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Three Essays on R&D, Economic Performance and Institutions : Knowledge Spillover, Intellectual Property Rights and Liberalization

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Abstract

Three Essays on R&D, Economic Performance and Institutions : Knowledge Spillover, Intellectual Property Rights and Liberalization

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This dissertation consists of three essays which analyze the effects of R&D and institutional change (intellectual property rights and liberalization) on industrial economic performance. Although the topic has been discussed for several decades, these essays investigate unexplored research questions taking into account the endogenous characteristics of knowledge. The first essay analyzes the spillover effect of knowledge among industries, which is regarded as a source of innovation-driven economic growth. The second essay analyzes the beneficial and detrimental effects of intellectual property rights, which grant exclusive rights to innovators to correct innovation market failure. The third essay analyzes the effect of electricity industry liberalization, which introduced market competition to the electricity industry. The purpose of the essays is to contribute to current research on modeling an integrated framework that evaluates industrial economic performance taking into account the endogenous characteristics of innovation,

and provide insight into how to harmonize traditional industrial policy and systemic innovation policy.

The first essay investigates the role of basic and applied R&D in productivity growth and innovation by focusing on the spillover effects of R&D. Knowledge spillover is regarded as a source of innovation-driven economic growth but also blamed for market failure for creating innovation. Using the production function approach, this essay examines the differential effects of basic and applied R&D by taking into account spillovers between industries and stages of research, applying the panel data of 18 manufacturing industries in Korea from 1999~2009. Unlike most previous literature, which does not distinguish inter-industry spillover effects from the overall R&D impacts of basic and applied research, this essay is the first empirical research to identify differential inter-industry spillovers of basic research and applied R&D. The results show that the spillovers of basic research are much bigger and exert a wider impact than do spillovers of applied research. The results emphasize the importance of basic research in economic growth. It suggests the need of systematic innovation policy taking into account the impact of knowledge.

The second essay analyzes the effect of intellectual property rights (IPR) on innovation and industry value added. Debate continues on whether strengthened IPR leads to technological development and economic growth: Patents promote innovation by protecting appropriation from invention and disclosing knowledge to the public, but they also create excessive monopoly power that may impede further innovation. Using simultaneous equations with cross-country panel data from 12 countries and 3 industries (chemical, electronics, and machinery), this essay estimates the direct effect of IPR on

industry value added and the indirect effect of it through enhanced research and development (R&D). Results suggest that IPR generally enhance industry value added and R&D investment but show a negative relationship with patented knowledge, suggesting that excessive propertization of knowledge may hinder sequential innovation. The positive role of IPR on R&D predominated in the chemical (discrete) industry whereas IPR exerted negative effects in the electronics and machinery (complex) industries.

The third essay analyzes the short-term and long-term effects of the liberalization of the electricity industry. While most previous literature has focused on the effect of liberalization on either short-term price change or R&D investment, this essay analyzes both the static effect caused by the change in market power and dynamic effect caused by the change in R&D investment. This essay applies the NEIO (New Empirical Industrial Organization) methodology and expands it to measure the effects of liberalization on R&D investments (dynamic efficiency) as well as market power (i.e., price and static efficiencies). The panel data of 17 Organization for Economic Co-operation and Development (OECD) countries from 1987 to 2012 is used. The results show that a trade-off exists between static and dynamic efficiencies caused by the liberalization of the electricity industry. Further, the results suggest complementary policy needs to be considered to mitigate the unexpected side effects of restructuring, which is reduced R&D and dynamic inefficiency

Keywords: innovation, economic performance, electricity industry liberalization, intellectual property rights, knowledge spillover

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Overall Introduction

Many economists have explored the determinants of industrial economic performance. The representative academic traditions studying this issue are industrial organization (IO) economics, on the one hand, and innovation economics which takes into account the technological change, on the other hand.

The IO literature focuses on the relation between institution (market structure) and economic performance. According to industrial organization (IO) theories, industrial structure determines the conduct and performance of an industry. This is a widely-known structure-conduct-performance theory (S-C-P). Traditional IO theories generally assume that the industrial economic performance is determined by exogenous institutional changes (or market structure) and do not consider endogenous factors in any detail.

In the innovation economics literature, innovation is regarded as an endogenous factor and is assumed to determine the industrial economic performance. The innovation can be stimulated or shrink by knowledge characteristics and institutional changes. For example, the strategic decisions on R&D investments inducing technology innovation depend on the long-term market structure and company ownership (Shapiro, 1989).

This dissertation consists of three essays which try to combine the two literature perspectives outlined above. Each essay provides a structure model which evaluates economic impact of R&D activities taking into account the effects of the characteristics of technology and institutional change. Through the structure model, the role of innovation for the industrial economic performance is modeled based on the endogenous characteristics of knowledge.

This dissertation focuses on two types of endogenous characteristics of knowledge and innovation. First, new knowledge is generated based on previous knowledge, implying that the production of knowledge is influenced by prior knowledge. Thus, when one tries to estimate the economic impact of R&D, not only the direct impact of R&D on economic performance, but also the effect on generating knowledge should be considered. Second, innovation incentives vary by institutional change (degree of market competition or the strength of intellectual property rights). Therefore, when one tries to evaluate the effects of institutional change and R&D activities on industrial economic performance both, the endogeneity caused by institution should be taken into account.

In view of the importance and characteristics of knowledge for industrial performance, this dissertation explores the following three research questions.

- What kind of knowledge needs to be encouraged for industrial economic performance? What kind of knowledge can be widely spread and have a larger economic impact?

- How can one create continuous innovation and overcome innovation market failures caused by knowledge spillover? Can the patent system work properly for this purpose?

- How critical is the effect of R&D on industrial economic performance? In the case of electricity industry, is the liberalization policy successful taking into account the effect of R&D and the endogenous characteristics of knowledge?

By using structural models which reflect the endogenous characteristics of knowledge and innovation, each of the three essays analyzes the effect of R&D and institutional change (intellectual property rights and liberalization) on industrial economic performance. The first essay focuses on the spillover effect of knowledge on economic performance and innovation. The second essay analyzes the beneficial and detrimental effects of intellectual property rights which grants exclusive right to innovators. The third essay considers the effect of electricity industry liberalization which introduces market competition to electricity industry. The purpose of the essays is to contribute to current research on modeling the integrated framework which evaluates the industrial economic performance taking into account the endogenous characteristics of innovation and to provide an insight into how to harmonize traditional industrial policy and systemic innovation policy. Figure 1 illustrates the framework of the three essays in this dissertation.

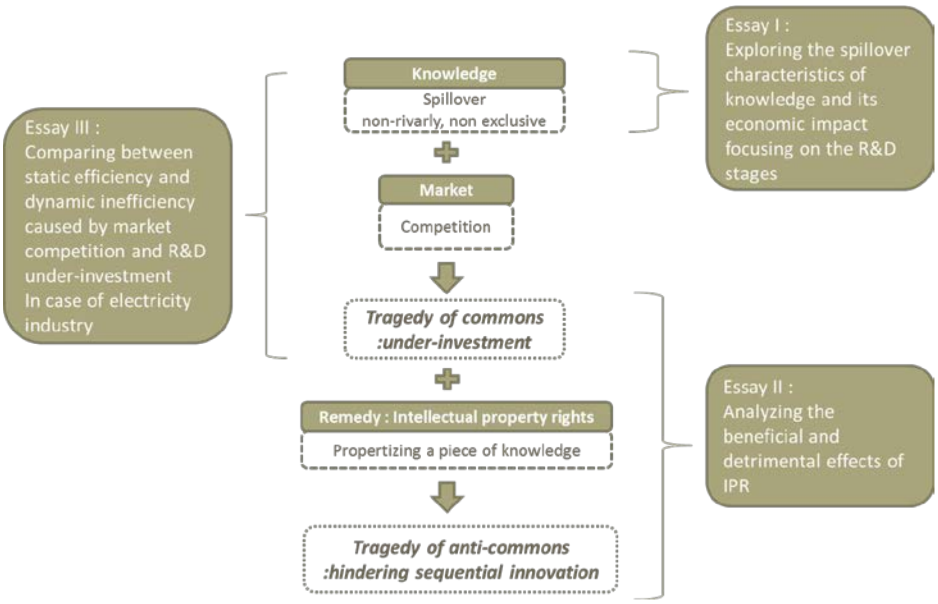

Figure 1: Research framework

By focusing on the spillover effects of R&D, essay I investigates the role of basic and applied R&D for productivity growth and innovation. The knowledge spillover is regarded as a source of innovation-driven economic growth. The spillover effect can create technology opportunities. Technological progress may not be solely determined by the innovation efforts that produced it, but also by other firms' research outcomes (Schmookler, 1966). Knowledge generated by one individual can contribute to another's research progress and productivity. In this respect, Griliches (1992) argued that the spillover effect is a source of increasing social return, which maintains the economic growth at an undiminished rate into the future. Accordingly, exact and accurate measures of spillover effects of R&D can lead to appropriate public innovations or R&D policies.

Using the production function approach, essay I examines the differential effects of basic and applied R&D by taking into account the spillovers between industries and stages of research with panel data of 18 manufacturing industries from 1999~2009 in Korea. Unlike in most previous studies where inter-industry spillover effects and the overall R&D impacts of basic and applied research are not diferentiated, this essay is the first empirical research attempt to identify differential inter-industry spillovers of basic research and applied R&D. The results show that the spillovers of basic research are much larger and exert a wider influence than the spillovers of applied research. The results also emphasize the importance of basic research in economic growth. Specifically, we suggest the needs of systematic innovation policy taking into account the impact of knowledge.

Although innovation and knowledge have been regarded as key determinants of economic growth in modern economy (Romer, 1990), they have public good aspects which are non-rivalry and non-exclusive. Then, the innovator who produced it cannot easily appropriate profit from the related innovation. The appropriation problem can lead to the 'tragedy of commons' with regard to knowledge production. Therefore, as suggested in recent economic literature on research and development, strict reliance on a market system can result in underinvestment in innovation (Martin & Scott, 2000).

To overcome the tragedy of commons, several public polices can be used (e.g. subsidies, public R&D investment, intellectual property rights, and so on). Unlike subsidies and public R&D, the patent system functions based on market mechanism by assigning property rights in a piece of knowledge. Patent system creates market for knowledge by giving property rights to innovators to overcome the appropriation problem. Generally, the patent system is expected to overcome the tragedy of commons. Nowadays, however, a concern has been voiced regarding its side-effect which is called 'tragedy of anti-commons'.

Essay II provides the analysis of the effect of intellectual property rights (IPR) on innovation and industry value added. Debate continues on whether strengthened IPR lead to technological development and economic growth: while patents promote innovation by protecting appropriation from invention and disclosing knowledge to the public, they also create excessive monopoly power that may impede further innovation (tragedy of anti-commons). Using simultaneous equations with cross-country panel data from 12 countries and 3 industries (chemical, electronics, and machinery), this essay estimates the direct and indirect effects of IPR on industry value added through enhanced research and development (R&D). The results suggest that IPR generally enhance industry value added and R&D investment, but show a negative relationship with patented knowledge, suggesting that excessive propertization of knowledge may hinder sequential innovation. Furthermore, the positive role of IPR on R&D is found to predominate in the chemical (discrete) industry and have negative effects in the electronics and machinery (complex) industries.

Essay III presents the analysis of the short-term and long-term effects of the liberalization of electricity industry. While most prior research focused on the effect of liberalization on either shot-term price change or R&D investment, this essay analyzes both the static effect caused by the change of market power and the dynamic effect caused by the change of R&D investment. This essay applies the NEIO (New Empirical Industrial Organization) methodology and expands it to measure the effects of liberalization on R&D investments (dynamic efficiency) and market power (i.e., price and static efficiencies). The panel data of 17 Organisation for Economic Co-operation and Development (OECD) countries from 1987 to 2012 are used. The results show the existence of trade-off between static and dynamic efficiencies caused by the liberalization of electricity industry. Furthermore, our results highlight that some complementary policies need to be considered to mitigate the unexpected side-effect of restructuring that is reduced R&D and dynamic inefficiency.

- Essay I -

Inter-industry R&D spillovers in Korean manufacturing: differences between basic and applied research

* The essay was submitted to *Asian Journal of Technology Innovation* and is now under revision. The title of the submitted paper is “Inter-industry R&D spillovers in Korean manufacturing: differences between basic and applied research”

1. Introduction

Advances in knowledge created through technical change are regarded as key determinants of productivity growth because of a spillover effect (Añón Higón, 2007) defined by new knowledge that may be used by agents other than the innovator. Generally, the spillover effects are discussed in two respects: appropriability and technology opportunity.

The spillover of knowledge originates from the public-good aspects of it. Because knowledge is non-rivalry and non-exclusive, the innovator who produced it cannot easily appropriate profit from the related innovation. The appropriation problem can lead to the tragedy of commons with regard to knowledge production. A firm's incentive to invest in innovation decreases if generated knowledge is transmitted to competitors involuntarily (Arrow, 1962).

However, the spillover effect can create technology opportunities. Technological progress may not be solely determined by the innovation efforts that produced it but also by other firms' research outcomes (Schmookler, 1966). Knowledge generated by one individual can contribute to another's research progress and productivity. In this respect, Griliches (1992) argued that the spillover effect is a source of increasing social return, which maintains the economic growth at an undiminished rate into the future.

When both aspects are combined, the spillovers of knowledge can be important drivers of economic growth if disincentives associated with them are appropriately resolved (Encaoua, Guellec and Martínez, 2006). Accordingly, exact and accurate measures of the spillover effects of R&D can lead to appropriate public innovations or R&D policies.

R&D activities can be divided into three types: basic research, applied research, and experimental development. According to the Organisation of Economic Co-operation and Development (OECD) (2002), basic research is defined as 'experimental or theoretical work undertaken primarily to acquire new knowledge'. Applied research and experimental development are characterised as 'investigation…directed towards a specific practical aim or objective'.

For several decades, a debate has centred around the role of basic research on economic value creation as contrasted with other R&D activities such as applied R&D and experimental development (Mansfield, 1980; Griliches, 1986). Although basic R&D stimulates new ways of thinking, which may lead to the creation of pioneering and revolutionary ideas, concepts and applications, many express scepticism on its value because of long lead times, high risk and low appropriation (Czarnitzki and Thorwarth, 2012).

This essay focuses on the spillover effects of basic and applied R&D between industries in Korea. First, a production function approach based on the R&D-based growth model of Jones (1995) is used to examine the impacts of R&D activities on the real output within a sector and in other manufacturing sectors (inter-industry spillovers). And the R&D stocks are divided into basic research and applied R&D; the latter is composed of applied research and experiment development[1]. Then, this essay empirically checks for differential spillovers between them.

[1] This paper does not distinguish the differential effects of applied research and experiment development because they have similar characteristics when contrasted with basic research.

Keller (2002), Añón Higón (2007) and Badinger and Egger (2008) wrote papers on inter-industry R&D spillovers. Recently, Luintel and Khan (2011) and Czarnitzki and Thorwarth (2012) examined the different impacts of R&D activities created by basic and applied research. However, they do not distinguish inter-industry spillover effects from the overall R&D impacts of basic and applied research. Judging the literature, this essay is the first to identify differential inter-industry spillovers of basic research and applied R&D.

This essay also check indirect spillovers, which are the result of previous knowledge from basic research and applied R&D stock, on current basic and applied R&D. Prior knowledge can inspire and stimulate new knowledge, which is called *inter-temporal knowledge spillover* (Nelson, 1982; Jones and Williams, 1998). Based on an approach similar to that of Jones and Williams (1998), Kim (2007) also found inter-temporal knowledge spillover in the Korean economy.

To identify the direct and indirect effects of various types of R&D stocks this essay expanded previously published approaches. However, the indirect spillover could not be identified in a single production function approach. Accordingly, R&D equations was added that contain information on alternative and outside-industry R&D stock as explanatory variables to the production function and the equations are estimated simultaneously. Thus, one can analyse differential spillovers of R&D stocks on the real output (direct) and R&D investment (indirect).

The results of this essay show that inter-industry spillovers exist and the degree of impact varies by the nature of the R&D types. Basic R&D of an industry contributes to the creation not only of the industry's applied R&D but also to that of other industries. Applied R&D also inspires basic research in the industry; however, it acts as a substitute for applied research in specific industries. The results suggest that basic research spillovers exert stronger and broader effects than those from applied R&D.

This essay is organised as follows: Section 2 describes basic concepts of R&D-related variables and summarises previous studies. It also includes descriptive statistics of R&D efforts in Korean manufacturing and specifies differences between the previous studies and this essay. Section 3 illustrates the model and its empirical technique. Section 4 presents the data and explains the variables. Section 5 includes the estimation results and a discussion. Section 6 provides conclusions.

2. Basic concepts of R&D and previous studies

2.1. Rate of return to R&D

Many studies present information about the economic impacts of R&D, including the effects of spillovers. Various methods of estimating the rate of return to R&D have also been developed and include those on social aspects or private profits on R&D investment. The literature presenting estimates on the rate of return to R&D can be categorized by the approach to the estimation and the aggregation level of sample data.

Two major approaches characterize the literature. The primal approach is used to estimate a production function with quantities as inputs. The dual approach is used to estimate a system of factor demand equations derived from a cost function of technology (Hall, Mairesse and Mohnen, 2010). Most researchers embraced the primal approach, where the output is related to the R&D stock.

In Table I. 1, the primal literature is summarized. The results show that R&D stock exerts significant impact on productivity, and the elasticity of R&D ranges from 0.01 to 0.20. The results vary by aggregation level (firm, industry or country) and time period of sample data.

Table I. 1: Survey on previous studies estimating return to R&D

Study	Sample & period	Output variable	Elasticity of R&D to output	Rate of return to R&D(%)
Griliches (1986)	386 firms (US) 1967, 1972, 1977	Value added	0.09 – 0.17	51 – 76
Bartelsman (1990)	20 industries (US) 1985 – 1986	Sales	0.12	
Bartelsman, van Leeuwen, Nieuwenhuijsen and Zeelenberg (1996)	200 firms (Netherlands) 1985, 1989, 1993	Sales Value added	0.006 – 0.033 (sales) 0.008 – 0.099 (VA)	
Sveikauskas (2000)	22 industries (US) 1958 – 1983	Total Factor Productivity		72.9
Griffith, Redding and Van Reenen (2004)	12 industries (OECD 12 countries) 1974 – 1990	Value added growth rate		47 – 67
Rogers (2010)	719 firms (UK) 1989 – 2000	Value added	0.12 – 0.23	
Luintel and Khan (2011)	10 countries (OECD) 1979 – 2006	GDP	0.015 – 0.099 (basic) 0.111 – 0.170 (applied)	
Czarnitzki and Thorwarth (2012)	13 industries (Belgium) 2002 – 2007	Sales	0.155 – 0.190 (high tech) 0.100 – 0.143 (low tech)	

Note: TFP is total factor productivity; GDP is gross domestic product.

2.2. Inter-industry R&D spillover

The knowledge produced by the R&D efforts of one firm can affect the productivity of other firms operating not only in the same industry but also in other industries. For example, nylon was developed by DuPont in the chemical industry and subsequently applied in the textile, automobile and military industries (Nelson, 1959).

The traditional production function approach, which has been used for measuring rate of return to R&D, can also measure the returns to spillover R&D through the inclusion of the external R&D stock variable in the simple model. Several studies analyzed the effect of inter-industry R&D spillovers, which are summarized in Table I. 2. Mostly, the results show that positive R&D spillovers exist between industries.

In many previous studies investigating the inter-industry spillover of R&D, the external R&D stocks were measured as a weighted sum of R&D stocks from sources outside the firm or industry. The weights were assumed to be proportional to the knowledge flows between firms, industries or countries. Various types of weights have been used: input-output matrix, Leontief inverse matrix, patent flow, and investment in capital goods, trade fair and so forth.

These weighted sums of R&D stocks are expected to capture ‘rent spillover’ (Griliches, 1992), which occurs when an economic transaction takes place. The technology embodied in purchased intermediate goods enhances the spillover receiver’s productivity, but rent spillovers cannot incorporate the entirety of knowledge spillover, which is constituted by ideas borrowed by research teams of industry *i* from the research results of industry *j* (Griliches, 1992). Thus, it is not clear whether the knowledge spillover is related to input purchase flow. In this essay, to estimate pure knowledge spillovers, external R&D stock is measured by simple summation of outside stock.

One of the interesting points about R&D spillover is that its effects on productivity, research and development can differ. For example, while rent or knowledge spillovers are expected to exert a positive impact on output productivity, negative spillover effects can influence R&D. Bloom et al (2013) suggested that knowledge spillover between industries can have ambivalent effects on productivity and research outcomes. In this essay, the effects of R&D stocks on R&D activities are called as ‘indirect spillovers’. To estimate them, R&D equations are added to the traditional production function.

