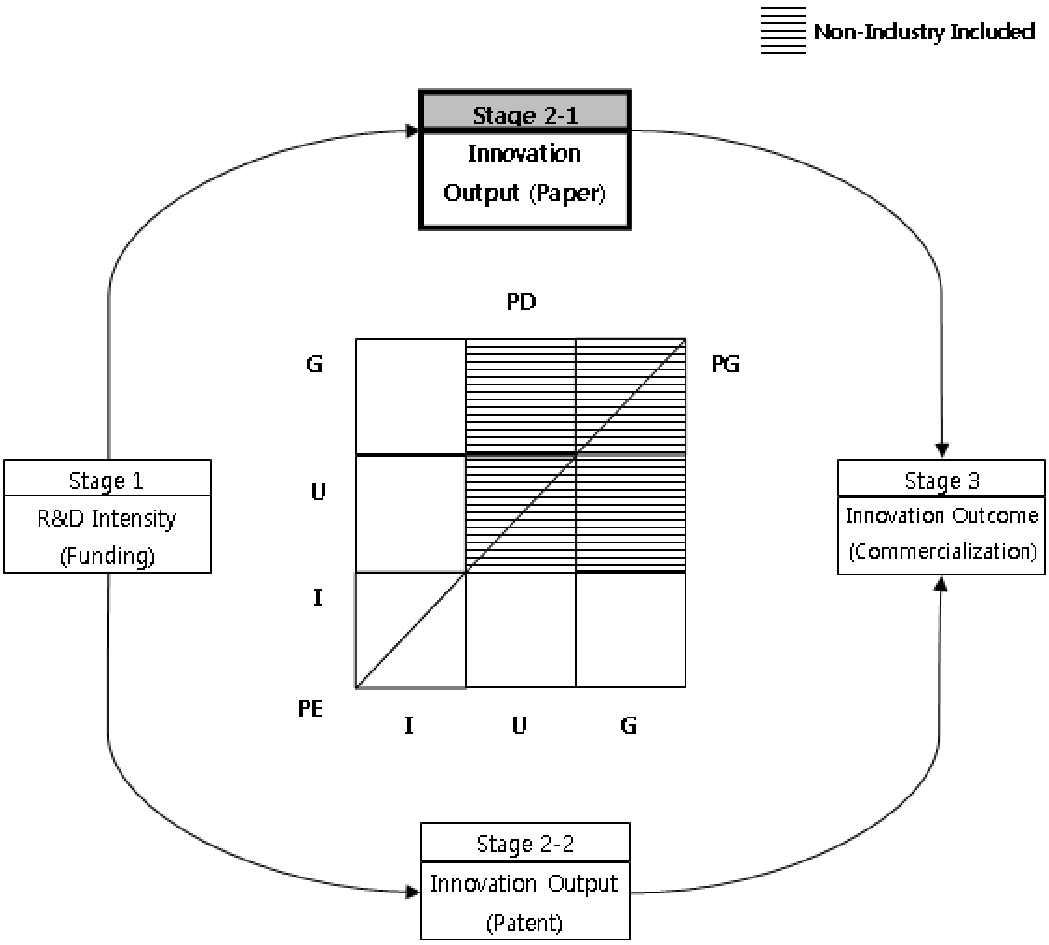


Figure 13. Diagram of Econometric Analysis on Stage 2-2

For Stage 2-2, the correlation and goodness of fit test were neglected since they were already conducted at Stage 2-1. According to econometric analysis, which was completed by negative binomial regression, “funding.gov.billion” and “duration.year” showed positive relationships with the patent innovation output within the considered quality.