Table I. 2: Survey on previous studies about inter-industry spillover of R&D

Study	Sample & period	Weighting method	Elasticity of R&D to output	Rate of return to R&D
Griliches and Lichtenberg (1984)	193 industries (US) 1959 – 1978	Patent flow	0.112 – 0.286 0.499 – 0.904	11 – 31 (internal) 50 – 90 (external)
Sterlacchini (1989)	15 industries (UK) 1945 – 1983	Leontief inverse matrix	0.09 – 0.19 0.14 – 0.30	12 – 20 (internal) 15 – 35 (external)
Goto and Suzuki (1989)	15 industries (Japan) 1978 – 1983	Input-output flow matrix	0.282 0.670	26 (internal) 80 (external)
Bernstein (1989)	11 industries (Canada) 1963 – 1983	Simple summation		24 – 47 (internal) 29 – 94 (external)
Verspagen (1997)	22 industries in 14 countries 1974 – 1993	Patent flow	0.10 (internal) 0.03 (external)	
McVicar (2002)	7 industries (UK) 1973 – 1992	Input-output flow matrix	0.015 (internal) 0.076 (external)	
Añón Higón (2007)	8 industries (UK) 1970 – 1997	Leontief inverse matrix	0.281 – 0.331 (internal) 0.942 – 2.553 (external)	

2.3. Basic research versus applied R&D

R&D activities can be divided into three types: basic, applied, and experimental development. According to the OECD (2002), basic research is defined as 'experimental or theoretical work undertaken primarily to acquire new knowledge'. Applied research and experimental development are characterised as 'investigation…directed towards a specific practical aim or objective'.

Because basic research is conducted without a predetermined outcome measure, the knowledge generated by it can be applied in elsewhere. Therefore, basic research is more likely to be transferred to competitors. Because of the appropriability problem caused by spillover, some have expressed concern about under-investment in basic research.

To show current situation, the statistics for the R&D expenditure of Korea are presented in Tables I. 3 and I. 4.

Table I. 3: R&D expenditures in private sector in Korea (average)

Year	Basic	%	Applied	%	Total
1984 – 1990	102,587	7.8	1,260,470	92.2	1,363,057
1991 – 1997	477,995	8.2	5,300,045	91.8	5,778,040
1998 –2004	1,065,497	8.5	10,865,402	91.5	11,930,899
2005 – 2011	3,404,934	12.4	23,553,406	87.6	26,958,340

Note: Unit is million won.

Source: KOSTAT

Table I. 4: R&D expenditure ratios by industry in Korea (%)

Industry	1991 – 1996		1997 – 2002		2003 – 2008	
	Basic	Applied	Basic	Applied	Basic	Applied
1. Food, Beverages and Tobacco	14.8	85.2	12.7	87.3	12.7	87.3
2. Textiles, Leather and Footwear	12.6	87.4	9.9	90.1	13.2	86.8
3. Pulp and Paper	9.5	90.5	11.7	88.3	10.9	89.1
4. Printing and Publishing	2.8	97.2	3.8	96.2	7.1	92.9
5. Coke, Refined petroleum and Nuclear fuel	4.0	96.0	9.2	90.8	5.0	95.0
6. Chemicals and Chemical products	11.5	88.5	9.8	90.2	12.4	87.6
7. Rubber and Plastics	8.7	91.3	6.7	93.3	3.5	96.5
8. Other non-metallic minerals	12.1	87.9	10.3	89.7	9.1	90.9
9. Basic metals	7.6	92.4	6.4	93.6	8.9	91.1
10. Fabricated metals	4.3	95.7	7.0	93.0	7.3	92.7
11. Machinery	5.1	94.9	4.7	95.3	5.8	94.2
12. Office, Accounting and Computing machines	8.0	92.0	6.6	93.4	2.6	97.4
13. Electrical machinery and Apparatus	5.7	94.3	6.1	93.9	6.7	93.3
14. Radio, Television and Communication equipment	7.8	92.2	9.1	90.9	15.2	84.8
15. Medical, Precision and Optical instruments	5.0	95.0	5.6	94.4	4.9	95.1
16. Motor vehicles, Trailers and Semi-trailers	8.6	91.4	5.1	94.9	8.3	91.7
17. Other transport equipment	6.2	93.8	3.6	96.4	10.2	89.8
18. Other Manufacturing and Recycling	6.0	94.0	5.0	95.0	6.6	93.4

Source: KOSTAT

Table I. 3 reports official statistics from KOSTAT (Statistics Korea) on private investment in basic and applied R&D for the noted period. In the private sector, across all time periods, the investment for basic research was considerably smaller than for applied R&D, which is represented by summation of applied research and experimental development. The ratio of basic research expenditure ranges from 7.8% to 12.4% and it has been increasing over time.

Table I. 4 presents the ratios of basic research and applied R&D expenditures in the private sector by industry. The ratios of basic research differ by industry. In some industries (food, textile, chemical, non-metallic mineral, communication equipment, transport equipment), especially in the later period, basic research seems to be conducted more intensively (above 10%). The ratio of basic research expenditure has been increasing in some industries (printing, communication equipment, and transportation equipment), but it has been decreasing in other industries (rubber, office machine) over time. The statistics for R&D expenditures by industry are presented in Table I-A.1 in Appendix.

The debate about role of basic research on economic value creation, as contrasted with that of other R&D activities, has been raging for some time. On one hand, basic research is expected to generate higher returns at the industry level. It is the basis for subsequent applied innovation and its outcome can potentially be applicable to many other firms within the industry (Akcigit, Hanley and Serrano-Velarde, 2013). It also generates the capability of a firm to absorb external information and enhance the productivity of applied R&D (Cassiman, Perez-Castrillo and Veugelers, 2002). On the other hand, the rate of return to basic R&D is expected to be low because of its higher risk and uncertainty (Mansfield, 1980).

Previous literature reports that basic research has higher returns than applied R&D. Mansfield (1980) suggested that there is a significant relationship between the amount of basic research conducted by an industry or firm and the growth rate of total factor productivity. Griliches (1986) also found similar results: Firms that spend a larger fraction of their R&D on basic research are more productive. Recently Czarnitzki and Thorwarth (2012) and Luintel and Khan (2011) analyzed the effects of basic R&D based on the production function approach. Luintel and Khan (2011) updated the works of Griliches (1986) and Mansfield (1980) with international level data and showed that both basic research and applied R&D contribute to output and productivity. Czarnitzki and Thorwarth (2012) also showed that basic research contributes to firms' output and the effect of basic research is bigger in high-tech industries. Their results are presented in Table I. 1.

There also have been studies which investigated the effect of R&D on economic performance in Korea. The brief results of the literature are presented in Appendix Table I-A2. The results vary by aggregation level (firm, industry or country) and time period of sample data.

The previous studies are limited in that they only showed the significance of basic research on productivity or estimated the rate of return to basic research. Previous researchers did not specifically focus on the differential spillovers. However, It is needed to account for the differences between basic research and applied R&D in light of spillovers. First, the spillover effects differ between types of research because of their unique applicability. Second, basic and applied research are not independent of each other. Basic research is considered the fuel that powers innovation. The outcomes of basic research can be key inputs for further investments in the R&D process (David, Hall and Toole, 2000). Third, the impact of extensive spillover of certain types of R&D remains unclear. On one hand, spillover means that the type of R&D is important in economic growth. On the other hand, due to the appropriability problem it causes, spillovers indicate that under-investment in basic research should be remedied. Therefore, it is needed to consider inter-industry spillovers and impacts not only on productivity of output but also on R&D activities.

This essay estimate the effects of basic research and applied R&D on productivity growth and innovation, then analyze whether differential spillovers of basic and applied R&D exist between industries and stages of research. Judging the previous literature, this essay is the first to identify differential inter-industry spillovers of basic research and applied R&D efforts. Similarly, Whang (2008) investigated inter-industry spillover of basic and applied R&D for Korean manufacturing industry. But They focused only direct effect of R&D stock on economic performance and neglected the indirect effect of R&D.

3. Model

To examine the impact of R&D on real output within and outside a manufacturing sector, a production function approach is used that permits input of different types of R&D (knowledge) stocks as factors (Mansfield, 1980, Romer, 1986, Jones, 1995). First the production function is assumed to be the Cob-Douglas specification:

$$Y = AL^{\alpha_L} K^{\alpha_K} R^{\alpha_R} \tag{I.1}$$

where Y is real output, K is physical capital stock, L is labor input and R denotes the knowledge capital (R&D stock) of an industry. A is a measure for the total factor productivity (TFP).

The objective of this essay is to estimate the differential effects of unique types of R&D. Following Griliches (1986), R&D are disentangled into basic research (R^b) and applied research and experimental development (R^a). To measure the spillover effects of R&D between industries, external R&D stocks are included, which are also disentangled into basic research and applied R&D:

$$Y = AL^{\alpha_L} K^{\alpha_K} [R^b]^{\alpha_b} [R^a]^{\alpha_a} [R^{ob}]^{\alpha_{ob}} [R^{oa}]^{\alpha_{ob}} \tag{I. 2}$$

Y is real output, K is physical capital stock, L is labour input and R^b and R^a, respectively, denote the stock of basic research stock and applied R&D stock of an industry. R^{oa} and R^{ob}, respectively, denote the stock of basic research and applied R&D of all manufacturing industries except for the one being considered.

Ordinarily, logs are taken of this equation to convert it to a linear model, which can be easily estimated:

$$\ln Y_{it} = c_y + \alpha_L \ln L_{it} + \alpha_K \ln K_{it} + \alpha_b \ln R_{it}^{b} + \alpha_a \ln R_{it}^{a} + \alpha_{ob} \ln R_{it}^{ob} + \alpha_{oa} \ln R_{it}^{oa} + \varepsilon_{yit}$$

with $\log(A_{it}) = c_y + \varepsilon_{yit}$ (I. 3)

where *i* denotes manufacturing industry (*i*=1,…, *N*) and *t* is time (year). c_y is a constant term and ε_{yit} is a disturbance. The parameters $\alpha_L, \alpha_K, \alpha_b, \alpha_a, \alpha_{oa}$ and α_{ob} denote unknown output elasticities of the inputs. By definition, the elasticity of R&D stock is $\alpha = \rho(R/Y)$; ρ is the marginal productivity (rate of return) of R&D stocks. By estimating the elasticities and rates of return of R&D stocks one can measure their direct impact.

Although the production equation can be used to estimate the effects of R&D stocks (basic and applied) on real output, it does not account for all of the spillover effects of R&D stocks. That is, it cannot explain the multilateral relation among R&D stocks. For example, the outcome obtained from basic research of an industry may contribute to the real output of other industries and also provide technology opportunities and stimulate the creation of new knowledge in other industries. The latter type of spillover is called as 'indirect spillover' in this essay.

R&D (investment) equations is added to Equation (I. 1) to identify the indirect spillovers from other types of R&D and other industries' R&D efforts. And four types of

R&D stocks ($R_{it}^{b}, R_{it}^{a}, R_{it}^{ob}, R_{it}^{oa}$) are included as regressors to estimate the effect of knowledge spillover from R&D stocks of other stages or industries. The real output is included as a determinant to measure market pull innovation effects (as per Spence 1984).

$$\ln E_{it}^{b} = c_b + \beta_a \ln R_{it}^{a} + \beta_{ob} \ln R_{it}^{ob} + \beta_{oa} \ln R_{it}^{oa} + \ln Y_{it} + \varepsilon_{bit} \quad \text{(I. 4)}$$

$$\ln E_{it}^{a} = c_a + \gamma_b \ln R_{it}^{b} + \gamma_{ob} \ln R_{it}^{ob} + \gamma_{oa} \ln R_{it}^{oa} + \ln Y_{it} + \varepsilon_{ait} \quad \text{(I. 5)}$$

where E_{it}^{b} and E_{it}^{a}, respectively, denote investment (expenditures) for basic and applied R&D. Parameters $\beta_a, \beta_{ob}, \beta_{oa}, \gamma_b, \gamma_{ob}$ and γ_{oa} measure indirect R&D spillover effects. The effect of these R&D stocks can be interpreted as inter-stage (β_a and γ_b) and inter-industry (β_{ob}, β_{oa}, γ_{ob} and γ_{oa}) knowledge spillovers. Figure I. 1 illustrates the direct and indirect impacts of R&D efforts.

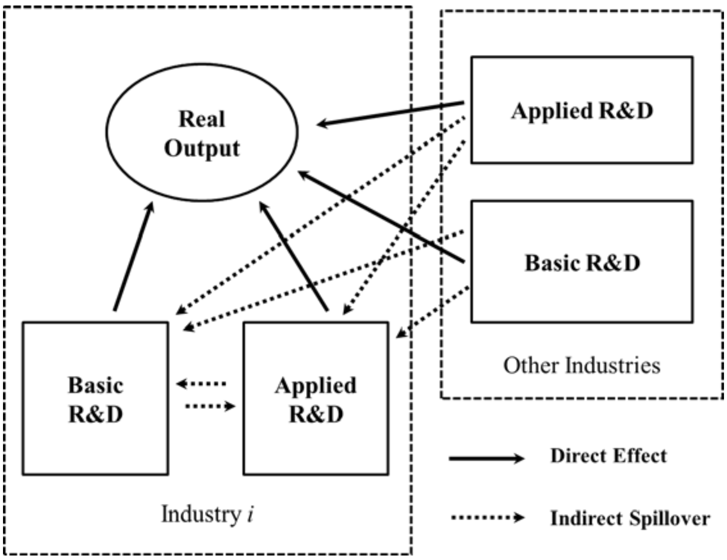

Figure I. 1: Direct and indirect impacts of R&D efforts

Production function approach is representative methodology to estimate the productivity or the effect of R&D investment on economic performance. It is an intuitive way to estimate the relationship between input factors and output factor using aggregate data. In general, the production function is assumed to have a Cobb-Douglas form. And the input factors (such as capital and labor) are assumed to independent. In some case, it requires 'constant returns to scale' assumption but it is not always necessary. Thus, most of previous literature used production function approach to analyze the relationship between R&D and productivity. However, this approach has some problems which can result in measurement bias especially when R&D is regarded as input factor.

The first is double-counting of R&D problem. When the capital data were aggregated, there is a possibility that R&D investment was included in capital data. In this essay, to overcome this problem R&D stock is subtracted from capital stock.

The second is the difficulty of constructing of appropriate R&D stock. In the perpetual inventory method which has been used widely, choosing proper depreciation rate is not easy because it can vary by technology and industry. In this essay, to alleviate the problem, different depreciation rates by industry are adopted. In addition the results of three models using same depreciation over industries (15%, 20%, 25%) are reported in appendix to enhance of credibility of the results.

The third is time-lag of R&D. There is time-lag that the effect of R&D stock on the economic performance realizes. Previous literatures reflected this aspects, used 1 ~ 5 years time-lag models. In this essay, three models that use time-lag (1, 2 and 3 years) are reported.

4. Data and variables

Annual information of 18 Korean manufacturing industries covering 19 years (1991–2009) constitute balanced panel data in the estimation (342 observations). Industry classification is based on the Korean Standard Industrial Classification System (KSIC). Real output, capital stocks and labor input data are from EU KLEMS and the Korea Industrial Productivity Data Base[2].

R&D expenditure data on basic and applied research are from the ‘Survey of Research and Development in Korea’. This essay uses R&D expenditures funded by private sectors; that is, government-funded R&D expenditures are excluded. The private R&D data are expected to show clear knowledge spillover effects because private R&D investment decisions are more sensitive to new technology opportunities than are those for public R&D. The expenditure data are used to compute R&D stocks of a specific industry through the perpetual inventory method (PIM) (Meinen, Verbiest and de Wolf, 1998).

According to PIM, R&D stock is defined as the weighted sum of past investments; the weights are determined by the relative efficiency of R&D capital goods at different stages according to the following equation:

$$R_t = E_t + (1-\delta)R_{t-1} \qquad \text{(I. 6)}$$

[2] To measure input correctly in the productivity analysis, one need to carefully measure R&D, which is comprised of expenditures composed of labour, capital and material cost. Unless the inputs are cleared of their R&D components, they are counted twice. R&D double counting can result in bias in the estimates. To minimise the double counting problem, R&D expenditures is substracted from capital input in this paper.

where R_t represents R&D stock in year t, E_t is R&D expenditure in year t, and δ is the R&D obsolesce rate. Different obsolescence rates are used for each industry as shown by Kim (1999), who investigated the Korean manufacturing industries. The R&D stock expenditures vary from 10% to 22% depending on the average life of the core technology in the specific sector. Summary statistics of the data are given in Table I. 5. And the mean values of main variables and the obsolescence rates of the industries are given in Table I. 6.

In some previous works in which researchers investigated the R&D spillover between industries, the external R&D indicators were constructed with a weight matrix to measure inter-industrial flow of technology (Terleckyj, 1974, Kaiser, 2002, Añón Higón, 2007). These indicators reflect the technology flow embodied in products purchased by an industry as distinguished by Griliches (1992) between knowledge spillover and rent spillover[3]. However, empirically disentangling rent from knowledge spillover is very difficult, and any measure of rent spillovers include knowledge stock (Guellec and Van Pottelsberghe de la Potterie, 2004). Furthermore, in terms of indirect spillover, one need not assume that the effect of a piece of knowledge on generating new knowledge in another industry is proportional to the weight ratio as determined by sales or other parameters. Therefore, the external R&D stock is measured by the simple summation of the R&D stocks of other industries in this essay.

In three essays of this dissertation, to evaluate the effect of R&D activity, R&D stock was constructed. And the specific ways of constructing R&D stock are slightly different

[3] Rent spillover occurs when goods are transferred from one industry to another.

according to the purpose of each analysis.

In the second essay (essay II), the traditional perpetual inventory method is used and same depreciation rate is adopted over each industry. Because the differential effect of IPR between industries are compared, it is proper that the R&D stock is constructed based on the same standard (20% depreciation rate). Thus, the different depreciation rates over industries are not considered. And to check the robustness of the model, the result of 15% depreciation rate model is also provide in the appendix. They show similar results.

In the first essay (essay I), the perpetual inventory method is also used. But to estimate the economic effect of R&D spillover between industries, it is important to approximate the valid size of R&D stock of each industry. Thus, the different depreciation rates over industries are considered. In addition, the results of same depreciation rate (15%, 20% and 25%) are also provided for the robustness test and methodological consistency of this dissertation. The results of the alternative models are provided in appendix. The models show similar results.

In the third essay (essay III), it is needed to estimate the effect of R&D stock on electricity generating cost. To construct knowledge stock for measuring the effect on electricity cost, the method of Popp (2001) is more suitable than the perpetual inventory method. Perpetual inventory method consider depreciation rate only. But Popp(2001)'s method consider depreciation rate(decay rate) and diffusion rate so that it construct R&D stock more realistically. But the method of Popp (2001) is not easy to apply to the other essays because the previous studies estimating the two rates (depreciation and diffusion) for general industries are not enough. But Popp (2001) provides the two rates for energy industry. By using it, the R&D stock can be constructed in the third essay.

Table I. 5: Data description

Variable	Description	Mean	S. D.
lnY	real output	17.034	0.745
lnK	physical capital stock	16.443	1.084
lnL	labour input	6.148	0.670
lnE^b	basic R&D expenditure of an industry	9.294	1.703
lnE^a	applied R&D expenditure of an industry	11.908	1.502
lnR^b	the stock of basic R&D of an industry	10.608	1.572
lnR^a	the stock of applied R&D of an industry	13.258	1.383
lnR^{ob}	the stock of basic R&D of other industries	14.498	0.689
lnR^{oa}	the stock of applied R&D of other industries	16.934	0.498

Note: All variables reflect natural logarithms.