Table 18. Regression Result for CoP + ToA.Type on innovation.quality.patent

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-0.82354	0.407435	-2.021	0.04325	*
funding.gov.billion	0.052575	0.017198	3.057	0.00224	**
funding.private.billion	-0.01949	0.012448	-1.566	0.11746	
funding.ratio	-0.60714	0.450222	-1.349	0.17748	
funding.stability	0.005995	0.047021	0.127	0.89856	
researcher.bs	0.002504	0.003318	0.755	0.45044	
researcher.ms	0.009743	0.0063	1.546	0.122	
researcher.ph.d	0.010458	0.012567	0.832	0.40531	
duration.year	0.221028	0.053694	4.116	3.85E-05	***
toa.type.i1	0.651897	0.276544	2.357	0.01841	*
toa.type.u1	0.310215	0.276258	1.123	0.26147	
toa.type.ii1	0.761275	0.2369	3.213	0.00131	**
toa.type.uu1	0.071798	0.452655	0.159	0.87397	
toa.type.rr1	-0.31757	1.080045	-0.294	0.76874	
toa.type.iu1	0.647651	0.225627	2.87	0.0041	**
toa.type.ir1	0.961182	0.24071	3.993	6.52E-05	***
toa.type.ur1	-0.23869	0.546984	-0.436	0.66257	
toa.type.iur1	0.817406	0.273824	2.985	0.00283	**

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Unlike patents, neither “funding.stability” nor numbers of researchers showed any strong relationship with the patent output. The result may be because patents cost more than paper, especially if they are for PCT or patents overseas. According to the R&D common operation regulation of MOTIE (MOTIE, 2015), the cost of a patent must be covered by “indirect cost”, which is fixed for only a certain amount of the total funding. Therefore, one can infer that increasing funding could provide more room for patents.

For ToA, the inclusion of industry shows a positive relationship with paper output. The non-alliance research institute project (“toa.type.r”) variable was omitted. The magnitude of positivity could be aligned as IR (0.96) > IUR (0.81) > II (0.76) > IU (0.64). It shows the impact of diverged alliances compared to converged (II). A similar result was also drawn from the previous research (Bae et al., 2014), however, the increase of patent output was due to the inclusion of industry alliance being added in this research.

Table 19. Regression Result for CoP + ToA.strategy.conv.div on innovation.quality.patent

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-0.09825	0.357928	-0.275	0.783697	
funding.gov.billion	0.057877	0.016748	3.456	0.000549	***
funding.private.billion	-0.02523	0.013065	-1.931	0.053461	.
funding.ratio	-1.19799	0.421667	-2.841	0.004496	**
funding.stability	0.014148	0.047911	0.295	0.767767	
researcher.bs	0.001886	0.003377	0.559	0.576487	
researcher.ms	0.01005	0.006493	1.548	0.121633	
researcher.ph.d	0.012591	0.01272	0.99	0.322228	
duration.year	0.252588	0.051713	4.884	1.04E-06	***
toa.strategy.conv.div1	0.26809	0.125227	2.141	0.032288	*

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Stage 3: Commercialization

The commercialization result that a project produces for R&D is, on average, higher when the ToA has divergent alliances.	***Significant***
The commercialization result that a project produces for R&D is, on average, higher when the leading role is given to SME.	***Significant***
The commercialization result that a project produces for R&D is, on average, different among CoE characteristics.	***Not Significant***