Table I. 6: Mean of variables and obsolescence rates by industry

Industry	lnY	lnK	lnL	lnE^b	lnE^a	δ
1. Food, Beverages and Tobacco	17.69	16.88	6.59	9.94	11.80	0.19
2. Textiles, Leather and Footwear	17.06	17.05	6.79	8.70	10.79	0.15
3. Pulp and Paper	16.38	16.23	5.50	7.28	9.51	0.15
4. Printing and Publishing	16.07	15.49	5.80	6.24	9.58	0.16
5. Coke, Refined petroleum and Nuclear fuel	17.49	16.74	4.97	8.56	11.56	0.14
6. Chemicals and Chemical products	17.86	17.59	6.37	11.38	13.46	0.14
7. Rubber and Plastics	16.83	16.25	6.46	9.02	11.86	0.14
8. Other non-metallic minerals	16.74	17.08	6.11	9.14	11.30	0.10
9. Basic metals	17.63	17.63	6.22	9.58	12.04	0.16
10. Fabricated metals	17.31	16.45	6.66	8.54	11.18	0.14
11. Machinery	17.12	16.96	7.04	10.03	13.04	0.19
12. Office, Accounting and Computing machines	16.74	14.30	4.97	9.06	12.08	0.16
13. Electrical machinery and Apparatus	17.03	15.29	6.28	9.52	12.24	0.12
14. Radio, Television and Communication equipment	18.22	17.52	7.08	12.93	15.10	0.22
15. Medical, Precision and Optical instruments	15.72	14.57	5.23	8.68	11.65	0.07
16. Motor vehicles, Trailers and Semi-trailers	17.82	17.08	6.83	11.47	14.26	0.20
17. Other transport equipment	16.83	17.46	5.92	9.75	12.50	0.20
18. Other Manufacturing and Recycling	16.08	15.40	5.85	7.49	10.40	0.16

Source: KOSTAT

5. Results and discussion

First, Equation (I. 3) is estimated using the ordinary least square method (Table I. 7). Because results can be affected by time lags for R&D stocks (Griliches, 1986, Luintel and Khan, 2011), various the lag values are adjusted from the first to the third order when estimating each equation[4].

Results show that an industry's basic R&D stock is significant over all the lag values and exerts a robust impact on real output (output elasticity: 0.14–0.17). Meanwhile, applied R&D stock is also generally significant (output elasticity: 0.13–0.16); however, the effect on output is slightly less vigorous than that exerted by basic R&D. The results coincide with previous findings showing that basic R&D contributes as much as applied R&D to real output (Luintel and Khan, 2011, Czarnitzki and Thorwarth, 2012). When it comes to inter-industry spillovers, neither those associated with basic nor applied R&D show significant effects, which is contrary to previous results that illustrated significant and considerable spillovers (Keller, 2002, Añón Higón, 2007, Badinger and Egger, 2008).

[4] Based on the PIM, we assume a specific R&D depreciate rate. However, the latest addition to the R&D stock probably does not become productive immediately. There is a time lag from expenditure to innovation and commercialisation.

Table I. 7: Single production function result

Variables	Lag of R&D Stock		
	1 year	2 years	3 years
lnK	0.261***	0.263***	0.259***
	(0.030)	(0.031)	(0.031)
lnL	0.072	0.053	0.04
	(0.045)	(0.046)	(0.047)
lnR^b	0.176***	0.156***	0.142**
	(0.055)	(0.056)	(0.056)
lnR^a	0.093	0.130**	0.160***
	(0.060)	(0.061)	(0.061)
lnR^{ob}	-0.415	-0.366	-0.387
	(0.262)	(0.265)	(0.268)
nR^{oa}	0.427	0.357	0.379
	(0.365)	(0.366)	(0.367)
Constant (c_y)	7.984***	8.290***	8.105***
	(2.563)	(2.565)	(2.563)

Notes: * Significant at the 5% level.; ** Significant at the 1% level. ; standard errors in parentheses

However, indirect spillovers may have remained unidentified in the single equation model, Equations (I. 3), (I. 4) and (I. 5) are estimated simultaneously. The three equations are interrelated via the real output variable (*lnY*), which may cause an endogeneity problem (Greene, 2003). Specifically, the three stage least square (3SLS) method (Greene 2003) is used, and instrument variables were all the exogenous variables in the system. The 3SLS method also has the advantage of allowing researchers to consider the correlation between error terms in the three equations (Greene, 2003).

Table I. 8 presents the results. It shows some indirect spillovers between R&D types. Basic R&D seems to remain unaffected by other industry R&D efforts (i.e., no inter-industry spillovers), but in an interesting finding, applied R&D is highly influenced by spillovers from basic and applied R&D.

Regarding applied R&D, as expected from theories, it shows high-level spillovers, not only from basic R&D within a specific industry, but also from the basic R&D of other industries. In fact, the impacts from other industries are more impressive than the ones found within any specific industry. However, negative effects emerge from outside industries' applied R&D, indicating a substitute relationship between applied R&D types.

Table I. 8: Simultaneous model result

		Lag of R&D stock		
Depreciation rate		1 year	2 year	3 year
Equation 1 Dependent variable: *lnY*	*lnK*	0.254***	0.261***	0.259***
		(0.030)	(0.030)	(0.031)
	lnL	0.078*	0.057	0.044
		(0.044)	(0.045)	(0.046)
	lnR^b	0.254***	0.201***	0.168***
		(0.054)	(0.055)	(0.056)
	lnR^a	0.007	0.078	0.131**
		(0.058)	(0.060)	(0.061)
	lnR^{ob}	-0.356	-0.33	-0.368
		(0.260)	(0.262)	(0.265)
	lnR^{oa}	0.34	0.304	0.351
		(0.361)	(0.362)	(0.363)
	constant	8.996***	8.875***	8.400***
		(2.534)	(2.535)	(2.533)
Equation 2 Dependent variable: lnE^b	*lnY*	0.690***	0.706***	0.748***
		(0.079)	(0.086)	(0.092)
	lnR^a	0.824***	0.785***	0.757***
		(0.043)	(0.047)	(0.050)
	lnR^{ob}	0.16	0.494	0.576
		(0.441)	(0.467)	(0.487)
	lnR^{oa}	-0.495	-0.961	-1.042
		(0.608)	(0.641)	(0.664)
	constant	-7.309*	-3.978	-4.133
		(4.118)	(4.361)	(4.500)
Equation 3 Dependent variable: lnE^a	*lnY*	0.074	0.177**	0.322***
		(0.078)	(0.086)	(0.094)
	lnR^b	0.820***	0.761***	0.686***
		(0.037)	(0.041)	(0.045)
	lnR^{ob}	1.702***	1.837***	1.857***
		(0.395)	(0.430)	(0.465)
	lnR^{oa}	-2.707***	-2.916***	-2.944***
		(0.545)	(0.590)	(0.633)
	constant	23.115***	23.609***	22.150***
		(3.743)	(4.075)	(4.367)

Notes: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level; standard errors in parentheses.

Figure I. 2 illustrates the simulation results. The simulation result is based on the 3-year lag time model because the result of the model presents the highest R square value among the models. (Table I. 8.). If the basic R&D stock of all industries increases by 1%, then applied R&D stock increases by 2.543%, of which 0.686 percentage points represents the spillover of basic R&D stock of a single industry and 1.857 percentage points reflect the spillover of basic R&D stock of other industries. If the applied R&D stock of all industries increases by 1%, basic R&D stock increases by 0.757%.

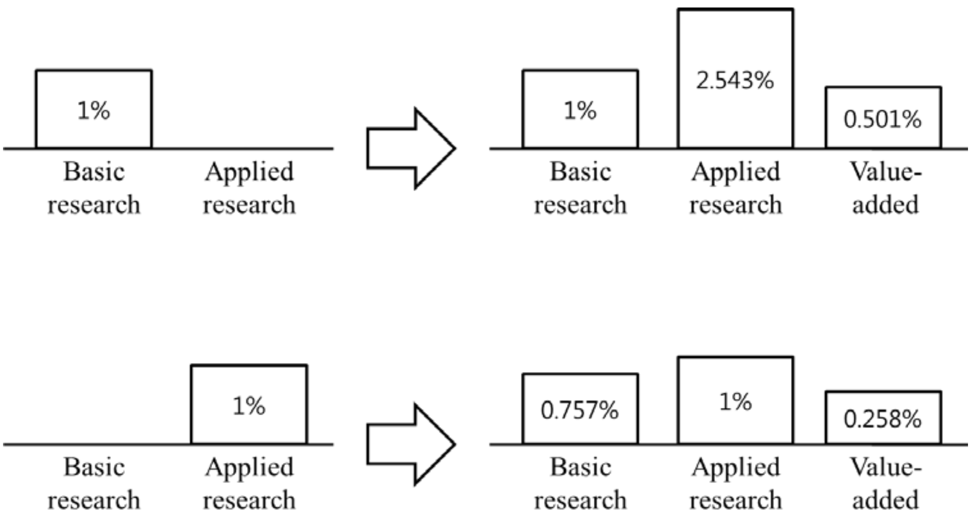

Figure I. 2: Simulation results

Taking account of all the spillover effects when the basic and applied R&D stocks of all industries increase by 1%, the real output increases 0.501% and 0.258%, respectively. These estimated values are higher than previously estimated R&D elasticities in other studies, which had solely accounted for direct effects.

The simulation results suggest that the whole effect of basic R&D on real output, including an indirect effect, is much larger than the sole direct effect of it: 66.5% of basic research impact is caused by indirect effects and 33.5% of it is caused by direct effects. The direct and indirect effects of applied R&D comprise 50.8% and 49.2% of the whole, respectively. Thus, neglecting indirect effects of R&D spillover, one could estimate only a small part of the economic value created by basic and applied R&D investment.

In summary, inter-industry spillovers (indirect effects) exist, and the degree of their impacts differs by the nature of the R&D types. Basic R&D contributes to the creation of not only an industry's applied research but also to other industries' applied research. Applied R&D also inspires basic research in an industry; however, it substitutes in other industries' applied research.

The result suggests the bright as well as the dark side of basic R&D. The term *knowledge spillovers* constitutes a factor of technological 'opportunity' and also of 'appropriability' (Samaniego, 2013). The higher level of spillover effect from basic R&D implies that the outcome of basic research can contribute to productivity and applied R&D activities by creating more technological opportunities. However, it also implies that the knowledge generated by basic research may be used by agents other than the innovator; that is, it is difficult to appropriate. Knowledge spillovers, while increasing social returns, also can cause disincentives to R&D investment (Spence, 1984, Bernstein and Nadiri, 1989). Only when the disincentives associated with them are appropriately resolved can knowledge spillovers of basic R&D be important drivers of economic growth. The results suggest that policy makers should consider the characteristics of basic research and its importance and make an effort to maximise knowledge spillover.

This essay has some limitations caused by the availability of data. The disentangled R&D data (basic and applied research by industries) of other countries are difficult to obtain. It requires good care to generalize of the result for all countries. Because of availability data, only private R&D data was used. Then the model does not consider the effect of public R&D. If it is considered, the role of R&D in the economic system can be modeled in better way.

And in this model, R&D stock is assumed to be independent with other input factors (such as capital and labor stocks). In this analysis, labor input is simple summation of laboring hour and does not account for the quality aspects of labor input. Thus, the relation between R&D stock and labor input is not considered. This can be a limitation of the model.

6. Conclusion

This essay investigated the role of basic and applied R&D for productivity growth and innovation by focusing on the spillover effects of R&D in the Korean manufacturing industry. Using the production function approach, we examined the differential effects of basic and applied R&D by taking into account spillovers between industries and stages of research. The results show that the spillovers of basic research are much bigger and exert a wider impact than do spillovers of applied research. The essay helps render a clear perspective of the relative importance of basic research in economic growth while recognizing the impact of knowledge spillovers.

- Essay II -

Effects of Intellectual Property Rights and Patented Knowledge in Innovation and Industry Value Added

* The essay was submitted to *Technovation* and is now under the 2nd revision. The title of the submitted paper is “Effects of Intellectual Property Rights and Patented Knowledge in Innovation and Industry Value Added”

1. Introduction

Today technological change is regarded as the most essential driver for long-term economic growth (Romer, 1990). Therefore, provision of innovation-friendly environments, including increased enforcement of intellectual property rights (IPR), emerged as an important policy agenda during the 1980s in developed countries. With the emergence of the free trade doctrine and the World Trade Organization's Trade-Related Aspects of Intellectual Property Rights (TRIPs) of 1994, developing countries were forced into involuntary tightening of IPR (Hall, 2007b). However, debates abound on whether such enforcement of universal IPR standards leads to technological development and economic growth. Specifically, is the world becoming more innovative after the efforts of global strengthening and standardization of IPR? Part of the answer may be revealed by the sharp rise of an innovator-friendly patent systems concurrently emerging with the information and communication technology revolution that resulted in enormous increases in patent filings at the turn of the 21st century (Kortum and Lerner, 1999). However, patent numbers alone are not good measures of innovation, because not all patented inventions represent successful innovations and many innovations are never patented (Pakes and Griliches, 1980).

Of course, many previous papers show, both in theory and as empirically measured, that strong IPR stimulates technological innovation by incentivizing the inventors who drive economic growth (Kanwar and Evenson, 2003; Park and Ginarte, 1997). However, some also acknowledged (potential) negative impacts of strong IPR. First, some articles discuss the negative effect of strong IPR on technology transfer, diffusion, and commercialization due to the excess monopoly power given to inventors as well as incentives for strategic patenting (e.g., blocking the competitors entering the market) (Allred and Park, 2007; Encaoua et al., 2006; Gallini, 2002; Hall and Ziedonis, 2001).

Second, the IPR impact may differ by the economic development level of countries (Falvey et al., 2006; Gould and Gruben, 1996; Park and Ginarte, 1997; Schneider, 2005). Researchers generally found that developed countries tend to benefit more than developing nations from strong enforcement of IPR.

Third, numerous scholars have addressed the limitations of IPR in terms of patentable technology of a sequential nature (Bessen and Maskin, 2009; Encaoua et al., 2006; Gallini, 2002; Murray and Stern, 2007). They argued that when an invention directly follows from previous ones, the exclusive rights may impede access to the knowledge embedded in the development of previous inventions and thus slow down technological progress. While the current patent holder attempts to hold up the future innovation of a rival through a strong IPR regime, the inventor will also be delayed by previous patent holders. Therefore, in this setting, the link between patent strength and innovation incentives remains ambiguous (Gallini, 2002).

This essay empirically estimated the effects of IPR on innovation and economic growth (value added) using international panel data of three main industries. An innovation (Spence, 1984) and a value added (production function) (Jones, 1995) equations are combined and estimated simultaneously to identify direct and indirect effects of IPR on economic growth. IPR may create two different influential paths: a direct effect on the value added (commercialization of technology) and an indirect effect via innovation (research and development [R&D]) (Park and Ginarte, 1997; Schneider, 2005). Additionally, this essay introduces a patented knowledge variable in the R&D investment equation to distinguish the specific IPR effects on the sequential innovation from the general IPR effects on the innovation (R&D investment).

This essay also focuses on the relationship between the characteristics of knowledge and IPR. Because IPR comprise a system in which property rights are enforced on intangible and non-rival goods rather than tangible and rival goods, this essay focuses on the characteristic of knowledge, or in an industrial context, of technology, to observe the potential varying effects of IPR on different industries. To do this, it is assumed that industry characteristics are largely distinguished by their specific technological compositions.

Inspired by ideas from previous literature regarding the varying characteristics of technology (industries), such as discrete versus complex industries (Cohen, 2000), complementary innovation versus isolated innovation (Bessen and Maskin, 2009), and tacit versus codified technology (Brusoni et al., 2005; Winter, 1998), theoretical framework is applied that explains the ways those characteristics work in an innovation system. By using industry level data, this essay empirically examines varying effects of IPR on commercialization, sector-specific innovations, and sequential innovations.

This essay is almost the first that empirically identifies the impact of IPR by the nature of technology (industry) and specifically on sequential innovation across main industries (Murray and Stern (2007) conducted similar research by only on bio-technology sectors). This essay examines how the compositions of technologies in different industries are affected due to IPR enforcement.

The essay is organized as follows: Chapater 2 review important literature on IPR, innovations, and the characteristics of technologies influenced by industry strategies. In chapter 3, the research framework and methodology are presented, including the development of a variable as a proxy for the characteristics of each industry. Chapter 4 shows the empirical results, chapter 5 discusses interpretation of the outcomes, and chapter 6 features conclusions.

2. Theoretical Frameworks

2.1. Intellectual property rights and technology

A description of the fundamental nature of technology, or *knowledge*, and the strategic behavior of the firms when utilizing these technologies, which are protected by property rights, explain the importance of this industry-level analysis. The difference in the technological composition of specific industries leads to different incentives for protecting intellectual assets through patents, and many scholars have drawn attention to the different patenting activities and motives across industries.

2.2. Discrete versus complex industry and sequential innovation

The discrete and complex nature of knowledge, an aspect of technology that tailors the innovation-incentive mechanism of the industry, means that one or many patents can apply to new inventions (products), which are subsequently characterized as discrete and complex, respectively (Cohen, 2000; Kash and Kingston, 2001; Kusunoki et al., 1998; Merges and Nelson, 1990; Reitzig, 2004). Examples of discrete products include new drugs and chemical products, and examples of complex products include those of electronics industry.

In case of a complex industry, numerous complementary technologies are developed via different and diverse R&D lines, which increase the overall probability of creating a successful innovation (Bessen and Maskin, 2009). Complex industries feature complementary technologies, which then relate to *sequential innovation* (Encaoua et al., 2006), described as the complementarity of technologies in dynamic perspective. Innovations are intrinsically cumulative (sequential) in that advances build on and interact with many other features of existing technology (Merges and Nelson, 1990).

2.3. Codified versus tacit knowledge

The following researchers distinguished knowledge between codified and tacit characteristics: Balconi (2002), Brusoni et al. (2005), Grimaldi and Torrisi (2001) and Johnson et al. (2002). Codified knowledge, sometimes called “explicit knowledge,” can be described as messages and generic algorithms that can be transmitted at relatively low costs and deployed in a context other than that in which they were originated (Brusoni et al., 2005).

In a philosophical context, Johnson et al. (2002) categorized these types of knowledge as “know-what” when referring to knowledge about the facts and “know-why” when referring to knowledge about principles and laws. These types differ from tacit knowledge, which is described by “know-how” and “know-who” characteristics. The transfer of codified knowledge tends to less require absorptive capacity in terms of necessary institutional support. In other words, codified knowledge, representing explicit content, is much less painfully transferred to and digested by rival entities.

Brusoni et al. (2005) defined tacit knowledge as an “inarticulable contextual framework that provides individuals’ cognitive processes in the background within which to focus and to attribute meaning to conditional statements.” Tacit knowledge embedded in skills is difficult to articulate but can be transferred through personal, informal contact and training (Winter, 1998). Examples of tacit knowledge include skills and know-how that are difficult to imitate.

2.4. Technologies and industries

According to Johnson et al (2002), chemical and electronic industry are science based industry which is based on know-why(science principle) rather than know-how(skill). Also Brusoni et al (2005) presented interesting empirical research concerning ways boundaries between tacit and codified knowledge vary across industries. Using the *Dutch Community Innovation Survey*, they estimated codification scores for 12 different industries and found that science-based sectors, especially the chemical and electronics industries, showed the highest codification scores. The machinery equipment industry placed between chemical and electronics industries, while the transportation equipment industry received estimate scores approximately one-half that of the chemical industry.

For discrete and complex industries, Cohen et al. (2000) have distinguished industries with ICIC codes less than 2900 (e.g., chemicals and drugs) as “discrete” while those with ISIC codes of 2900 or above (e.g., machinery and electronics) as “complex. ” A similar distinction can be found in Kusunoki et al. (1998)’s empirical paper. Meanwhile, industries such as those producing automobiles, aircraft, electric light systems, semiconductors, and computers show sequential innovation; that is, technology advances are built upon and interact with many other features of existing technology (Merges and Nelson, 1990).

2.5. Different effects on innovation by industry

In case of an industry characterized by complex products, conflicting view arise on firm's behavior to patent complex invention. In order for firms to patent their invention, the invention must be novel, meaning that the invention often requires a substantial level of complexity. Rivkin (2000) and Rivkin(2001) argue that because complex products are difficult to imitate because of their complex nature, firms do not have an incentive to patent their complex inventions. On the other hand, Gopalakrishnan and Damanpour (1994) and Jonsson and Regnér (2009) argue that imitators would have a higher incentive to copy an innovative company when its product is more complex (Pérez-Luño and Valle-Cabrera, 2011).

Codified knowledge is explicit and maximizes non-rival characteristics of knowledge, which is recordable and transferable at negligible costs; these qualities help justify public supports created to solve associated market failure (Romer, 1990), including a patent system that grants provisional monopoly rights so the innovation can be used to recover R&D costs. However, tacit knowledge, which is difficult to patent, offers less effective support for R&D incentive environments. The empirical findings in fact support the positive relationship between codified knowledge and patenting suggesting that firms can effectively protect their invention by patenting them when the nature of knowledge is codified (González-Álvarez and Nieto-Antolín, 2007; Pérez-Luño and Valle-Cabrera, 2011). Therefore, IPR may not effectively stimulate industries in which innovations are based largely on tacit knowledge, but innovation-based articulated (codified) knowledge could be more easily stimulated by strengthened IPR.

However, this positive effect of IPR can be reversed in situations characterized by sequential innovation, such as in industries with complementary technologies. In these cases, the benefits provided from stronger legal rights of the patent holder can be offset by the costs incurred by an infringement lawsuit levied by a previous patent holder. In other words, while the current patent holder attempts to delay the future innovation of a rival through a stronger IPR case, they will also experience legal roadblocks put up by previous patent holders (Gallini, 2002).

Recently, Bessen and Maskin (2009) developed a model describing a strong IPR regime that hinders sequential and complementary innovations. They argued that an industry accompanied by sequential innovation is more dynamic when imitation is taking place (without IPR) and first (previous) innovators can cover their costs of innovation. Because imitation based on innovation could improve the overall technology, innovation could be greater without IPR enforcement. That is, IPR may reduce welfare by blocking imitation and thus interfering with further innovation. Of course, licensing can offer a solution, but due to asymmetry in information about future profits between potential innovators, licensing efforts may fail (Bessen and Maskin, 2009).

From these theories, one can hypothesize that in complex industries with complementary and sequential technologies, the negative impact of strong IPR is greater than in discrete industries based on isolated technology. Additionally, it is expected that negative effects for codified technology is stronger than tacit technology because patent holders can more easily block follow-on innovations.

2.6. Intellectual property rights and technological commercialization

Strong IPR procured during the last two decades led to increased use of intangible assets, such as patents, in licensing and commercialization activities (Arora and Fosfuri, 2003). Traditionally, the central role of IPR was as an incentive mechanism. However, recently researchers have started to emphasize the ability of IPR to provide an environment for commercialization (Gans and Stern, 2003). Lichtenthaler (2008) argued that besides applying technological knowledge to products and services, firms may externally leverage their technology assets and licensing. Arora and Fosfuri (2003) suggested that recent technology commercialization activities challenge the traditional wisdom by suggesting that an innovator can best profit by self-commercializing an invention. Innovative and incumbent firms may find private licensing profitable.

Various theories explain the effects of strong IPR on commercialization (direct impact to valued added). Previous literature mentions the opposite effects of market expansion and market power (Allred and Park, 2007). *Market expansion effects* refer to the increase of commercialization activities because economic rewards are appropriated by stronger IPR; that is, IPR may induce firms to commit resources to the development of new businesses based on new technology (Mazzoleni and Nelson, 1998). Strong IPR also may facilitate the transfer (licensing) of technology because they clarify property rights (Arora and Merges, 2001; Green and Scotchmer, 1995; Merges, 1998), which reduces transaction costs when technology is traded (Arora et al., 2001; Somaya and Teece, 2001). On the other hand, *Market power effects* refer to enhanced monopoly power created by strong IPRs, which then results in market distortion and static efficiency loss. It may create market entry barriers, such as strategic patenting activities (Hall and Ziedonis, 2001).

The effects of market expansion and power can differ by industries and technologies. Discrete industries seem to benefit from strong IPR. Levin et al. (1987) argued that industries composed of discrete products, such as those in the chemical sector, can patent innovations relatively easily because the molecular structure of each invented product is unique; however, these products are very vulnerable to imitation from competitors. Strong IPR creates a licensing-friendly environment and the obvious overall impact of IPR on discrete-industry market expansion are strengthened when the technology is codified. However, the negative market power effect of discrete and codified technology is also clearly increased by strong IPR. Accordingly, the overall effects remain ambiguous.

Uncertainty of IPR effects also characterizes complex industries (Cohen, 2000). Firms do not have proprietary control over complementary technologies required for constituting complex products, and because required technologies are often patented by rival firms, environments with rigorous licensing activities evolve between firms. These traditional complement problems caused by a patent thicket raise the overall cost of product development (Shapiro, 2001). Strong IPR may bolster proprietary control of a patent holder while simultaneously increasing the power of another patent holder of complementary technologies such that the overall impact on market expansion is ambiguous. The market power effect also remains unclear as the increasing power of each patent holder may not lead to conclusive results.

2.7. Synthesis

Table II. 1 summarizes how different characteristics of technologies are associated with IPR regime, and Table II. 2 presents these differences are associated with general and sequential innovation under the presence of IPR regime. It shows the positive and negative effects of strong IPR that may co-exist in an innovation environment; the overall impact on innovation depends on the size of the specific effect. The influence on value added (commercialization, direct effects) are also ambiguous. Because R&D is an important driver of economic growth (value added), IPR exert an indirect impact on innovation (increased innovation by strong IPR drives economic growth). Accordingly, it is needed to develop a comprehensive model to empirically analyze, not only the direct impact of IPR on value added, but also their indirect impact via R&D.

Table II. 1 Characteristic of knowledge and intellectual property rights (IPR).

Characteristics of knowledge	Arguments for strong IPR	Arguments for weak IPR
Complex	Patent thicket problems can be solved by cross-licensing (Green and Scotchmer, 1995)	Impeding potential diverse R&D lines decrease the overall success of innovation (Bessen and Maskin, 2009)
		Rise in strategic patenting activities cause patent thickets problem (Cohen, 2000)
		Costs of complementary patents increase under monopoly (Shapiro, 2001)
Discrete	Prevent invent-around (Levin et al., 1987)	
Codified	Require less absorptive capacity when imitated (Brusoni et al., 2005)	
Tacit		Know-how type of knowledge is hard to imitate (Winter, 1998)

Table II. 2 Varying effects of intellectual property rights (IPR) on characteristics of technology.

Type	Discrete	Complex
Codified	General Innovation (++)	General Innovation (++) Sequential Innovation (--)
Tacit	General Innovation (+)	General Innovation (+) Sequential Innovation (-)

2.8. Past empirical evidence

Many empirical studies show divergent roles of IPR on economic growth, prompting continuous empirical research on this issue. Gould and Gruben (1996) suggested that IPR plays an important role in economic growth. At the same time, the authors emphasized the role of economic openness in countries where strong IPR exerts a significant impact on economic growth, asserting that developing countries need to abandon their protectionist policies to benefit fully from strong IPR. And Kanwar and Evenson (2003) suggested that strong IPR enhance R&D investment even in developing countries. Park and Ginarte (1997) showed that strong IPR significantly affects economic growth only for developed countries by using their own developed IPR index. However, there have been contrary empirical works that suggested IPR has no relationship with R&D investment (Hall and Ziedonis 2001; Jaffe, 2000; Sakakibara and Branstetter, 1999). Hall and Ziedonis (2001) analyzed the patenting behavior of US semiconductor firms.

Table II. 3 shows how past empirical literature differs in explaining the role of IPR on economic growth and innovation. Interestingly, macroeconomic analysis focused on the role of IPR in gross domestic product (GDP) growth tends to present a positive role of IPR, while firm-level analysis tends to show no significant role for IPR.

While numerous works, based on country- or firm-level data, have empirically shown the role of IPR on economic growth and R&D, few researchers have focused on the varying effects of IPR at the industry level. Some of the few attempts include that of Allred and Park (2007), but their study was based on firm-level analysis in which they used industrial classification to distinguish firms' major activity, and then they employed the resulting categories as proxies for industries.

Table II. 3 Past empirical works on the role intellectual property rights (IPR).

Role of IPR	Literature	Level of Analysis
	Gould and Gruben (1996)	country-level
Enhance	Park and Ginarte (1997)	country-level
innovation	Kanwar and Evenson (2003)	country-level
	Allred and Park (007)	firm-level
No relation or	Sakakibara and Branstetter (1999)	firm-level
impede	Jaffe (2000)	firm-level
innovation	Hall and Ziedonis (2001)	firm-level

3. Model and Data

3.1. Model

In this essay, an innovation (Spence, 1984) and a value-added equation (production function [(Jones, 1995)) are set up and estimated simultaneously to identify direct and indirect effects of IPR on economic growth. IPR may exert impacts in two different ways: They may directly affect the value added (commercialization of technology) or indirectly influence innovation (R&D) (Park and Ginarte, 1997). Because IPR theoretically promote R&D, which in turn promotes economic growth, a simultaneous equation model can be implemented to analyze virtuous cycles between IPR, R&D, and economic growth. However, the interest of this essay in the characteristic of knowledge (or in an industrial context, of technology) as a means to observe the varying effects of IPR on different industries led us to apply a two-equation system to various industries and compare the estimates between them. The general framework of the model for industries is shown in Figure II. 1.

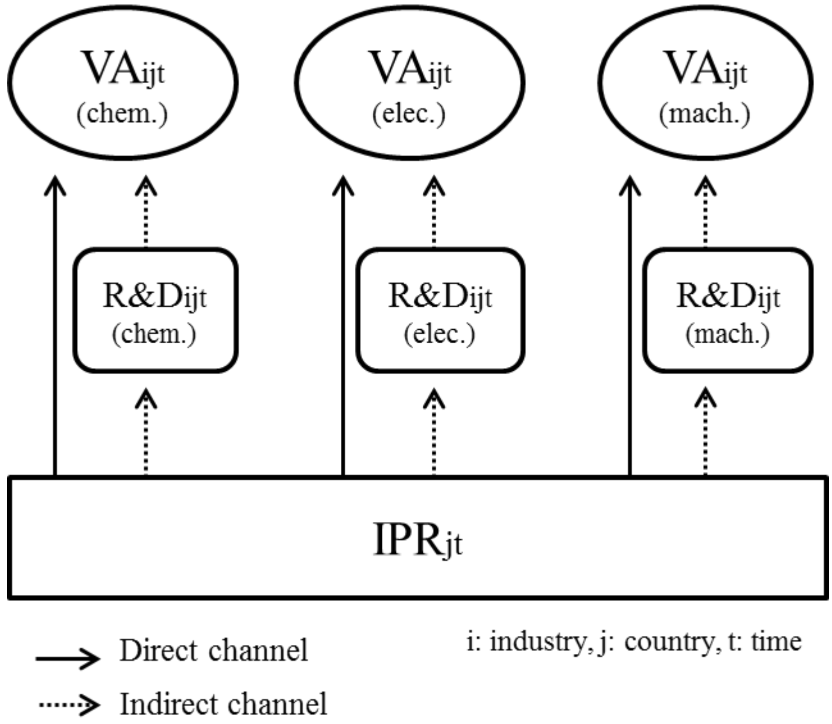

Figure II. 1 : General model framework: different channels of intellectual property rights contributions on value added (VA) to the chemical (chem.), electronics (elec.), and machinery (mach.) industries.

To examine the direct impact of IPR on the value added of industry sectors, a production function approach is used that permits input of R&D (knowledge) stocks and the IPR indices as factors (Jones, 1995; Mankiw et al., 1992; Mansfield, 1980; Romer, 1986). It is assumed to be the Cobb–Douglas production function specification:

$$\ln Y_{ijt} = c_y + \alpha_L \ln L_{ijt} + \alpha_K \ln K_{ijt} + \alpha_R \ln R_{ijt} + \alpha_{IPR} IPR_{jt} + \alpha_{IPR2} IPR2_{jt} + \varepsilon_{yijt} \quad \text{(II. 1)}$$

where i denotes industry (i=1,…, N), j denotes countries, and t is time (years). Y_{it} is real output (value added), c_y is a constant term, K_{ijt} is physical capital stock, L_{ijt} is labor input, and R_{ijt} denotes the stock of R&D of an industry. IPR_{jt} is the index for strength of IPR. $IPR2_{jt}$ is the quadratic value of IPR_{jt}. ε_{yijt} is an error term.

The parameters α_L, α_K, and α_R denote unknown output elasticities of the inputs. By including IPR_{jt} and R_{ijt} in the value-added equation, one can distinguish the direct and indirect effects of IPR on value added. The indirect effects of IPR via R&D are captured by α_R. Lastly, α_{IPR2} presents information about whether a non-linear relationship exists between IPR and value added. Based on the literature, patent protection exerts negative effects after an excessive level of protection has been reached, yielding an inverted U-shape (Allred and Park, 2007).

Also the R&D (investment) equation (Spence, 1984) is added to the value-add equation (Eq. 1) to identify the indirect impact of IPR on new idea generation. Value added (output) is included as a determinant to measure market-pull innovation effects (Spence, 1984) and R&D stock lagged by 1 year ($R_{ijt\text{-}1}$) as a regressor to estimate the effect of past ideas on current R&D (Jones, 1995; Jones and Williams, 1998):

$$\ln E_{ijt} = c_E + \beta_R \ln R_{ijt-1} + \beta_Y \ln Y_{ijt} + \beta_{IPR} IPR_{jt} + \beta_{IPRPK} IPR_{jt} \cdot PK_{ijt} + \varepsilon_{Eijt} \qquad \text{(II. 2)}$$

E_{ijt} denotes investment (expenditures) for R&D. *IPR* is included to measure the IPR effects on general innovation (R&D investment). An interaction term between *IPR* and patented knowledge (*PK* = PS (patent stock)/ R (R&D stock)) is introduced to examine whether strong IPR impede sequential innovation.

In this essay, *PK* measures the relative size of the patent stock (previous patents granted) to total R&D stock. According to theories mentioned in Section 2, in cases characterized by sequential innovations (complementary technology), previously granted patents can discourage follow-on innovation by blocking imitation by potential inventors (Bessen and Maskin, 2009). Two factors work together to discourage innovation: granted (previous) patents and strong IPR, which block imitation. Accordingly, if PK is the source of negative IPR impact on sequential innovation, then the parameter-of-interaction term between *IPR* and patented knowledge (β_{IPRPK}) is negative.

In the R&D equation (Eq. II. 2), the effect of IPR on R&D is estimated (β_{IPR}), and through the value-added equation (Eq. II. 1) the effect of R&D stock on value added (α_R) is estimated. Synthesizing the two effects, one can capture the indirect effects of IPR on R&D and observe whether a virtuous cycle between IPR, R&D, and value added exists. Increased R&D investments from strengthened IPR accumulate to form more knowledge (R&D) stocks, becoming one of the main factors contributing to the value-added function. In the value-added equation (Eq. II. 2), the direct effect of IPR is captured by the parameter α_{IPR} , which indicates the effect of IPR varying across countries and time when K_{ijt}, L_{ijt}, and R_{ijt} are fixed. Eq. (II. 2) presents information about whether the stronger IPR provide a better environment for technology commercialization, including technology licensing, than weaker IPR (Allred and Park, 2007; Arora et al., 2001; Arora and Merges, 2001; Green and Scotchmer, 1995; Merges, 1998; Somaya and Teece, 2001). Therefore, equations encompassing a simultaneous calculation of Eqs. (1) and (2) are adopted to provide a more accurate explanation of the role of IPR on value-added industries in a dynamic setting.

Eqs. (II. 1) and (II. 2) are interrelated via the value-added (*lnY*) variable, which may cause an endogeneity problem (Greene, 2003). With a simple OLS regression, the estimations would be biased and inconsistent. Therefore, the three stage least squares (3SLS) method (Greene, 2003) is used, and instruments are all the exogenous variables in the system. The 3SLS method offers advantages with regard to correlations between the error terms in two equations (Greene, 2003). Therefore, to capture the dynamic structures of the IPR-R&D-VA virtuous cycles, the 3SLS method is implemented, which captures the relationship between two structural equations by assessing their structural disturbances simultaneously.

3.2. Data and variables

3.2.1. Measuring R&D stocks

In this model, using R&D investment data, R&D stocks is calculated for different industries in each country. To calculate R&D stock, the most commonly used approached was employed: the perpetual inventory method (PIM) (Meinen, 1998). In PIM, R&D stock is defined as the weighted sum of past investments with the weights given by the relative efficiency of R&D capital goods at different ages according to the following equation:

$$R_t = E_t + (1-\delta)R_{t-1} \qquad \text{(II. 3)}$$

R_t represents R&D stock in year *t*, E_t is R&D investment in year *t*, and δ is the R&D obsolesce rate respectively.

Two types of R&D stocks are employed. One is an input factor for value added, the other is an input factor for new knowledge production (R&D investment). Because the profit from the knowledge produced by R&D activities decreases over time, the obsolesce rate is needed to be considered for constructing the R&D stock term for the value-added equation. There has been many attempts to employ R&D depreciation rates for constructing R&D stocks. Among a few notable attempts, Pakes and Schankerman (1984)'s estimation, using patent renewal data, showed that the average annual R&D deprecation rate at 25%, while Nadiri and Prucha (1996)'s estimation was around 12%. Meanwhile, Bureau of Economic Analysis (BEA)'s 2006 R&D Satellite Account Paper (Okubo et al., 2006) used 15 percent as the annual depreciation rate for all R&D capitals.

Overall, the rate differs by each studies and it ranges from about 10% to 30%. 20% obsolescence rate was used based on the fact that 20% obsolescence rate has been widely used and the resulting elasticity is insensitive to the choice of obsolescence rate theoretically (Hall et al, 2009).

Past works also attempted to differentiate the R&D depreciation rates among different industries based on the conventional consensus that industries generally differ in their product life-cycles and competitive environments. Lev and Sougiannis (1996) estimated the depreciation rates for six selected industries, finding a range from 12 to 20 % of the depreciation rate with average depreciation rate of 15%. Goto and Suzuki (1989) have employed different depreciation rates among industries based on Science and Technology Agency's survey of the "life span" of technology. However, this essay chose to use same obsolescence rates by different industries for simplicity of analysis. Although using different obsolescence rate by different industries is not expected to significantly change the results, it makes analysis of the differential effects of IPR by different industries difficult.

To check the model's robustness, the model was estimated with the alternative R&D stock using 15% obsolescence rate. The results is provided in Table II-B4, Table II-B5 and Table II-B6 in the Appendix, where m1 and m2 incorporated RDS20 (20% obsolescence rate) and RDS15 (15% obsolescence rate) respectively. The results show that RDS20 and RDS15 have almost the same coefficients in all industries, suggesting that the results are insensitive to R&D obsolescence rate. And it also shows that using same obsolescence rate across industries doesn't change the main results.

On the other hand, for the input factor for new knowledge production (R&D

investment), o% of obsolesce rate was used. Assuming that previous knowledge produced by R&D activities can contribute to the production of new knowledge, R&D stock term for the R&D investment equation with a 0% obsolesce rate (*RDS0*) was adjusted.

3.2.2. Measuring patented knowledge

The most critical elements of this research reflect the analysis of the contribution of IPR to R&D in a sequential setting and the ways these contributions differ across different industries. To capture the negative impact of IPR on sequential innovation, the amount of PK was quantified as part of the available knowledge, namely R&D stocks, that has accumulated in each industry. As shown in Figure II. 2, PK is basically proportion of patent stocks to R&D stocks and is expressed as Eq. (II. 4).

$$PK_t = PS_t / R_t \tag{II. 4}$$

Where PS_t represents patent stock in t year. The methodology for the construction of patent stocks will be explained in Section 3.2.3.

Figure II. 2 illustrates the effects of patented knowledge in an industry. Adding an interaction term between IPR and PK in the R&D equation (Eq. II. 2), one can analyze the variation levels of the IPR effects on R&D as industry knowledge is increasingly patented. A negative sign for this interaction variable may explain the reason that excessive patented knowledge detracts from the positive effects of IPR on R&D.

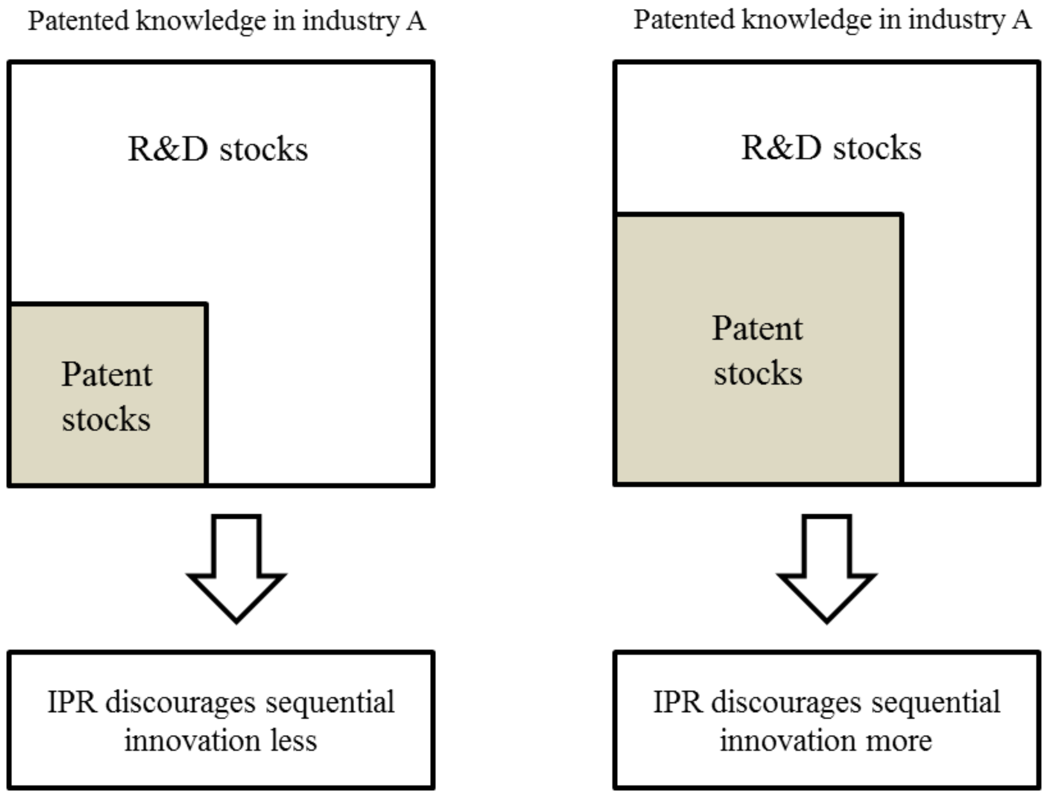

Figure II. 2 : Level of patented knowledge and R&D incentives.