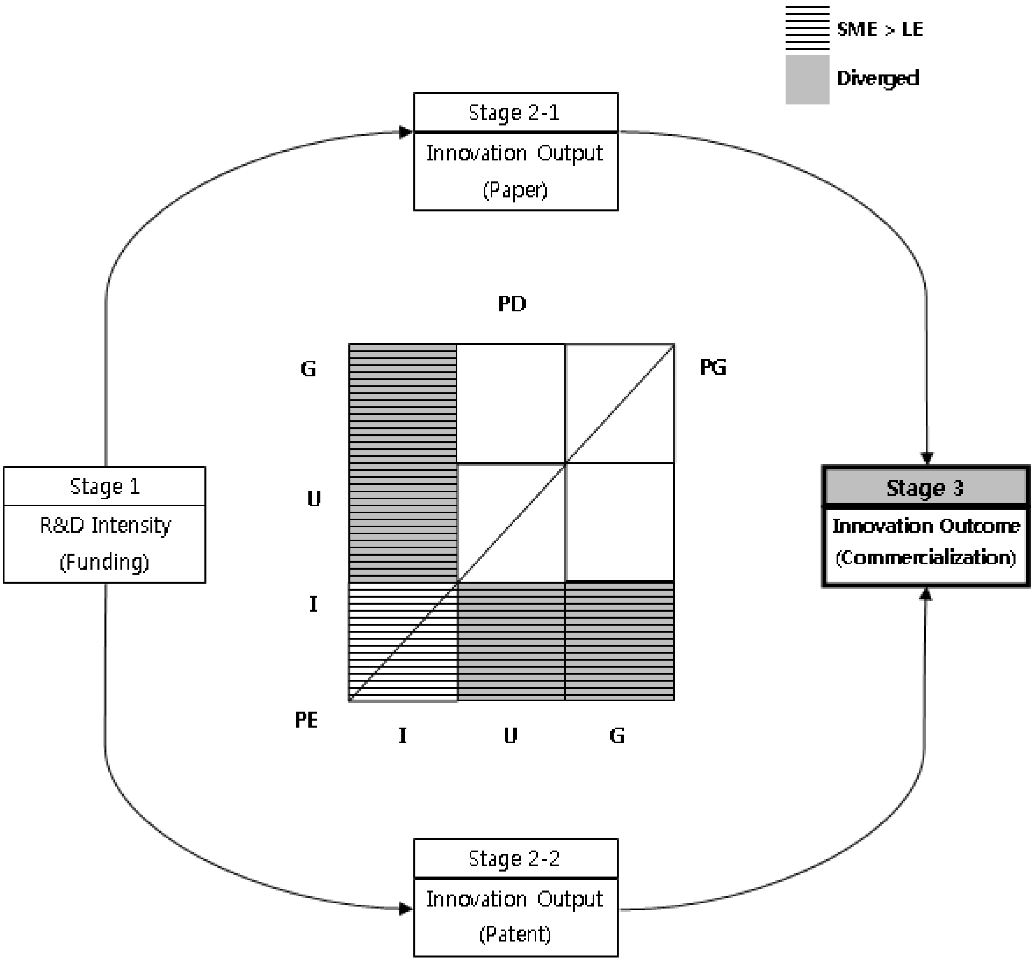


Figure 14. Diagram of Econometric Analysis on Stage 3

For Stage 3, few more correlations were found. The variables shown below were avoided being used together for the econometric analysis (Table 20).

Table 20. Correlation test for Stage 3 Commercialization

	toa.strategy.conv.div	toa.strategy.industry
toa.ox	0.68	0.72

Regression for Stage 3 was completed by using the binary logit model since the dependent variable "comm.ox" is made of either 1 (commercialized) or 0 (not-commercialized). The Hosmer-Lemeshow test is a statistical test for goodness of fit for the logistic regression model (Lemeshow & Hosmer, 1982). The test assesses whether or not the observed event rates match expected event rates in subgroups of the model population. The Hosmer-Lemeshow test specifically identifies subgroups as the deciles of fitted risk values, which means if null hypothesis are rejected, then risk shows up between the two groups. The Hosmer-Lemeshow test statistic is given by Eq 6:

$$H = \sum_{g=1}^{G} \frac{(O_g - E_g)^2}{N_g \pi_g (1 - \pi_g)} \qquad \textbf{(6)}$$

Here O_g, E_g, N_g, and π_g denote the observed events, expected events, observations, and predicted risk, respectively, for the g^{th} risk decile group, and G is the number of groups (Lemeshow & Hosmer, 1982). Using this method, the fitness of model for Stage 3 was tested and the null hypothesis was accepted (Eq 7):