3.2.3. Measuring patent stocks

As seen in Eq. (II. 5), a patent stock is measured by the perpetual inventory method, but with obsolete rate, δ=0, because the duration of patent last maximum of 20 years. PG_t represents patent granted in year t and P_{t-1} represents patent stock accumulated in t-1 year. So patent stock P_t is simply the sum of PG_t and P_{t-1}.

$$P_t = PG_t + (1-\delta)P_{t-1} \tag{II. 5}$$

Two major problems characterized the measurement of patent stocks for different industries and different countries. First, because patent data are not classified at the industry level, it is needed to effectively match the level of concordance between the International Patent Classification (IPC) and the International Standard Industry Classification (ISIC) schemes. Second, it is difficult to secure sufficient international patent data by technological domain for this cross-country analysis. Currently, only United States Patent and Trademark Office (USPTO), European Patent Office (EPO), and Patent Cooperation Treaty (PCT) provide raw patent data classified in the IPC. Although PCT data represent a collection of internationally filed patents, they could yield some unexpected distortion, because they do not fully capture the level of patents filed within the domestic patent office. In the United States, for example, more than 50% of patents are filed in the USPTO by foreign applicants, therefore PCT data of US does not necessarily represent the domestic patent data of the USPTO. PCT data only capture the nationality of the applicants, not the total number of patents granted in the domestic patent office.

To overcome constraints in the collection, the data from the World International Property Organization (WIPO) IP Statistics was used, which were created by a methodology developed by the Fraunhofer Institute for Systems and Innovation Research. Unlike YTC (Yale Technology Concordance), the technology concordance developed by the Fraunhofer Institute assigns IPC codes within a classification of 30 major technologies (Schmoch, 2008). Then, in a similar manner to the way WIPO's World Intellectual Property Indicators have used patent data to describe the relationship between patents and associated industries, Fraunhofer grouped the 30 major technologies into 6 major technological domains: electrical engineering, instruments, chemistry, process engineering, mechanical engineering, and consumption. Then pertinent technologies were selected for the selected industries of chemical, electronics, and machinery as classified by ISIC rev. 3. This classification method does not provide perfect correspondence between IPC and ISIC, but it is the only method that allowed gathering international patent data classified by technologies granted in domestic patent offices.

3.2.4. Intellectual property rights index

Countries differ widely in the strength of the protection that they provide to intellectual property (Kanwar and Evenson, 2003). Previous literature (Chen and Puttitanun, 2005; Javorcik, 2004; McCalman, 2001; Oxley, 1999; Zhao, 2006) feature the index developed by Park and Ginarte (1997), which was developed for 110 countries from 1960 through 1990. This index is composed of the unweighted sum of five separate scores: coverage (inventions that are patentable), membership in international treaties, provisions for a loss of protection, the duration of protection, as well as enforcement mechanisms and restrictions (e.g., compulsory licensing for an insufficiently exploited patented invention) (Park, 2008). However, this index only provides scores in each quinquennium, too short-term for this essay. Instead, the IPR index for IMD World Competitiveness Online is used, which provided a yearly IPR index score from 1995 to 2012. Unlike the one by Park and Ginarte (1997), The index is derived from the executive survey of senior business leaders and was designed to measure competitiveness issues that are not easily quantifiable. The survey data from 4,200 responses of participants in 60 countries resulted in scores on a 0-10 scale. Table II. 4 presents a yearly IPR index for 12 selected countries from 1995 through 2005.

Table II. 4 IMD World Competitiveness Index for intellectual property rights.

Countries	Year										
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Australia	7.58	7.31	6.95	7.20	8.59	8.89	8.63	8.16	8.14	8.29	7.67
Czechoslovakia	4.48	4.24	4.03	4.09	4.86	5.13	6.19	6.56	6.14	6.00	5.70
Finland	7.84	7.47	7.42	6.94	8.58	8.75	8.64	8.97	8.97	8.06	8.33
Germany	8.23	8.11	8.09	8.00	8.74	9.15	8.49	8.47	8.46	8.00	8.12
Italy	5.80	5.60	5.38	5.54	6.17	6.21	5.95	5.61	5.42	4.85	5.19
Japan	6.96	6.83	7.03	5.83	7.40	7.39	7.50	6.76	7.11	6.56	6.44
Korea	5.42	5.70	5.13	3.95	4.61	6.91	6.00	5.82	5.18	5.63	5.62
Netherlands	7.68	7.81	7.57	7.41	8.26	8.84	8.51	8.23	7.81	7.95	7.94
Portugal	6.21	4.94	4.94	5.30	6.47	6.04	5.96	5.64	5.44	5.55	5.38
Slovenia	-	-	-	-	4.27	4.76	4.60	5.27	5.10	5.03	4.14
UK	7.77	6.94	6.72	7.02	7.93	8.72	8.24	7.69	7.48	6.72	6.02
USA	8.29	7.74	7.44	7.44	8.29	8.76	9.09	8.95	8.41	8.27	8.00

Source: IMD World Competitiveness Online, various years

3.2.5. Data and descriptive statistics

The panel data were constructed from the chemical, electronics, and machinery industries with a cross-country sample of 12 countries. The estimation model involves industry-specific data, such as value-added and capital stocks across different industries, which are provided by EU KLEMS data. 12 countries, including Australia, Czechoslovakia, Finland, Germany, Italy, Japan, Korea, Netherlands, Protugal, Slovenia, UK and USA from EU KLEMS had sufficient panel data from the year 1995 to 2005 to conduct the estimation. (The IPR index from Slovenia was available from 1999). The sub-categories for the three selected industries are described in the appendix (Table II-A1). The unbalanced panel data covers the period of 1995 through 2005. Quantitative data for industry value-added, capital stocks, and total labor-hour information were collected from EU KLEMS data, which provides data for nearly all Organization of Economic Co-operation and Development (OECD) countries. Data for R&D investment by sectors and foreign currency in the 12 countries were collected from the OECD, and the GDP deflators for 2005 for the 12 countries were collected from the International Monetary Fund. The IPR index is from the IMD World Competitiveness Online. Finally, all of the data were deflated and converted to 2005 in US dollars (USD). Tables II. 5 and II. 6 show descriptions of the variables used for the simultaneous equations and Table II. 7 shows the basic statistics for variables.

Table II. 5 Descriptions of variables for the R&D investment equation.

Variable	Description
RDI	Natural logarithm of R&D investment (USD)
RDS0	Natural logarithm of R&D stocks (zero depreciation rate)
VA	Natural logarithm of value added (USD)
IPR	IMD IPR index
IPRPK	Interaction term between IMD IPR and the level of patented knowledge

Note: USD = US dollars.

Table II. 6 Descriptions of variables for the value-added equation.

Variable	Description
VA	Natural logarithm of value added (USD)
K	Natural logarithm of the capital stock (USD)
L	The total hours worked by employees
RDS20	Natural logarithm of the R&D (20% depreciation rate)
IPR	IMD IPR index
IPR2	IMD IPR quadratic

Note: USD = US dollars.

Table II. 7 Descriptive statistics for three selected industries.

Variable	Chemical		Electronics		Machinery	
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
VA	23.150	0.145	23.564	0.166	24.001	0.157
K	23.853	0.140	23.985	0.168	24.467	0.158
L	19.122	0.122	20.128	0.139	20.633	0.132
RDI	20.513	0.195	21.185	0.227	21.180	0.219
RDS20	22.008	0.202	22.694	0.234	22.644	0.229
RDS0	22.057	0.203	22.742	0.236	22.721	0.230
IPR	6.878	0.127	6.775	0.131	6.775	0.131
IPR2	49.279	1.703	47.846	1.741	47.846	1.741
IPRPK	36.279	4.592	13.02	1.106	13.889	1.390
Observations	124		115		115	

Note: Unit: 2005 constant US dollars (USD); *VA*, *K*, *RDI*, *RDS20*, *RDS0*: deflated with base year 2005; GDP deflator for 12 countries is from the International Monetary Fund.

4. Results

Table II. 8, Table II. 9, and Table II. 10 represent the simultaneous equation results in three selected industries. The equation in Model 2 (m2) differs from that in Model 1 (m1) by variable *IPR2*, which is used to determine the potential existence of an inverse-U shaped relationship between IPR and industry value added levels.

4.1. Industry value-added model (direct channel)

The empirical evidence revealed by the value-added model suggests that all industries show a positive effect of IPR on value added (m1). The largest *IPR* coefficient was found in the machinery industry followed by that of the electronics industry. The *IPR* value of the chemical industry was not significant, suggesting that a direct relationship does not exist between IPR and the value-added. The positive sign of *IPR* coefficients of the machinery and electronics industries may be capturing the positive market expansion effects exerted through technology commercialization. Possible negative market power effects and positive market expansion effects result in strong IPR, making the overall effects of IPR ambiguous. Although the results do not reveal the individual contributions to these outcomes, the overall impact turned out to be more salient in the complex and codified industries of the machinery and electronics sectors.

Considering the parameter of *IPR2* (m2), one can see an inverse-U relationship between *IPR* and industry value-added in the complex industries of the electronics and machinery sectors. The electronics industry showed a slightly larger absolute value of the coefficient. The empirical results support the logic behind using complementary problems that reflect a situation in which increasing costs of individual input technology raise overall licensing costs in the presence of patent thickets under excessive IPR enforcement (Deardorff, 1992; Falvey et al., 2006).

4.2. R&D investment model (indirect channel)

For all three industries in this essay, IPR showed a positive and significant effect on R&D investment. This finding implies that strong IPR generally provides sound incentives to invest in R&D. The results from the value-added model also support the role of R&D stock in the industry value added. Synthesizing the results of two models suggests the presence of a virtuous cycle between IPR, R&D investment, and industry value-added. IPR promotes R&D investment, which accumulates R&D stock, and the increased R&D stock contributes to the industry value added as a significant input factor.

Meanwhile, previous R&D stock (*RDS0*) has a positive and significant effect on R&D investment. This result implies that the past knowledge in industry has contributed to R&D activities. It also means that the innovation process depends on past knowledge. Bessen and Maskin (2009) argued that strong IPR may hinder the innovation in sequential settings such as shown in the results. As expected, the role of past knowledge on current R&D activities was most salient in the electronics industry.

Thus, the model has incorporated PK (patented knowledge) concepts to explain whether strong IPR and excessive patenting negatively affect sequential innovation. The results show that the coefficient of *IPRPK*, which represent cross-terms between *IPR* and *PK* turned out to be negative in all three industries. They indicate that the more knowledge patented, the greater the negative impact of IPR on R&D investment increases. In other words, IPR hinders sequential innovation growth when the knowledge of an industry is excessively patented.

4.3 Using time-lag IRR Variables

The time-lag for the effect of IPR is important since the effect of such institutional changes may require some time to influence the industries' R&D activities. Accordingly, the time-lag variables of IPR which are IPR (n-1) and IPR (n-2) variables are employed in the model and showed the results in Table II-B1 and Table II-B2 in the Appendix. Data limitations precluded us to go beyond two lags.

For the value-added model, the results were almost consistent with the original result except that IPR (n-2) turned out to be significantly positive in the chemical and electronics industries. And the coefficients of IPR slightly increase over the time-lags. It suggests that there exists some time-lag in reflecting the change of IPR in value-added. In the R&D model, IPR(n-1) and IPR(n-2) turned out to be less or insignificant in every industry results. And the coefficients of IPR highly decrease over the time-lags. It suggests that there exists no time-lag for reflecting the change of IPR in R&D investment decision.

However, using the time-lag variable doesn't alter the qualitative nature of the coefficients and the results still support the main conclusion. Although the significance of IPR variables varies over time-lag, there is no change of coefficient signs and the orders of magnitudes of coefficients in three industries. These results suggest that IPR generally enhances industry value added and R&D but it has a negative relationship with patented knowledge regardless of IPR time-lags. And the consistency of the signs and the orders of magnitudes of IPR coefficients shows the robustness of the results and the conclusion in the difference of IPR time-lag as well.

4.4 Using Ginarte-Park IRR Variables

The reliability of IPR index is crucial in this essay since the results are dominantly determined by this measurement of IPR index, meaning that incorporating alternatively measured IPR variables are essential. Besides IMD index, for measuring the strength of intellectual property rights, Ginarte-Park IPR index also have been widely used. Ginarte-Park Index has five quantifiable categories including coverage, membership in international patent agreements, provisions for loss of protection, enforcement mechanisms, and duration (Park, 2008).

However, the Ginarte-Park Index only measures IPR level of the country in each quinquennium, which makes it difficult to match the index to the yearly panel data which range from the year 1995 to 2005. And Ginarte-park does not take account of potential innovation actors' sentiments toward IPR institution of particular countries. Thereby, since much part of the research focuses on the behavior of innovation actors, namely their R&D activities, IPR index developed by IMD report, which takes account of their sentiment toward IPR institutions, were as useful as Ginarte-Park IPR Index.

But to check the robustness of the result using IMD index, the model with GP Index was also estimated. Since Ginarte-Park Index only measures IPR level of the country in each quinquennium, it was assumed that the IPR index has the same value for each 5 years after the year it measured. Ginarte-Park Index was incorporated in the model and the results are showed in Table II-B4, Table II-B5 and Table II-B6 in the Appendix, where m1 and m3 have incorporated original IMD IPR (IPR) and Ginarte-Park IPR (IPRGP) variables, respectively.

For the value-added model, while the exact coefficients are different from the model with IMD index, size order of the IPR effected by industries in the new model is same as the IMD index model. IPR was by far was the most effective mechanisms in machinery industries followed by electronic and chemical industries for both IPR indexes. IPR index variable, which was not significant for chemical industry in IMD index model turned out to be significantly positive when Ginarte-Park Index was used.

In the R&D investment model, both IMD and Ginarte-Park IPR index are most influential in chemical industries. However, IPR for electronics and machinery industries turned out to be not significant for Ginarte-Park index. The results for IPRPK, which measure potential blocking effects, turned out be almost identical in both models. Machinery industries by far had the most negative effects followed by electronics and chemical industries, respectively.

In general, the results with Ginarte-Park Index are not much different from the original results. It means that the model's results are insensitive by IPR index. Even though exact numbers of coefficients have changed slightly, new index doesn't alter the qualitative nature of the coefficient. The results show that both measurements provide similar outcomes in terms of the effectiveness of IPR among three industries. These are another basis to show the model's robustness.

Table II. 8 Value Added and R&D Investment for the chemical industry.

Variables	Value Added Model		Variable	R&D Investment Model	
	m1	m2		m1	m2
K	0.610***	0.546***	*IPR*	.172***	0.171***
	(0.036)	(0.053)		(0.036)	(0.036)
L	0.256***	0.282***	*IPRPK*	-0.008***	-0.008***
	(0.040)	(0.042)		(0.001)	(0.001)
RDS20	0.158***	0.186***	*VA*	0.496***	0.495***
	(0.019)	(0.025)		(0.047)	(0.047)
IPR	0.019	0.189*	*RDS0*	.369***	.370***
	(0.015)	(0.107)		(0.053)	(0.053)
IPR2		-0.013			
		(0.008)			
Number of observations	124	124	Number of observations	124	124
R^2	0.999	0.999	R^2	0.999	0.999

Notes: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level; standard errors in parentheses.

Table II. 9 Value Added and R&D Investment for the electronics industry.

Variables	Value Added Model		Variables	R&D Investment Model	
	m1	m2		m1	m2
K	0.404***	0.231***	*IPR*	0.148***	0.147***
	(0.052)	(0.070)		(0.046)	(0.046)
L	0.518***	0.583***	*IPRPK*	-0.019***	-0.019***
	(0.048)	(0.050)		(0.004)	(0.004)
RDS20	0.142***	0.220***	*VA*	0.305***	0.300***
	(0.022)	(0.031)		(0.044)	(0.044)
IPR	0.034*	0.384***	*RDS0*	.583***	.588***
	(0.018)	(0.104)		(0.050)	(0.050)
IPR2		-0.028***			
		(0.008)			
Number of observations	115	115	Number of observations	115	115
R^2	0.999	0.999	R^2	0.999	0.999

Notes: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level; standard errors in parentheses.

Table II. 10 Value Added and R&D Investment for the machinery **i**ndustry.

Variables	Value Added Model		Variables	R&D Investment Model	
	m1	m2		m1	m2
K	0.686***	0.621***	*IPR*	0.095**	0.095**
	(0.043)	(0.040)		(0.039)	(0.039)
L	0.223***	0.188***	*IPRPK*	-0.026***	-0.026***
	(0.052)	(0.052)		(0.004)	(0.004)
RDS20	0.070***	0.131***	*VA*	0.475***	0.473***
	(0.022)	(0.033)		(0.053)	(0.053)
IPR	0.150*	0.458***	*RDS0*	.419***	.420***
	(0.018)	(0.127)		(0.058)	(0.058)
IPR2		-0.024**			
		(0.010)			
Number of observations	115	115	Number of observations	115	115
R^2	0.999	0.999	R^2	0.999	0.999

Notes: * significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level; standard errors in parentheses.

5. Discussions

5.1 IPR and Industry Value-added

Chapter 2 discussed how the direct effects of IPR on industry value added can be explained by the *market expansion effect* and *market power effect*. Previous literatures emphasize the importance of IPR in vitalizing markets for technologies by providing property rights (Ginarte and Park, 1997; Green and Scotchmer, 1995; Park, 2008) and reducing transaction costs (Murray and Stern, 2007; Park and Ginarte, 1997). The stronger IPR could also harm industries by exerting market power effect by creating market entry barriers (Hall and Ziedonis, 2001). The empirical evidence shows the positive relationship between IPR and value added in machinery and electronics industries, which leads to question of whether these industries posses more vibrant market for technologies that ascribes to potential market expansion effect. In fact, according to Murray and Stern (2007)'s paper, the value of technology transactions by industries were the highest in the electronics industries followed by machinery and chemical industries, respectively. The greater values of technology transactions in electronics and machinery industries may explain the positive role of IPR, which could have exerted the positive market expansion effect on these industries.

The result of chemical industry was surprising because some convention logic argues in favor of IPR in industries composed of discrete products (Levin et al., 1987). Because discrete products are relatively easy to patent, stronger IPR could enhance the market for technologies. Thus, the empirical outcome suggests that the overall effects of IPR on chemical industry remain ambiguous.

The inverse-U relationship between IPR and value-added in electronics and machinery industries is noteworthy. Past literatures have discussed increasing patenting activities in complex industries (Hall, 2004; Kortum and Lerner, 1999) and suggested how patent thickets problems were most frequent in semi-conductor firms (Hall and Ziedonis, 2001). In recent attempts to measuring the density of patent thickets based on patent citation, Von Graevenitz et al. (2011) have identified that complex technologies (particularly electronics) were most affected by patent thickets. The findings accords well with these results. Excessive IPR could engender excessive patenting activities exacerbating patent thicket problems in complex industries.

5.2 IPR and R&D Investment

As Cohen (2000) and Kusunoki et al. (1998) defined, the electronics and machinery industries can be categorized as complex, while the chemical industry as seen as discrete. According to Levin et al. (1987), discrete industries are more effective in retaining protection from a patent system, and the results of this essay showed that the impact of IPR on R&D investment was greatest in the chemical industry, supporting conventional logic behind the characterizations of discrete industries. Complex industries (i.e., the electronics and machinery sectors) showed meaningfully high *IPR* coefficients that were lower than the *IPR* coefficient of the chemical industry. As Cohen (2000) has argued, complex industries typically do not favor patents as the preferred mechanism to protect intellectual assets, which may explain the relatively limited effects of IPR on R&D investment in these sectors. Cohen (2000) further argued that complex industries tend to value secrecy and lead time advantages as effective appropriability mechanisms for product innovation.