$$X\text{-squared} = 9.711,\ df = 8,\ p\text{-value} = 0.2859 \tag{7}$$

Table 21. Linear Regression Result for CoP + Type.ToA on comm.ox

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-2.51E+00	1.39E+00	-1.799	0.07206	.
innovation.intensity.paper	-7.33E-01	7.59E-01	-0.966	0.33429	
innovation.intensity.patent	-1.32E-03	3.04E-01	-0.004	0.99654	
inty.funding.gov.billion	4.19E+00	1.98E+00	2.122	0.03387	*
inty.funding.private.billion	-1.70E+00	2.06E+00	-0.826	0.40863	
funding.ratio	-2.10E+00	1.20E+00	-1.741	0.08166	.
funding.stability	9.00E-02	1.13E-01	0.798	0.42464	
researcher.bs	1.06E-02	8.18E-03	1.29	0.1971	
researcher.ms	1.71E-03	1.57E-02	0.109	0.91344	
researcher.ph.d	-3.59E-02	4.20E-02	-0.855	0.39241	
duration.year	-1.92E-01	1.39E-01	-1.384	0.16629	
toa.type.i1	3.24E+00	1.12E+00	2.901	0.00372	**
toa.type.u1	-1.38E+01	9.75E+02	-0.014	0.98869	
toa.type.ii1	2.47E+00	1.09E+00	2.264	0.02356	*
toa.type.uu1	-1.39E+01	1.80E+03	-0.008	0.99385	
toa.type.rr1	-1.35E+01	6.52E+03	-0.002	0.99835	
toa.type.iu1	3.21E+00	1.06E+00	3.031	0.00244	**
toa.type.ir1	3.24E+00	1.09E+00	2.978	0.0029	**
toa.type.ur1	-1.45E+01	2.14E+03	-0.007	0.9946	
toa.type.iur1	2.82E+00	1.14E+00	2.483	0.01304	*

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

The intriguing result is that no variable from CoP made an impact on Stage 3 (Table 21). The result indicates that there are no other effects that come directly from Stage 1 to Stage 3, except for ones that are already reflected in Stage 2. The regression was completed with different variable combinations (e.g. innovation.intensity.paper and innovation. intensity.patent, separately), however, the results were similar. Therefore, a conclusion may be made that no additional R&D intensity effects from Stage 1 to Stage 3 without passing through Stage 2.

For ToA, the industry-included alliance shows a propensity for greater commercialization output, but this is due to all projects with commercialization records coming from the industry-included alliances. However, if we align the order among industry-included alliance from Table 21, the order would be I (3.23) = IR (3.23) > IU (3.20) > IUR (2.82) > II (2.46). For industry alone, there are 33 projects completed and 11 of them are commercialized, and out of those 11, 7 of them are large enterprises.

Table 22. Linear Regression Result for CoP + ToA.strategy.conv.div on comm.ox

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
Intercept)	0.470402	0.90409	0.52	0.60285	
innovation.intensity.paper	-1.57987	0.828776	-1.906	0.05662	.
innovation.intensity.patent	0.176163	0.286034	0.616	0.53797	
inty.funding.gov.billion	4.637405	1.510693	3.07	0.00214	**
inty.funding.private.billion	-1.40512	1.699107	-0.827	0.40825	
funding.ratio	-3.56968	1.157418	-3.084	0.00204	**
funding.stability	0.056035	0.110917	0.505	0.61342	
researcher.bs	0.007655	0.008288	0.924	0.35563	
researcher.ms	0.003571	0.015718	0.227	0.82026	
researcher.ph.d	-0.06625	0.042753	-1.55	0.12124	
duration.year	-0.13599	0.134431	-1.012	0.31174	
toa.strategy.conv.div1	1.042291	0.306788	3.397	0.00068	***

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

Another regression was processed with the converged/diverged type of alliances. This study found that diverged alliance is relatively higher than converged alliance. According to analysis, diverged alliance has a more positive relation (1.042) with the commercialization result than the converged one. In addition, "inty.funding.gov.billion" and "funding.ratio" also show the significance level. .

Lastly, leading organization was considered. The only meaningful sign was that Small-Medium Enterprise (SME) (2.07) > Large Enterprise (LE) (1.27).

Table 23. Linear Regression Result for CoP + ToA.leading on comm.ox

Variables	Estimate	Std. Error	t value	Pr(>|t|)	sig
(Intercept)	-1.10788	1.141709	-0.97	0.33186	
innovation.intensity.paper	-0.71638	0.704316	-1.017	0.30909	
inty.funding.gov.billion	3.595432	1.521357	2.363	0.01811	*
inty.funding.private.billion	-1.38762	1.611118	-0.861	0.38908	
funding.ratio	-2.50052	1.48754	-1.681	0.09277	.
funding.stability	0.041294	0.107719	0.383	0.70146	
researcher.bs	0.011615	0.008089	1.436	0.15104	
researcher.ms	-0.0054	0.015709	-0.343	0.73125	
researcher.ph.d	-0.00244	0.036091	-0.068	0.94605	
duration.year	-0.06614	0.138754	-0.477	0.63361	
toa.leading.le1	1.278943	0.492645	2.596	0.00943	**
toa.leading.sme1	2.078284	0.415486	5.002	5.67E-07	***