Codified and tacit characteristics of industries may also explain for different outcomes among industries. Codified knowledge, because of its non-rival characteristics, best provides sufficient incentives for innovators to invest in R&D when under patent. Grimaldi and Torrisi (2001) empirical research showed that the chemical industry was most codified followed by the electronics industry. Absorptive capacity may explain the strong indicators of IPR in the chemical industry, which we defined as having codified characteristics. For example, innovations in pharmaceutical production are comparably easy to invent around, meaning firms require less absorptive capacity to imitate the invention. Because the machinery industry includes machines and transport equipment, the classification of it may be somewhat ambiguous. However, regardless of such ambiguity in the machinery industry, the greater contribution of IPR in the chemical industry may be best explained by its high-codification basis of knowledge.

Among the sectors, the machinery industry showed the largest absolute value of the *IPRPK* coefficient, followed by the electronics industry, meaning that a high level of patented knowledge with strong IPR may be blamed for impeding R&D investment in complex industries.[5] This empirical evidence supports Bessen and Maskin (2009) theory that strong IPR hinder innovation in sequential settings. Indeed, conventionally, complex

[5] The coefficient of *IPRPK* means $\frac{\partial RDI}{\partial IPR \cdot \partial PK}$, which implies marginal impact of patented knowledge(*PK)* onto the effect of IPR on R&D.

industries, regarded as a highly sequential, are built upon existing innovation.

The results also suggest that the innovation processes in the electronics and machinery industries are more sequential than those of the chemical industry; that is, the *RDS0* coefficients for the complex industries were higher than for the chemical industry. The results suggest that chemical industry innovation is less sequential and the blocking effect of IPR by a piece of patented knowledge is relatively small.

When it comes to overall effect of IPR ($\partial RDI / \partial IPR = \beta_{IPR} + \beta_{IPRPK} \cdot \overline{PK}$), the effect of IPR is 0.129, 0.111 and 0.042 in chemical, electronic and machinery industries respectively. It implies that although the marginal effect of a piece of patented knowledge on chemical R&D is small, but the detrimental effect of whole patented knowledge of chemical industry is not negligible.

This result also suggests that complex industries, with sequential innovation, face anti-common tragedy under strong IPR. As discussed in the value-added model, patent thickets create frequently encountered problems in industries with numerous complementary technologies patented as they induce firms to hack through overlapping intellectual property rights that make commercialization difficult. Therefore, complex industries, including the electronics and machinery sectors, may face patent thicket problems under strong IPR, thus reducing R&D incentives.

5.3 Limitation

This essay has some limitations caused by the availability of data. Generally R&D is classified by industrial classification (ISIC) and patents are classified by technology classification (IPC). To overcome this mis-matching problem between ISIC and IPC, WIPO’s World Intellectual Property Indicators have been used. Based on the data, only 3 industries can be analyzed. It requires good care to generalize of the result for all industries.

6. Conclusion

This essay investigated various channels of IPR affecting R&D investment and value added. The result shows that strong intellectual property rights has positive impact on value-added and R&D investment in all industries. However, it also shows that the more knowledge are patented, the strong IPR decreases R&D investment in all three industries. It implies that the positive and negative effects of IPR can arise commonly in many industries.

And this essay also identified the ambivalent effects of IPR. The results suggest that the direct and indirect influence of the IPR in value added varies by industry. IPR indirectly influences R&D incentives such that the discrete industry, the chemical sector, benefits most from the strengthened IPR. In contrast, the blocking effects of IPR were greatest in complex industries of the electronics and machinery sectors. This result introduces some important insights on the fundamental role of IPR. The conventional arguments concerning the importance of IPR, especially in the chemical industry, can be supported by the empirical results. Despite ongoing debate on the morality of patent breadth and duration for pharmaceutical products, the chemical (including pharmaceutical companies) industry increased R&D in the presence of strong IPR, at least in developed countries. This essay also shows how blocking effects from patent thickets were not merely theoretical problems for complex industries.

As shown by the *value-added model*, complex industries witnessed a significant increase in value added from strengthened IPR. It is explained that this phenomenon in terms of technology commercialization activities in which IPR enforcement directly and simultaneously increases the value of intangible assets and promotes licensing activities (market expansion effects). The results also reveal some insights about the nature of IPR, especially when excessively protected, as such an effort yields varying effects on different industries. Complex industries, such as the electronics and machinery sectors, reflect the negative effects of excessive IPR, and it suggests an IPR enforcement policy for complex industries that acknowledges the concerns for technology commercializations and licensing.

With the presence of the ongoing debate on whether IPR optimize environments for innovation, the results suggest that the current patent system needs to be readdressed, especially when concerning varying impacts of IPR on different industries. This essay has shown that varying impacts on different industries stem from the specific nature of the technologies that constitute the unique characteristics of an industry. Finally, this research has also shown that IPR, in general, provides a good mechanism for encouraging a virtuous cycle of R&D and value added. The effect of IPR appears in R&D activities, which then accumulate into knowledge stock, and ultimately contribute to value-added industries. Besides these indirect effects, this essay has observed the anti-common tragedy under strong IPR in complex industries characterized by sequential innovation. IPR promotes innovation by securing profit from other innovations and diffuse that knowledge through granting patents. The results suggest the government could play a greater role in providing a flexible IPR regime that comports to technological and industrial characteristics and thus resolve any negative effects.

- Essay III -

Liberalization, R&D investment, and the trade-off between static and dynamic efficiency: an integrated study of the electricity industry at the aggregate level

* The essay was submitted to *The Energy Journal* and is now under the revision. The title of the submitted paper is "Liberalization, R&D investment, and the trade-off between static and dynamic efficiency: an integrated study of the electricity industry at the aggregate level"

1. Introduction

Market power has been blamed for creating dead weight loss and market inefficiency. According to the structure-conduct-performance theory, based on neo-liberalism, the more competitive the industrial structure the better the industrial performance through reduced market power (Nickell, 1996). Over the last two decades, many public utilities markets, which had been known to exert significant market power, have undergone liberalization to introduce competition into the vertically integrated monopoly.

The neo-liberalism argument may be valid if technology innovation which can affect the cost structure of the firm were regarded exogenous and not affected by the industrial structure. However, since Schumpeter (1942) proposed the circular relationship between entrepreneurship, market structure, and innovation, many discussions have revolved around the effects of market structure and ownership on the incentives for innovation. The classical industrial organization literature, such as the contributions of Dasgupta and Stiglitz (1980) and Kamien and Schwartz (1982), predicted innovation declines in the face of increased competition because the firm experiences difficulty appropriating the profit from the invention. Calderini et al. (2003) and Sheshinski and López-Calva (2003) suggested that the privatization of public utilities affects R&D decisions in a negative way.

Schumpeterian studies raise concerns about the tension between static efficiency and dynamic in-efficiency following liberalization. The main aims of the liberalization are to reduce market power and increase static efficiency (Joskow, 2008). The restructuring, however, can create unintended consequences, which include disincentives on innovation and dynamic inefficiency (Calderini et al., 2003). To assess the overall effect of liberalization on market performance, we consider the ambivalent effects generated by the trade-off between static and dynamic efficiency.

The electricity industry offers a good case to study the effects of liberalization. First, the electricity industry has significant market power because of its natural monopoly characteristics (Posner, 1968). Second, in many countries, the electricity industry has been structurally reformed through competition introduced into the vertically integrated monopoly and privatization of publicly owned utilities. Third, the worldwide liberalization of it has raised concerns about R&D disincentives. We can observe the relationship among industrial structure, innovation and market performance over time.

Some expressed worry that R&D disincentives in the liberalized market may undermine the reliability and the efficiency of the electricity system in the long run (Hattori, 2007; Jamasb and Pollitt, 2008; Sanyal and Cohen, 2009; Kim et al., 2012). Although the literature noted reduced R&D investment in the electricity industry after liberalization, studies focusing on the specific impacts of reduced R&D investment on industrial performance are scarce. The apparent disinterest of researchers may reflect the relatively low intensity of R&D activities in the electricity industry, but the technology innovation lays the fundamental foundation for long-term growth in every industry.

In this essay, structural model is applied that accounts for the effects of liberalization, such as market structure and ownership changes, on the performance of the electricity industry as measured by market power and R&D investment. The traditional New Empirical Industrial Organization (NEIO) framework (Bresnahan, 1989) is applied and expanded to measure the effects of liberalization on R&D investments (dynamic efficiency) as well as market power (i.e., price and static efficiencies). And an industry-level R&D investment decision equation is incorporated into the NEIO model and link the R&D equation to structural equations of oligopolistic competition.

In this model, firms make R&D investment decisions based on previous industrial knowledge stock (accumulation of overall R&D investments and inter-temporal knowledge spillover) and engage in quantity competition based on the market circumstances and their own cost structure, which is determined by internal and industry knowledge stock (inter-firm knowledge spillover). The firms can utilize the information from knowledge stock to reduce production costs. The proposed integrated framework enables us to observe trade-off between the static and the dynamic efficiency and compare the magnitude of both aspects.

This model is estimated for 17 Organisation for Economic Co-operation and Development (OECD) countries from 1987 to 2012 and focused on three important liberalization measures in the electricity industry: entry liberalization, privatization, and vertical unbundling.

Previous literature offers assessments of the liberalization effect on the electricity industry. Most of the studies addressed static efficiency changes caused by the restructuring (Steiner, 2001; Hattori and Tsutsui, 2004). Although some recent literature showed reduced R&D investment in the electricity industry after liberalization (Hattori, 2007; Jamasb and Pollitt, 2008; Sanyal and Cohen, 2009; Gugler et al., 2013; Kim et al., 2012), studies addressing simultaneously affected static and dynamic efficiencies are rare.

Recently Gugler et al. (2013) tested for the presence of a trade-off between static and dynamic efficiency in the electricity industry. They suggested the presence of the trade-off indirectly based on their result that higher electricity prices lead to larger investments. But, it was not direct comparison between the two effects. Jang et al. (2013) were the first to propose a model integrating static and dynamic efficiencies in one framework for comparing two effects. However, multiple limitations of the model affect its applicability because it requires detailed firm-level data, which are not easy to access.

As an alternative, the model in this essay is based on NEIO, which employs measures of market equilibrium obtained by market-level aggregation of company decisions. It is simple and easy to handle, requiring easily accessible industry-level aggregate data. In addition, to identify the effects of industry knowledge stocks on overall (average) industry performance, one need not distinguish between internal and spillover effects. Using this simple model, this essay covers more data than could Jang et al. (2013), who focused on electricity industries of 3 countries. The broad sample coverage of this essay that is for 17 OECD countries from 1987 to 2012 enables to conduct a more general analysis covering various liberalization cases.

The result shows that entry liberalization raises electricity prices by disincentivizing R&D investment in the long run while it reduces price by decreasing market power in the short run. The findings imply a trade-off between the beneficial and deleterious effects of entry liberalization. Comparing the two effects, one can find that the enhanced static efficiency may fail to offset the dynamic inefficiency of entry liberalization in the long run. And the result shows that privatization exert no significant effect on market power but decreases R&D investment, which causes dynamic inefficiency. The results suggest some complementary policy need to be considered to mitigate unexpected side effect of restructuring that is reduced R&D and dynamic inefficiency.

The rest of this essay is structured as follows: Chapter 2 addresses the theoretical background and previous literature on issues relevant to electricity industry liberalization measures, and Chapter 3 introduces the model and presents the estimable demand, price, and R&D equations. Chapter 4 covers results and implications. The conclusion is presented in Chapter 5.

2. Literature review

Since the 1990s, the worldwide electricity industry has experienced structural reform, called *liberalization*, which introduced competition into the vertically integrated monopoly and encouraged privatization of publicly owned utilities to increase market efficiency. The main liberalization measures are comprised of entry liberalization, privatization of public electric utilities, and vertical unbundling of the generation, transmission, and distribution of electricity (Jamasb and Pollitt, 2008).

Chapter 2 presents summary of the literature on the effects of liberalization measures on electricity price and R&D investment. The review suggests that, despite extensive advocacy for liberalization, no consensus has been reached about whether consumers are better off as a result of the restructuring (Steiner, 2001; Hattori and Tsutsui, 2004; Barmack et al., 2007; Kwoka, 2008). However, much of the literatures suggest that the liberalized electricity market may negatively affect R&D investment (Hattori, 2007; Jamasb and Pollitt, 2008; Sanyal and Cohen, 2009; Jamasb and Pollitt, 2011).

Assessing the impact of electricity liberalization is difficult because reform often involves different combinations of a number of elements (such as entry liberalization, privatization, and vertical unbundling) being implemented simultaneously (Pollitt, 2012). The previous studies are organized by each liberalization measure as follow.

2.1. Entry liberalization

Before liberalization, the electricity market was dominated by regulated traditional monopoly utility entities and not protected from competition, which is promoted via an established wholesale pool, third party access (TPA), and deregulation of the retail market. In a wholesale market, an electricity producer faces many rivals willing to supply at a competitive price. TPA facilitates entry into the market by granting newcomers access to the existing (generally the incumbent's) power grids. Without TPA, entrant firms may need to build power networks, which may weaken incentives for entry. In a retail market, regulatory authorities allow consumers, from large industrial to small residential customers, to change their electricity suppliers over many years. Entry liberalization with those measures encourages new entrants into the market and can be interpreted as a means of increasing competitive pressure (Kim et al., 2012).

The relationship between competition and price seems obvious. However, researchers do not agree that entry liberalization measures culminate in the benefits of competition. Steiner (2001) investigated the relationship between electricity price and entry liberalization measures in OECD countries, suggesting that TPA of networks and the establishment and operation of an electricity wholesale pool each effectively reduce prices. Hattori and Tsutsui (2004) suggested that TPA was likely to lower the price but a wholesale pool did not necessarily lower the price. Kwoka (2008) reviewed 10 of the major quantitative studies regarding the effect of restructuring in the U.S. electricity industry and concluded that there is little reliable and convincing evidence showing that consumers benefits as a result of restructuring.

Much of the theoretical literature suggests that the relationship between competition and innovation varies depending on the assumptions regarding strategic considerations, the types of existing competition, and the kinds of innovation (Tishler and Milstein, 2009). Furthermore, recently the relationship between competition and innovation is considered nonlinear such as inverted-U shape (Aghion et al., 2005). However, empirical evidence on the general relationship remains unclear.

In the electricity industry, the relationship between competition and innovation is likely to be negative. Using data from the U.S. electricity market from 1990-2000, Sanyal and Cohen (2009) investigated the R&D behavior of regulated firms transitioning to a competitive environment. They found that firms reduce their R&D significantly during the early stage of restructuring. Hattori (2007) suggested that the competitive pressure has led to a decline in R&D expenditure in the Japanese electricity industry. Kim et al. (2012) examined the impact of entry liberalization based on firm-level data and concluded that competition reduced R&D investment.

2.2. Privatization

Many long discussions have focused on whether private ownership is more efficient than public ownership. The aim of privatization of state-owned enterprises (SOEs) is to improve microeconomic efficiency (Sheshinski and López-Calva, 2003). The incentive to pursue profit through cost savings and efficient operations is an important outcome of privatization (Jamasb and Pollitt, 2008). Because of profit-maximizing behavior, the efficiency of production done by privately owned firms does not necessarily lead to a lower price. In the electricity industry, the effect of privatization on the electricity price remains unclear (Pollitt, 1995). Hattori and Tsutsui (2004) suggested that privatization decreases the price. Steiner (2001), however, argued that privatization increases the electricity price.

Calderini et al. (2003) pointed out the tension between ownership and innovation. SOEs are regarded as government policy instruments to maximize social welfare because they produce public goods and encourage knowledge spillovers (Munari, 2003). However, privatized SOEs are profit-maximizing entities and focus on the areas closest to their core business (Munari, 2002). Munari and Sobrero (2003) investigated the effect of privatization on corporate R&D and patenting activities. They concluded that privatization lowers corporate R&D investment in the electricity industry. Kim et al. (2012) argued that the effect of privatization is not independently salient but interacts with a wholesale pool to lower R&D investments. Lestage et al. (2013) suggested that in the electricity and telecom industries the effect of competition pressure on innovation may vary depending on the ownership of the firms. Recently, Sterlacchini (2012) argued that a decline of R&D investment in the field of electricity is clearly pronounced and the drop of R&D expenditure was particularly strong among the private companies.

2.3. Vertical unbundling

Unbundling of vertically integrated functions in electricity generation and transmission is a liberalization measure. It promotes competition in the electricity generation sector by facilitating new entrants, thereby lowering the price. However, it also may be affected by economies of vertical integration (Kwoka, 1996; Nemoto and Goto, 2004). The effect of vertical unbundling depends on the magnitude of the two opposite effects.

The empirical results do not allow for the formation of a consensus. Steiner (2001) submitted that unbundling of electricity generation from transmission should decrease the price by facilitating new entry into energy creation; however, the results of the study were not statistically significant. In opposition to Steiner (2001), Hattori and Tsutsui (2004) found that unbundling increased prices. Copenhagen Economics concluded that higher levels of unbundling led to price reductions in 15 E.U. countries (Economics, 2005). Recently, Fiorio and Florio (2009) showed that vertical integration leads to higher final consumer prices in the electricity industry.

As for R&D activities, vertical unbundling has some disadvantages in terms of technological information flow. According to Armour and Teece (1980), sharing and transferring of certain interdependent technologies within an organization create costless benefits. However, between separate firms, transaction costs arise from information asymmetry. Helfat and Teece (1987) pointed out that information flow can be facilitated within a vertically integrated entity due to common communication codes and routines. Therefore, vertically integrated firms are expected to invest more in some technologies than vertically unbundled firms. In support of this supposition, Armour and Teece (1980) found a positive relationship between R&D investment and vertical integration in U.S. manufacturing industries and oil companies. However, Kim et al. (2012) investigated the effect of vertical unbundling on corporate R&D investment in the electricity industry, but the results were not statistically significant.

3. The model

A two-stage structural model is constructed that accounts for the effect of market structure and ownership change on performance of the electricity industry in two ways: market power and R&D investment. In the first stage, firms make R&D investment decisions based on previous industrial knowledge stock: accumulation of data on overall R&D investments and inter-temporal knowledge spillover (Arrow, 1962, Nelson, 1982) and other factors. This decision-making process determines industry-level R&D expenditures.

In the second stage, firms engage in quantity competition based on the market circumstances and their own cost structure, which is determined the first stage by overall industry knowledge stock (from within the company and other firms in the industry as well as inter-firms knowledge spillover) (Bernstein and Nadiri, 1989, Acs et al., 2009). As the knowledge stock gained from R&D investment accumulates, firms utilize the information to reduce production costs. By integrating the results of the two stages, one can observe whether a trade-off between static and the dynamic efficiency exists in the electricity industry and to compare the magnitude of each effect.

3.1. Market competition modeling(the 2nd stage)

To model electricity market competition, we adopted a NEIO method, proposed by Bresnahan (1982) and Bresnahan (1989), which formulates an oligopoly model that allows researchers to identify market power using aggregated industry data without actual marginal cost data. We manipulated the firm-level conjectural variation equation in Bresnahan (1989), which was derived from the first-order condition of firm's profit maximization equation. Like Parker and Röller (1997), individual firm's marginal costs are assumed to be identical[6] to each other. Summing the conjectural variation equations across firms, one can obtain Eq. (III. 1):

$$\theta \frac{\partial p_{tc}(Q_{tc}, Z_{tc})}{\partial Q_{tc}} Q_{tc} + p_{tc}(Q_{tc}, Z_{tc}) - MC(w_{tc}) = 0 \qquad \text{(III. 1)}$$

Where *c* indicates the country and *t* indicates the time period. Q_{tc} is the aggregate quantity produced in the market. Z_{tc} is a vector of exogenous market factors that affect the demand, which is denoted by $p_{tc}(Q_{tc}, Z_{tc})$. $MC(w_{tc})$ is average marginal cost of firms, which is a function of market factor w_{tc}. Z_{tc} and w_{tc} should be specified to obtain supply and demand models of the variation in price and across time and countries. The detail derivation procedure of Eq (1) is in Appendix I-A.

6 we assumed individual firms' marginal costs are identical within the each country. Note that this assumption is not contradictory to this marginal cost equation setting (Eq. 4). We take into account the variation in marginal costs across countries rather than within a country.

θ indicates market power in a particular industry. Despite controversy around the meaning of θ, in this essay θ indicates the degree to which the price is set higher than the marginal cost (Corts, 1999, Nunn and Sarvary, 2004). If θ = 0, then price equals marginal cost, which means that the industry can be considered perfectly competitive. If θ = 1, then marginal revenue equals marginal cost, reflecting monopoly or cartel pricing, θ =1/N is the Cournot–Nash equilibrium, where N is the total number of firms in the market. Generally, at larger values of θ, the market power is considered greater.

Demand is specified as [7]

$$lnDEMAND_{tc} = A_0 + \eta_1 PRICE_{tc} + \eta_2 ln(POP_c) + \eta_3 ln(GNI_{tc}) + \eta_4 URBAN_{tc} + \epsilon_1 \quad \text{(III. 2)}$$

where $PRICE_{tc}$ is defined as annual average industrial electricity price, and $DEMAND_{tc}$ is quantity (i.e., the electricity consumption). POP_c is the population of the country, which is used to explain demand differences caused by nonidentical market sizes across countries. GNI_{tc} is the gross national income per capita of the country, which represents the relative wealth of potential customers and their willingness to pay for electricity. $URBAN_{tc}$ measures the urbanization level of the country. ϵ_1 denotes the error term.

[7] An alternative demand specification can be possible such as the one introduced in Berry (1994), which allows for a much richer analysis of product differentiation.

To implement empirical analysis, Eq. (III. 1) is changed into Eq. (III. 3), which is expressed with the parameter η_1 and the error term (ϵ_2). η_1 is estimated in the demand equation (Eq. III. 2). The long-term price elasticity is calculated on the basis of η_1 ($price\ elasticity = P \cdot \eta_1$),

$$PRICE_{tc} - MC(\omega_{tc}) + \frac{\theta_{tc}}{\eta_1} + \epsilon_2 = 0 \qquad \text{(III. 3)}$$

By using Eq. (III. 4), depicting marginal cost (MC), we can estimate demand (Eq. 2) and supply (Eq. III. 3) simultaneously using the aggregate data. We can thus obtain the parameters θ_{tc} and η_1.

$$\begin{aligned} MC(\omega_{tc}) = {} & \gamma_1 S\_COAL_{tc} + \gamma_2 S\_HYDRO_{tc} + \gamma_3 S\_NUCLEAR_{tc} \\ & + \gamma_4 COALPRICE_t + \gamma_5 GASPRICE_t + \gamma_6 GOV\_ST_{tc} + \gamma_6 PRI\_ST_{tc} \end{aligned} \qquad \text{(III. 4)}$$

Eq. (III. 4) is composed of the variables that explain the fluctuation of marginal cost. Based on previous literature, we found that the variables possibly affecting the marginal cost. Steiner (2001) includes fuel type, technology preference, GDP, and urbanization as the variables that can affect price in his country-by-country analysis. The type of electricity generation and the price of fuel as main cost shifters are included. S_COAL_{tc}, S_HYDRO_{tc} and $S\_NUCLEAR_{tc}$ are ratios of coal power generation, water power generation and nuclear power generation to the total electricity generation, respectively. $COALPRICE_t$ and $GASPRICE_t$ are price of steam coal and price of natural gas respectively.

Unlike previous literature on electricity market models, knowledge stock is regarded as an important input factor to account for the effect of R&D investment on cost (marginal cost; dynamic efficiency). Knowledge stock can contribute to the efficient operation of plants and the generation of electricity, which affects the marginal cost (Popp, 2001). R&D investment is not included in the MC equation because the knowledge that a firm utilizes was not created by R&D efforts in a specific year but is based on accumulated R&D activities over years. Public R&D stock is also included in the cost function. Public R&D can be used to remedy underinvestment in innovation within the electricity industry.

PRI_ST_{tc} is private industry R&D stock accumulated by private R&D investment. GOV_ST_{tc} is government (public) industry R&D stock accumulated by government R&D investment. To build knowledge stock data, we adopted the method of Popp (2002) was adopted. R&D activity does not directly affect present outcomes, but it slowly diffuses and becomes utilizable. However, the R&D effect also grows obsolete over time. These two effects are expressed as R&D diffusion rate and R&D decay rate respectively. Unlike Popp (2002) who used patent numbers to illustrate knowledge stock, R&D investment was used. The modified equation is expressed as follows:

$$Knowledge\,Stock_{c,t} = \left[\sum_{s=0}^{t-1} R\,\&\,D_{c,t} \exp\left[-\beta_1 (t-s)\right] \times \left\{1 - \exp\left[-\beta_2 (t-s)\right]\right\} \right] \qquad \text{(III. 5)}$$

where β_1 is R&D decay rate (0.353) and β_2 is R&D diffusion rate (0.00199). The values follow Popp (2002)'s results for the energy industry.

Substituting MC (Eq. III. 4) into Eq. (III. 3), we can obtain

$$
\begin{aligned}
PRICE_{tc} = {} & \gamma_1 S\_COAL_{tc} + \gamma_2 S\_HYDRO_{\mathrm{tc}} + \gamma_3 S\_NUCLEAR_{tc} \\
& + \gamma_4 COALPRICE_t + \gamma_5 GASPRICE_t \\
& + \gamma_6 GOV\_ST_{tc} + \gamma_6 PRI\_ST_{tc} - \theta_{tc} / \eta_1 + \epsilon_2
\end{aligned}
\qquad \text{(III. 6)}
$$

In Eq. (III. 7), if the market power θ has different values depending on country, θ can be defined as a function of market characteristic (μ_{tc}):

$$
\theta_{tc} = \theta(\mu_{tc}) = \theta_o + \beta_1 ELEC\_ENT_{tc} + \beta_2 ELEC\_PRI_{tc} + \beta_3 ELEC\_SEP_{tc} \qquad \text{(III. 7)}
$$

where μ_{tc} includes liberalization measures, such as entry liberalization (*ELEC_ENT*), privatization (*ELEC_PRI*), and vertical separation (*ELEC_SEP*). By decomposing θ, one can estimate market power by country and also analyze the effect of each liberalization measure on market power.

If one estimates a single value for it across the entire market, θ indicates an average value for the market power of the electricity industry across countries (Eq. III. 6). If θ is allowed to vary across countries depending on liberalization status, the coefficients of the liberalization index account for the effect of the measures on market power. Substituting $\theta(\mu_{tc})$ into Eq. (III. 6), one can finally obtain

$$
\begin{aligned}
PRICE_{tc} = {} & \gamma_1 S\_COAL_{tc} + \gamma_2 S\_HYDRO_{\mathrm{tc}} + \gamma_3 S\_NUCLEAR_{tc} \\
& + \gamma_4 COALPRICE_t + \gamma_5 GASPRICE_t + \gamma_6 GOV\_ST_{tc} + \gamma_6 PRI\_ST_{tc} \\
& - (\theta_o + \beta_1 ELEC\_ENT_{tc} + \beta_2 ELEC\_PRI_{tc} + \beta_3 ELEC\_SEP_{tc}) / \eta_1 + \epsilon_2
\end{aligned}
\qquad \text{(III. 8)}
$$

3.2. Endogenizing the R&D decision (the 1st stage)

Recently, the interaction between product market competition and other input market inputs, such as R&D, advertisement, and capacity, have received notable attention. It raises fundamental issues regarding endogenous costs and market structure. The endogenous problem is usually handled with a two-stage model (Röller and Sickles, 2000).

R&D investment may be an important input factor to reduce marginal cost and enhance dynamic efficiency. To account for the effect of liberalization on R&D investment and its dynamic impact, R&D decisions should be endogenized in the model.

Therefore, a two-stage model was set up to endogenize the R&D decisions. The R&D investment accumulates knowledge stock and impacts on the marginal cost in the second stage. The industry R&D expenditure equation (Eq. 9) is specified as the reduced form following Spence (1984). It contains the variables for electricity price (*PRICE*), oil price(*P_OIL*), market competition and ownership (*ELEC_ENT, ELEC_PRI*, and *ELEC_SEP*), and public R&D stock *(GOV_ST)*. And gross national income($GNI \cdot POP$) is included to control the difference of the size of R&D investment among the countries.

$$\begin{aligned} PRIRND_{tc} = {} & C_0 + \beta_1 PRICE_{tc} + \beta_2 ELEC\_ENT_{tc} + \beta_3 ELEC\_PRI_{tc} + \beta_4 ELEC\_SEP_{tc} \\ & + \beta_5 \ln(GNI_{tc} \cdot POP_{tc}) + \beta_6 GOV\_ST_{tc} + \beta_7 P\_OIL_t + \epsilon_3 \end{aligned} \qquad \text{(III. 9)}$$

where $PRIRND_{tc}$ is private R&D investment expenditure.

Ongoing discussions reflect the uncertainty about whether government R&D support increases firms' incentives to invest in R&D or whether it crowds out private R&D efforts (David et al., 2000, Lee, 2011). The *GOV_ST* variable can be used identify the existence of a crowding out effect of public R&D on private R&D investment in the electricity industry.

3.3. Estimation structural equations

The structure equations consisting of the demand (Eq. III. 2), price (Eq. III. 8) should be estimated simultaneously because the coefficient η_1 in the demand equation appears in the price equation and the equations are interrelated via the *PRICE* variable. Also R&D (Eq. III. 9) with demand(Eq. III. 2) and price (Eq. III. 8) equations needs to be estimated simultaneously because of endogenity problems. First *Price* variable is also included R&D equation.[8] Second, when costs are endogenized through the first stage(R&D) simple one stage specification would result in a bias in the measurement of market power (Röller and Sickles, 2000). Thus simultaneous estimation of the three equations is desirable, such as 3SLS, FIML or GMM (Kadiyali et al., 2001).

Furthermore the price equation is intrinsically nonlinear in its parameters (θ and η_1). Because of the nonlinear relations in the parameters, the model is estimated using the

[8] If the relation between R&D investment and the price is assumed as one way (that is from R&D to price), reculsive structure is more desirable rather than simultaneous. However, higher electricity price can be financial source of R&D investment. Higher prices increase the rents that can be earned from investments and trigger more investments (Gugler et al. 2013). Thus, the relation is not one way but two way so that the simultaneous structure is desirable.

non-linear three stage least square (NL3SLS) method (Gallant, 1977). NL3SLS procedure is the nonlinear counterpart to 3SLS estimator, which is Generalized least squares(GLS) with instrumental variables. Following the standard procedure of NL3SLS, all exogenous variables in the system were used as instruments. NL3SLS allows us to consider a flexible variance-covariance structure of the stochastic influences of the individual equations (Greene, 2003)

4. Data and empirical results

4.1. Data

Unbalanced panel data is used which is for 17 OECD countries obtained from 1987 to 2012. The data coverage depended on the availability of restructuring index data. The indices for liberalization status (*ELEC_ENT*, *ELEC_PRI*, and *ELEC_SEP*) were provide from the OECD International Regulation Database(OECD).

The values of the liberalization indices (*ELEC_ENT*, *ELEC_PRI* , and *ELEC_SEP*) range from 0 to 6 as they reflect the degree of increased liberalization. For example, before entry liberalization was implemented, TPA was not allowed, wholesale power market did not exist, and the consumer could not choose the electricity retail seller; at this time, the value of *ELEC_ENT* was 0. When the entry barriers are fully liberalized, TPA is regulated, wholesale power market operates, and even the smallest cohorts of consumers choose their power supplier, then the value of *ELEC_ENT* is 6. The indicator for privatization records the prevailing ownership structure, ranging from fully public

(*ELEC_PRI* = 0) to fully private (*ELEC_PRI* = 6). The indicators for vertical separation focus on whether the generation of electricity and the supply of it to the final consumer are separated from natural monopoly activities. The degree of separation ranges from full integration (*ELEC_SEP*=0) to mere legal/accounting separation to separation into different companies owned by different shareholders (*ELEC_SEP*=6). More detail explanation of the liberalization index is described in Appendix III-B.

PRICE, the industrial electricity retail price (including tax), was obtained from the International Energy Agency (IEA). We converted the raw data (currency/toe) into USD/MWh based on the exchange rate, GDP deflator, and unit conversion for international comparison. The standard year is 2005. The electricity consumption data were also obtained from the IEA. Population, urbanization, and GDP data were obtained from the World Bank. Ratios of generation type (coal, hydro, nuclear) were also obtained from the World Bank. Fuel price data for steam coal and natural gas were collected from the IEA database.

Private R&D investment expenditures were obtained from “Business enterprise R&D expenditure (BERD)” in OECD structure analysis data (OECD STAN). The private R&D investment data was aggregated from electricity, gas, and water sectors at the most disaggregated level. In other word, the OECD private R&D data contains gas and water supply sectors’ R&D investment expenditure. In order to use more relevant R&D investment data, it is needed to extract electricity R&D data. Fortunately recent OECD database(2005~2012) provides electricity, gas and water R&D data excluding sewage by

ISIC 4(International Standard Industrial Classification Rev.4)[9]. When it is available the data was used. If not, approximated value was used by assuming that the ratios of sewage R&D part of each country are constant over time.

If the R&D of gas and water supply sector is not related with the reduction of electricity generation cost, the relationship between the marginal cost for generation and R&D stock in the electricity supply sector can be under-estimated and the standard errors of the estimate grows larger. Note that nor is the relation over-estimated neither interpretation of the main result of this essay is changed because of using the aggregated private R&D data.

And according to Sanyal and Ghosh (2012), it is worth to consider the innovation of upstream technology suppliers. But for the simplicity of the model, the upstream technology innovation was not included.[10]

Government R&D investment budgets were obtained from "Energy technology R&D budgets" of IEA. The budget categories which have more relation to the generation, transmission, and distribution of electricity were selected, which are 1) fossil fuel

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[9] The ratios of the sewage part vary by countries from 2% to 58% (average 23%)

[10] Major innovators in the electricity industry can be upstream producers (i.e. General electric) rather than utilities. However, there are some reasons not to include the upstream innovation in this paper. First, one of the objectives of this paper is to check the presence of the trade off between static and dynamic efficiency caused by liberalization. The agents that are affected directly by the liberalization are the utilities. Second, selecting relevant upstream R&D investment is not simple in the aggregated level data. Third, to include relevant upstream innovation, one possible way is to use patent to calculate the knowledge stocks. But there are some limits to the use of the patents as an indicator of innovation in our analysis. Innovative output is not necessarily patentable or patented(especially in case of basic research). Furthermore "patent propensity" may be variable because of strategic interests of agents after the liberalization.

combustion & conversion, 2) renewable energy sources, 3) nuclear, 4) electric power conversion and electricity transmission & distribution. Summary statistics are given in Table III. 1.

In the electricity industry, government R&D plays important role as much as private R&D. In some countries, government R&D budget is much larger than private R&D investment. The figures that show the trend of government and private R&D expenditure of each country are provided in appendix.

Table III. 1 Statistics

Variables	Description	Mean	Std.Dev.	Min.	Max.
PRICE	Industrial electricity price (USD/MWh)	94.00	44.60	23.05	271.31
ln(DEMAND)	Natural logarithm of electricity consumption (MWh)	19.04	1.04	16.91	20.80
ln(POP)	Natural logarithm of population	17.09	1.01	15.25	18.67
ln(GNI)	Natural logarithm of GNI per capita (USD)	9.80	0.51	8.23	10.68
URBAN	A ratio of urbanization (%)	73.88	8.83	46.87	91.14
S_COAL	A ratio of coal fuel generation to the total electricity generation (%)	31.14	21.97	0.00	84.00
S_HYDRO	A ratio of water power generation to the total electricity generation (%)	19.45	25.19	0.00	100.00
S_NUCLEAR	A ratio of nuclear power generation to the total electricity generation (%)	20.67	21.06	0.00	79.44
COALPRICE	Average steam coal price (USD/toe)	69.22	17.07	49.18	110.90
GASPRICE	Average natural gas price (USD/toe)	226.18	103.24	131.94	480.15
OILPRICE	Average oil product price (USD/toe)	729.00	345.05	373.27	1599.45
ELEC_ENT	Entry liberalization index (value 0 to 6)	3.22	2.73	0.00	6.00
ELEC_PRI	Privatization index (value 0 to 6)	2.28	2.25	0.00	6.00
ELEC_SEP	Vertical separation index (value 0 to 6)	0.85	0.84	0.00	2.81
GOV_ST	Government R&D stock	8.14	15.42	0.01	67.06
PRIRND	Private R&D investment (million USD)	136.12	165.82	0.04	733.70
PRI_ST	Private R&D stock	3.05	3.43	0.00	11.62

* The number of observations = 329

4.2. Estimation results and discussion

4.2.1. Average θ analysis

The demand (Eq. III. 2), the price (Eq. III. 6), and the R&D equations (Eq. III. 9) are estimated simultaneously using NL3SLS. The results with constant (average) θ are reported in Table III. 2. As a preliminary analysis, specification tests of having chosen the right structure for the data is needed.

First, the fit of the estimated structure model is quite good. McElroy R-squared for the system is 0.9112. The high values of the system R-square suggest that this model does fit well with the data (McElroy, 1977). General R-square value is not presented because NL3SLS procedure is an instrumental variable estimator. R-square has no sound statistical interpretation.

The parameter η_1 is -0.0034. One could calculate price elasticity of demand by multiplying η_1 and the *PRICE*. The sample mean price elasticity is -0.3227, which comports to findings from previous literature. According to Lijesen (2007), the price elasticity of industrial electricity ranges from 0.3 to -0.9. The values of control variables in the demand and price equations imply that this model provides reasonable results. The explanation for control variables is described in 4.2.2.

The estimates of θ is 0.329 with a standard error of 0.065. This estimate is statistically different from 0 (t = 5.038) as well as from 1 (t = -10.258). It indicates that the electricity industry is different from a perfect competitive market ($\theta = 0$) and a monopoly or cartel ($\theta = 1$). This finding suggests that electric utilities exercise some form of market coordination.

Table III. 2 Non-linear three-stage least square estimates (average θ analysis)

Variables	Coefficients	Standard Errors
Demand Eq. (2)		
Intercept	-0.814**	0.342
ln(POP)	0.767***	0.019
ln(GNI)	0.661***	0.040
URBAN	0.008**	0.004
η_1	-0.0034***	0.001
Price Eq. (6)		
P_COAL	-0.160**	0.077
P_HYDRO	-0.357***	0.070
P_NUCLEAR	-0.545***	0.093
COALPRICE	0.450***	0.130
GASPRICE	0.012	0.020
GOV_ST	2.658***	0.196
PRI_ST	-11.488***	0.852
θ	0.329***	0.065
R&D Eq. (9)		
Intercept	-192.505	129.941
PRICE	-2.247***	0.144
ELEC_ENT	-8.124***	2.090
ELEC_PRI	-6.938***	2.031
ELEC_SEP	5.858	7.107
$\ln(GNI \cdot POP)$	15.579***	4.994
GOV_ST	8.953***	0.504
OILPRICE	0.115***	0.021

Notes : McElroy R-squared for the system =0.9112 ; Number of observations: 329 ; *** $p < 0.01$; **$p < 0.05$; *$p < 0.1$

4.2.2. Full model with $\theta(\mu_{tc})$ dependent on the liberalization status

To estimate the effect of liberalization measures on market power, the demand (Eq. III. 2), the price (Eq. III. 8), and the R&D (Eq. III. 9) equations are estimated simultaneously using the NL3SLS. The results are reported in Table III. 3.

The fit of the estimated full structure model is quite good. McElroy R-squared for the system is 0.9092. The high values of the system R-square suggest that this model does fit well with the data(McElroy, 1977). General R-square value is not presented because NL3SLS procedure is an instrumental variable estimator, R-square has no sound statistical interpretation.

The parameter η_1 was -0.0034 and the calculated price elasticity was -0.323. These values are the same as those presented Table III. 2 and also similar to data reported in previous literature. The results shown for the control variables in Tables III. 2 and Table III. 3 suggest that the model we proposed reflects reality. In the demand equation (Eq. 2), coefficients of all variables were statistically significant. *POP, GNI*, and *URBAN* are found to be factors increasing electricity consumption as expected. In the price equation, the coefficients of *P_COAL*, *P_HYDRO* and *P_NUCLEAR* are negative on *PRICE*. The coefficients of *P_COAL*, *P_HYDRO* and *P_NUCLEAR* are -0.177, -0.375 and -0.579 respectively. It reflects the fact that the coal, hydro, and nuclear generation has lower marginal cost than average cost (NEA and IEA, 2005).