※ Significant levels: *** p < 0.01; ** p < 0.05; * p < 0.1

4.2 Further Analysis

.The econometric analysis had done with only using binary variable, where 0 stands for not-commercialized and 1 for commercialized. On this section, by taking one step further, the time-series data for commercialization was analyzed. The elasticity was a concern at this stage, where it stands for amount of output divided by input. In this case, the output was set to annual average economic result ($B/yr), while the input was set to annual average total funding ($B/yr). The result came out to be the following (Figure 15):

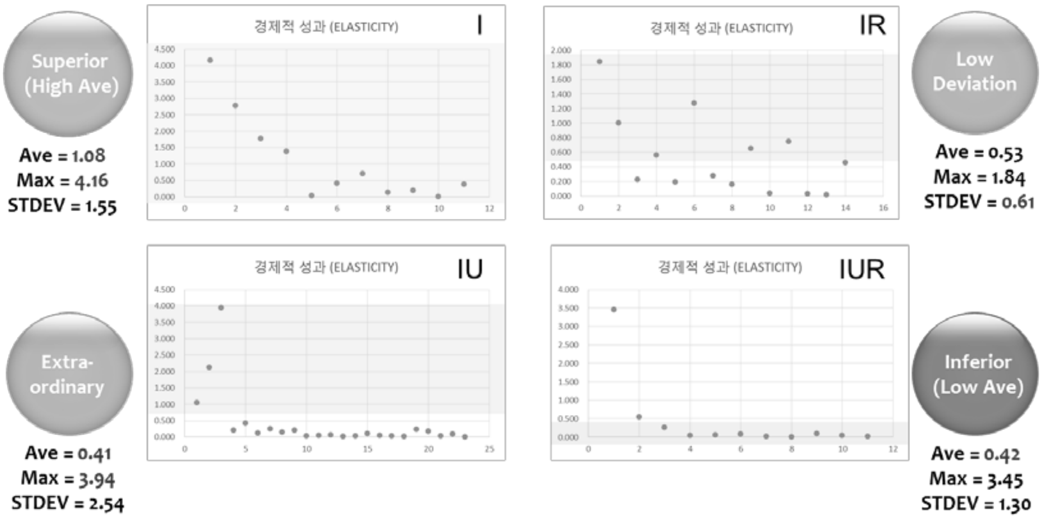


Figure 15. Categorization of time-series data for commercialization

The non-alliance group with the industry has a high average of elasticity as well as a few superiors. This group shows that most of them are LE with massive networks or SME with high technical capacity. For these individual firms, they don't necessarily need to have alliance to reach the commercialization level because cooperation with other groups could cause delay in the decision making process.

For projects belonging to Industry-Gov. Research Institute alliance, they have a relatively low average of commercialization outcome, but it also has the lowest standard deviation. The characteristic of IR alliance was that many of them (9 out of 14) included public enterprise in their project consortium. A previous study shows that the investment of public enterprise has a feasible impact on economic stability (Snyder, 1971). This study may have relative information with the econometric result in this research.

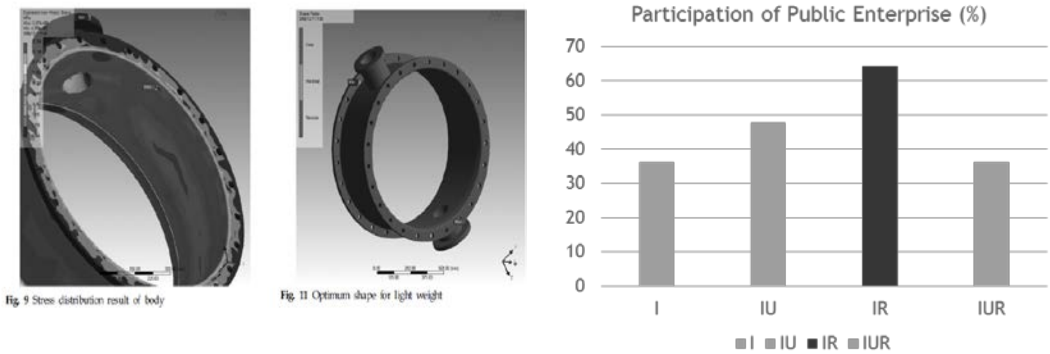


Figure 16. Product from an IU alliance (Butterfly Valve) / Rate of Public Enterprise participation

Projects in the Industry-University alliance group are either superior or below average. In other words, they are either highly cost-efficient or very low efficient. Two of the most cost-efficient projects targeted localization of special “component/part development”, while others focused on inspection or surveillance technologies. One of the successful products was a 1,000A “butterfly valve” component (Figure 16). It is a type of valve used for controlling heavy flow of fluids in relatively low pressure environments. Such components can be applied to control fluids like natural gas and nuclear waste disposal (Kong, Kim, & Jung, 2009).

Finally, Industry-University-Gov. Research Institution alliances are categorized as a low average group. This is mainly because half of them finished technical development within a year at the time of the survey. These projects were part of the Jeju Smart-Grid Test bed projects (Figure 17), which was the world's biggest smart grid test-bed project that lasted from 2008 to 2013. It was a gigantic project where $228 million was invested in 8 sub-projects and 168 institutions (Korea Smart Grid Institute, 2012). However, the project failed to generate an expected economic outcome due to a lack of standardization for each project and regulation system. A follow-up project was initiated in 2013 to standardize the systems developed in each project. Economic result is likely to increase in the future if the problem is solved.

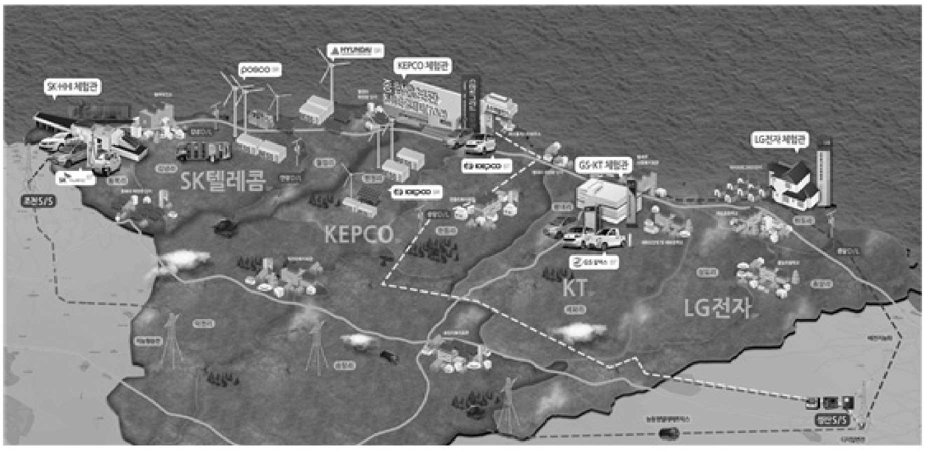


Figure 17. Jeju Smart Grid Test-bed (Image from KSGI)

5. Conclusion

5.1 Summary of Results

In this empirical study, we have applied econometric analysis to identify determinants of successful R&D commercialization in the Korean electricity industry from the perspective of alliance. By using CDM, the econometric analysis was categorized into three different stages (R&D intensity, innovation output, and commercialization) to determine what variables were effective on each stage. By using several hypotheses, this research tested what ToA and CoE affected each stage within CoPs.

Relationship between R&D Input (CoP) and Performance

This study found the relationship between R&D input and performance as follows:

I. Intensity of funding has a positive relationship with innovation outputs and commercialization. Investments from both the government and the private sector are important; however, a bigger portion from private funding has more impact.

II. The amount of researchers has a positive relationship with innovation outputs (papers). However, it does not necessarily have a significant relationship with patents or commercialization results. Also, the productivity of labor is in a decreasing return to scale (DRS) relationship with the intensity of funding.

III. Innovation output does not have a significant impact on commercialization.

Table 24. Relationship between CoP with R&D performance

CoP	R&D Intensity	Innovation. (Paper / Patent)	Comm.
Intensity of Funding		+ / +	+
- Ratio	Gov. < Private	NS / Gov. < Private	Gov. < Private
- Stability		Stable / NS	NS
Researcher	DRS	+ / NS	NS
Duration	+	+ / +	NS
Output (Paper)			NS
Output (Patent)			NS

※NS = Not Significant; DRS = Decreasing Return to Scale; (+) = Significant (positive); (-) = Significant (negative)

Relationship between Alliance (ToA) and Performance

This study found the relationship between R&D alliance and performance as follow:

I. Industry-included alliances have a positive relationship with R&D intensity, patent, and commercialization. However, it has a negative relationship with paper.

II. When the leading role is given to small-medium enterprises (SME), compared to large enterprise, it has a stronger positive relationship with the performance.

III. Diverged alliance > converged alliance, however, the R&D alliance is not always the best choice for improving performance. I > IR > IUR > II > IU for R&D intensity and I = IR > IU > IUR > II for commercialization was found. The case studies were conducted on each type with a descriptive analysis approach.

IV. From the descriptive analysis, Type I shows that LE has high capability on R&D performance without forming an alliance. Type IR shows low deviation and high involvement of public enterprise. Type IU shows polarization: either high or low. Focusing on a special “component/part” shows higher performance. Type IUR shows low average; they need to work on regulation & standardization problems.

Table 25. Relationship between ToA with R&D performance

ToA	**Intensity.**	**Innovation. (Paper / Patent)**	**Comm.**
Industry-Included	+	(-) / (+)	+
Conv./Div.	NS	NS / Conv < Div	Conv < Div
Leading Role			LE < SME
Type	(+) I > IR > IUR > II > IU	(-) I > II > IR > IU / (+) IR > IU > II > I = IU	(+) I = IR > IU > IUR > II

※NS = Not Significant; (+) = Significant (positive); (-) = Significant (negative)

Relationship between Competition (CoE) and Performance

This study found the relationship between competition and performance as follows:

I. *Sector differences within a level of competition are not significant for R&D performance, while it has a positive relationship with R&D intensity*.

II. *Involvement of public enterprise is not significant for R&D performance, while it has a positive relationship with R&D intensity.*

Table 26. Relationship between CoE with R&D performance

CoE	Intensity.	Innovation. (Paper / Patent)	Comm.
Public Enterprise	+	NS / NS	NS / NS
PG vs. PD	PG > PD	NS / NS	NS / NS

※NS = Not Significant; (+) = Significant (positive); (-) = Significant (negative)

5.2 Discussion

Maximizing the performance with limited resources doesn't exclusively raise a concern for firms. Researchers and policymakers are also called to achieve the same objectives as R&D interest shifts toward applicable research rather than basic science.

Such changes in the R&D culture led researchers to align with others in their field while competing with each other. Finding the right partner can sometimes generate synergy to their research and greatly enhance their performance, though undesirable outcomes could occur if the alliance strategy is unsuccessful.

The Korean electricity industry is the backbone of the energy industry of Korea where applicable researches are more in demand than any other sector. The industry used to be led by the monopolistic governance of public enterprises; however, the emergence of liberalization opened the room for private sectors to compete, even though improvements were still needed in the sector.

Concerning the case of ER&D program in Korean electricity industry this research was conducted to analyze whether determinants of successful R&D could be found both internal and contextual factors. The following are some further thoughts on the findings:

- Increase of investment in the project means the degree of concern has increased as well. Especially, if investment comes more from the private sector, the concern for productivity becomes one of the top priorities.
- Alliance is a positive factor for R&D performance in the electricity industry. But, it is not an indispensable factor. Depending on the objective technology and available resources, alliance formation should be reviewed. However, if an alliance must be formed, diversity (e.g. IU, IR, or IUR) could generate more synergy than convergence alliance.
- The current degree of competition in Korean electric industry is not significantly effective on R&D performance. But, that does not necessarily mean the *escape-competition effect* is insignificant. Rather, it should be viewed as if the competition had not really been promoted in a desirable way.

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