COALPRICE and *GASPRICE* have positive impact on *PRICE.* In sample countries, the ratios of coal and gas generation are averages 31.4% and 16% of the total electricity generation respectively. So the coal and gas prices are expected to have close relationship with average generation cost. The coefficients of *COALPRICE* is higher than *GASPRICE* . It can be explained by the fact that generators operate as a base loader and gas generators react to peak demand, when the prices of natural gas grows more expensive, the peak demand which is planned to be supplied with electricity by gas generators can be satisfied by electricity supplies by generators using cheaper fuels.

In this model with $\theta(\mu_{tc})$, one can observe the effect of liberalization measures on market power. In the price equation, the estimates of θ_o, the average market power originated from the unique characteristics of electricity industry and unswayed by the liberalization policy, yielded an average value of 0.327. The coefficients of *ELEC_ENT*, *ELEC_PRI*, and *ELEC_SEP* indicate the effects of each liberalization measure on market power. The coefficient of entry liberalization (*ELEC_ENT*) was negative and statistically significant. The coefficients of privatization (*ELEC_PRI*) and vertical separation (*ELEC_SEP)* were negative but statistically insignificant. These results indicate that entry liberalization decreased market power but privatization (*ELEC_PRI*) and vertical separation (*ELEC_SEP*) failed to show meaningful effect on market power.

In the R&D equation (Eq. III. 7), entry liberalization and privatization showed statistically significant effect on R&D. The coefficient of *ELEC_ENT*, *ELEC_PRI* were -17.048 and -8.541 respectively and they were statistically significant. And the vertical separation *(ELEC_SEP)* did not show significant effect on R&D. It means that the private R&D investment decreases by 102.3 mUSD after the entry barriers are fully liberalized (from ELEC_ENT=0 to ELEC_ENT=6), decreases by 51.2 mUSD after the largest public generating utility is totally privatized(from ELEC_PRI=0 to ELEC_PRI=6) .

Particularly, in the *PRICE* equation, the coefficient of private R&D stock (*PRI_ST)* should be concerned. The coefficient of R&D stock is a link to access the effect of the declined R&D investment on the electricity generation cost. The coefficient is negative and statistically significant, which implies that the knowledge accumulated by R&D activities play an important role in reducing the marginal cost. It gives reasons to take R&D investment into account when determining the dynamic effect change after liberalization.

The results show that the entry liberalization (*ELEC_ENT*) reduced the price by decreasing market power in the short run. On one hand, regulating TPA, establishing the wholesale power market, and permitting consumers to choose power suppliers were successful measures for removing entry barriers and reducing market power. On the other hand, the entry liberalization measures may raise electricity prices through disincentivizing R&D investment in the long run. This finding indicates an extant trade-off between static and dynamic efficiency after entry liberalization.

Privatization (*ELEC_PRI*) exerted no significant effect on market power, suggesting that privatization did not meaningfully change firms’ pricing behavior. Almost every country has electricity price regulation and bidding systems for its wholesale power market (Steiner, 2001). By the regulations and rules, the pricing behavior of privatized firms may be like that of the previous public-own utilities. However, the coefficient of *ELEC_PRI* in R&D equation was negative and showed significance. This negative coefficient is in line with the argument that privatized firms have different objectives in investment from the public-owned ones and have smaller incentives to invest on R&D (Munari, 2002).

According to the results, liberalization (entry liberalization and privatization) may reduce R&D incentives and result in dynamic inefficiency. In the electricity industry, government R&D plays important role as much as private R&D. Therefore, it is needed to be investigated that whether the government R&D can contribute to alleviate the dynamic inefficiency.

The result shows that the coefficient of GOV_ST in the price equation was positive and significant. It implies that public R&D stock could not contribute to decreasing marginal cost, but rather to increasing it. The government tends to invest in R&D activities for public projects (Munari and Sobrero, 2003). Governments show more interest than private firms in environmental (such as renewable energy) and future (such as nuclear fission) technologies, which require huge and long-term investments. These two types of technologies are not directly related to electricity-generation cost reductions.

The coefficient of GOV_ST in the R&D equation was positive significantly, suggesting that the government R&D investment can be a remedy to promote private R&D. It implies that government R&D can contribute to alleviate the dynamic inefficiency by preparing the ground for private R&D activities.

Table III. 3 Non-linear three-stage least square estimates (full model with θ)

Variables	Coefficients	Standard Errors
Demand Eq. (2)		
Intercept	-0.816***	(0.343)
ln(POP)	0.770***	(0.019)
ln(GNI)	0.659***	(0.040)
URBAN	0.008**	(0.004)
η_1	-0.0034***	(0.001)
Price Eq. (8)		
P_COAL	-0.177**	(0.079)
P_HYDRO	-0.375***	(0.071)
P_NUCLEAR	-0.579***	(0.093)
COALPRICE	0.493***	(0.128)
GASPRICE	0.067***	(0.025)
GOV_ST	2.559***	(0.232)
PRI_ST	-11.007***	(0.857)
θ_o	0.327***	(0.065)
ELEC_ENT	-0.012**	(0.005)
ELEC_PRI	-0.002	(0.005)
ELEC_SEP	-0.004	(0.016)
R&D Eq. (9)		
Intercept	-228.820**	(131.045)
PRICE	-2.234***	(0.146)
ELEC_ENT	-17.048***	(4.040)
ELEC_PRI	-8.541**	(4.033)
ELEC_SEP	3.763	(13.416)
ln(GNI)	17.114***	(5.031)
GOV_ST	8.834***	(0.584)
OILPRICE	0.155***	(0.023)

Notes: McElroy R-squared for the system = 0.90921 ; Number of observations: 329 ; *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

4.3. The size of the liberalization effects: comparison of static and dynamic efficiency

The results shown in Table III. 3 suggest a trade-off exists between static and dynamic efficiency due to entry liberalization. To measure the size of the static and dynamic effects of entry liberalization, one can simulate price decrement caused by entry liberalization and the price increment caused by R&D stock (*PRI_ST*) decrement after entry liberalization. The calculation is based on the results shown in Table III. 3.

The static effect of entry liberalization was calculated by multiplying $1/\eta_1$ by the coefficients of the *ELEC_ENT* in the *PRICE* equation. When the index of entry liberalization (*ELEC_ENT*) increases from 0 to 6, the market power θ decreases by 0.072 (0.012×6). The reduced market power decreases the electricity price by 21.8 USD/MWh(0.072/. It means that after all the barriers to entry are fully removed, the market power of the electricity industry is reduced and the electricity price decreases by 21.8 USD/MWh.

When fully entry liberalized, that is *ELEC_ENT* increases from 0 to 6, and the private R&D investment (*PRIRND*) decreases by 102.3 (17.05×6) mUSD. It is a very drastic change. The effect of reduced R&D investment decreases the private R&D stock (*PRI_ST*) over time. If the reduced R&D investment stays the same over long time, the R&D stock will be decreased at the same proportion. Finally, the reduced knowledge stock increases the electricity price by 25 USD/MWh, which is slightly bigger than the price reduction caused by that static effect. It shows that for entry liberalization the dynamic inefficiency should not be neglected.

In the result, privatization has no significant effect on market power but it has negative impact on R&D investment. Then, when fully privatized, that is *ELEC_PRI* increases from 0 to 6, and the private R&D investment (*PRIRND*) decreases by 51.3 (8.541×6) mUSD. The effect of reduced R&D investment decreases the private R&D stock (*PRI_ST*) over time. The reduced knowledge stock increases the electricity price by 12.77 USD/MWh

The simulation results for price and R&D changes that show static and dynamic effects of entry liberalization are illustrated in Figure III. 1 and Figure III. 2. In Figure III. 1, electricity price decreases by 14.77 USD/MWh because of the static effect after full entry liberalization. And based on the assumption that the decreased R&D stays the same after the entry liberalization, the decreased R&D decreases R&D stock over time. And the decreased R&D stock gradually increases electricity price. Figure III. 2 shows the effect of privatization on price and R&D in the same way. The value of price and R&D expenditure in the simulation were calculated based on the assumption that other variables take average values except for the each liberalization measure.

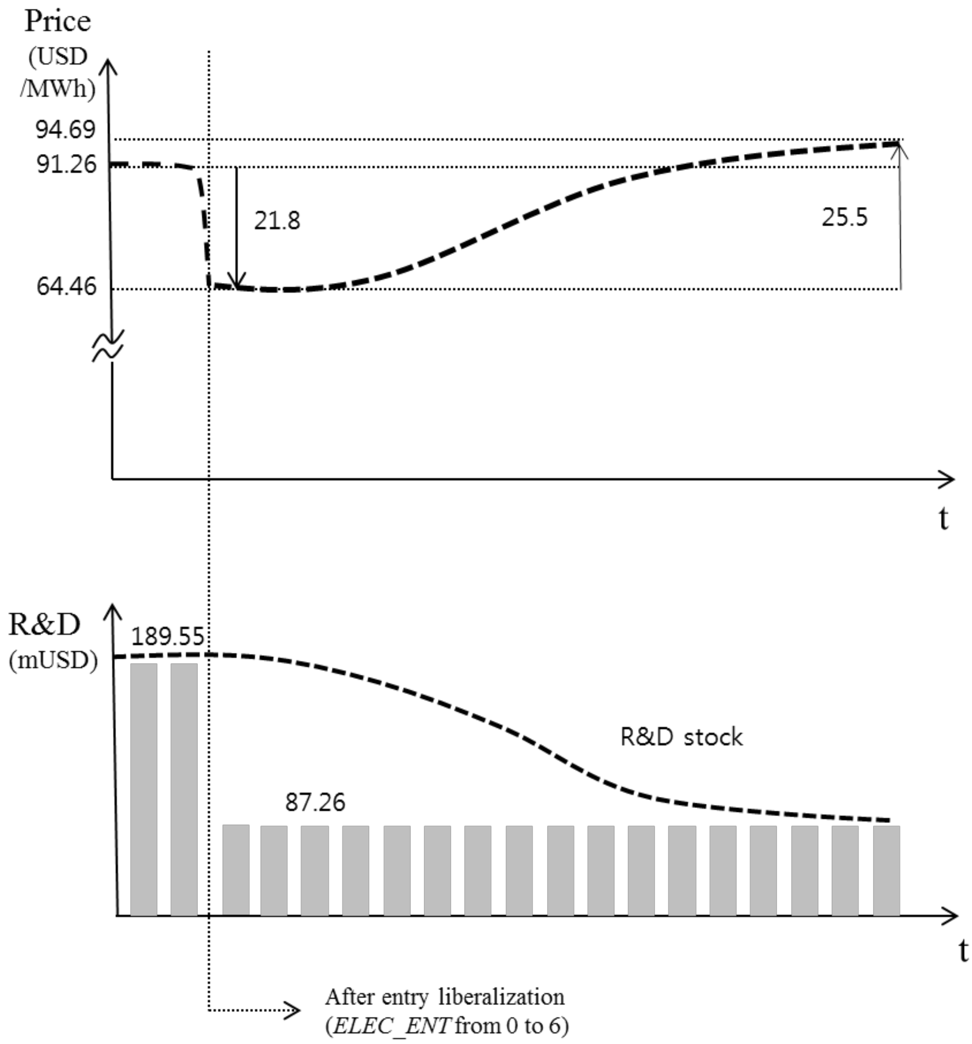

Figure III. 1 Simulation results: fully entry-liberalized electricity market

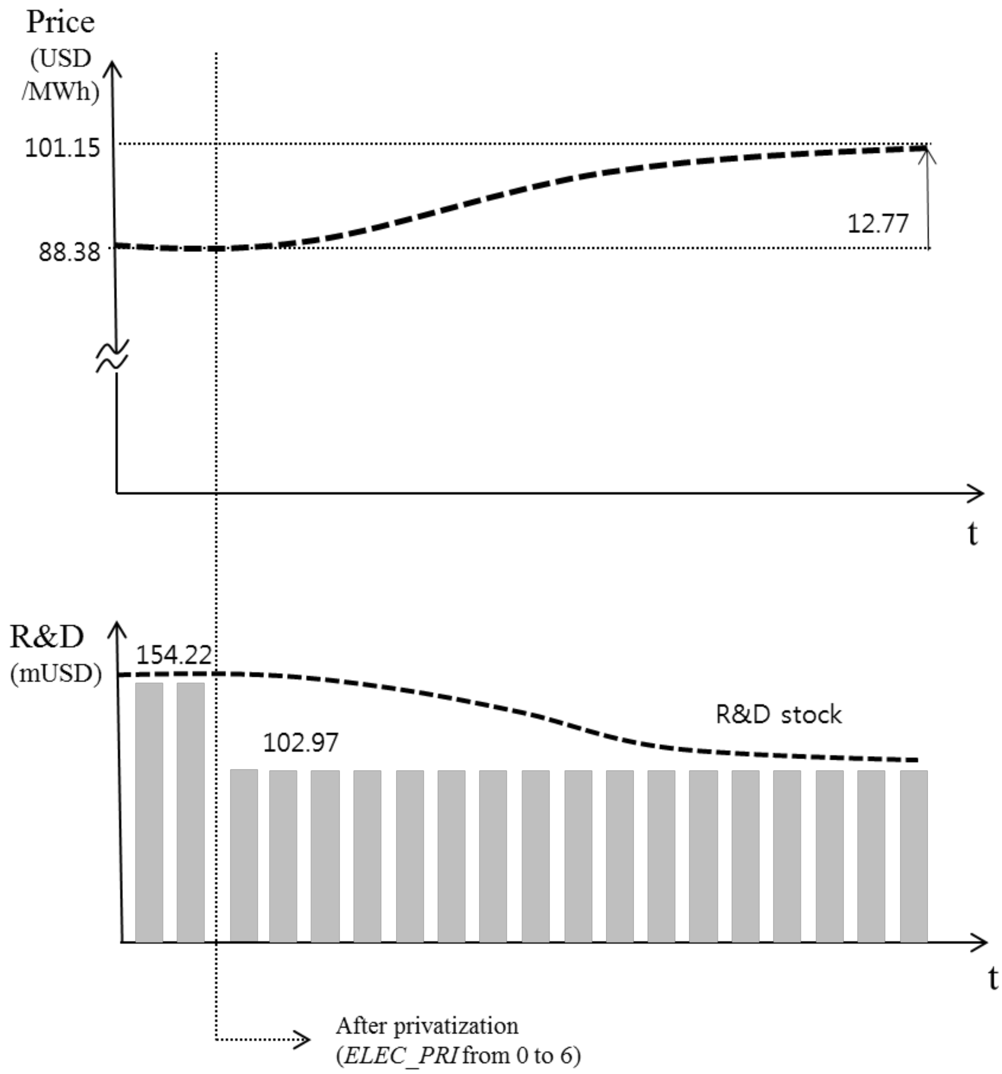

Figure III. 2 Simulation results: fully privatized electricity market

5. Conclusion

After the worldwide liberalization of the electricity market, concerns have been raised concerning R&D disincentives. Although the literature noted reduced R&D investment in the electricity industry after liberalization, studies focusing on the specific impacts of reduced R&D investment on industrial performance are scarce.

In this essay, a structural model is proposed that accounts for the effects of liberalization, such as market structure and ownership changes, on the performance of the electricity industry as measured by market power and R&D investment. The traditional New Empirical Industrial Organization (NEIO) framework (Bresnahan, 1989) is applied and expanded to measure the effects of liberalization on R&D investments (dynamic efficiency) as well as market power (i.e., price and static efficiencies). An industry-level R&D investment decision equation is incorporated into the NEIO model and link the R&D equation to structural equations of oligopolistic competition. The integrated framework only requires industry-level aggregate data, which enabled us to identify the impacts of knowledge accumulation and spillovers in the electricity industry. This model is estimated for 17 OECD countries from 1987 to 2012.

In these market structure equations, the results show that the R&D investment can be an important input factor for reducing marginal cost. It implies that the reduced R&D in the electricity industry could harm dynamic efficiency with respect to R&D investment. It provides an evidence to support the previous concerns about reduced R&D in the electricity industry, suggesting that the concerns can be actual threat to long-term efficiency in the future.

And the results suggested that the effects of liberalization are different depending on the specific measures and times when the effect is realized. The entry liberalization reduces the price of electricity in the short-term by decreasing market power but also raises the price through decreasing R&D investment in the long-term. The findings imply a trade-off between the beneficial and deleterious effects of entry liberalization. Comparing the two effects, one can find that the enhanced static efficiency may fail to offset the dynamic inefficiency of entry liberalization in the long run. And the result shows that privatization exert no significant effect on market power but decreases R&D investment, which causes dynamic inefficiency. The results suggest some complementary policy need to be considered to mitigate unexpected side effect of restructuring that is reduced R&D and dynamic inefficiency.

The empirical implementation of the proposed model has some limitations caused by the availability of data. R&D data was not just on electricity including gas, and excluding relevant upstream innovation. It might give biased results (that is under-estimates for dynamic effects). And although major determinants of electricity generating cost were included in the model, not all the cost shifters were included such as network cost or subsidy for renewable generators (while they are a small part of the average prices of electricity).

Despite of the limitations, the model in this essay can be useful integrated model to analyze interaction among liberalization, R&D investment, market structure and price. It is easy and simple to handle so that it requires industry level aggregate data. This feature can encourage more empirical research on important topics in this field. And the results obtained in this essay can sound an alarm that there exists trade-off between static and dynamic efficiencies caused by the liberalization of electricity industry. The approach and the results of this essay would stimulate future research on similar topics in restructured energy industries.

Overall Conclusion

This dissertation presents three essays which analyzes the effect of R&D and institutional change(intellectual property rights and liberalization) on industrial economic performance. The first essay analyzes the spillover effect of knowledge on economic performance and innovation (Essay I). The second essay analyzes the beneficial and detrimental effects of intellectual property rights which grants exclusive right to innovators (Essay II). The third essay analyzes the effect of electricity industry liberalization which introduces market competition to electricity industry (Essay III).

Essay I is devoted to investigate the role of basic and applied R&D for productivity growth and innovation by focusing on the spillover effects of R&D. Using the production function approach, this essay examines the differential effects of basic and applied R&D by taking into account spillovers between industries and stages of research. The results show that the spillovers of basic research are much larger and exert a wider impact than do spillovers of applied research. The result emphasizes the importance of basic research in economic growth. It suggests the needs of systematic innovation policy taking into account the impact of knowledge.

Essay II provides the analysis of the effect of intellectual property rights (IPR) on innovation and industry value added. Using simultaneous equations, this essay estimates the direct effect of IPR on industry value added and the indirect effect of it through enhanced research and development (R&D). The results suggest that IPR generally enhance industry value added and R&D investment but show a negative relationship with patented knowledge, suggesting that excessive propertization of knowledge may hinder sequential innovation. Furthermore the positive role of IPR on R&D is found to predominate in the chemical (discrete) industry and have negative effects in the electronics and machinery (complex) industries.

Essay III presents the analysis of the short-term and long-term effects of the liberalization of electricity industry. While almost prior literature focused on the effect of liberalization on either shot-term price change or R&D investment, this essay analyzes both the static and dynamic effect by applying expanded NEIO method. The results show that the existence of trade-off between static and dynamic efficiencies caused by the liberalization of electricity industry. Furthermore, our results highlight that some complementary policies need to be considered to mitigate the unexpected side effect of restructuring that is reduced R&D and dynamic inefficiency.

The three essays presented in this dissertation analyze different industries. Therefore, it is difficult to formulate comprehensive implications based on all three essays. Nevertheless, through synthesizing the conclusions of each essay, general implications for industrial and innovation policies can be outlined.

First, the economic impact of basic research is important as much as that of applied R&D. Furthermore, considering the endogeneity of knowledge where knowledge produces knowledge, the long-term economic impact of basic research is much more powerful than that of applied R&D.

Second, IPR, in general, provides a good mechanism for encouraging a virtuous cycle of R&D and value added. However, in complex industries (such as electronics and machinery industry), strong IPR and granting too much patent can hinder sequential innovation and thus cause anti-common tragedy. Government should play a greater role in providing a flexible IPR regime that comports to technological and industrial characteristics and, in doing so, resolve any negative effects.

Third, an industrial policy (such as liberalization) may unintentionally cause R&D disincentive and dynamic inefficiency. In the long-run, the dynamic inefficiency can offset the static efficiency. The policy makers should consider the institutional endogeneity of R&D and its dynamic effect.

The purpose of the essays is to contribute to current research on modeling the integrated framework which evaluates the industrial economic performance taking into account the endogenous characteristics of innovation and to provide an insight into how harmonize traditional industrial policy and systemic innovation policy. The essays focus on the complex effects of institutions on innovation (beneficial or detrimental effects of market liberalization policies and intellectual property rights). The source of institutional failure in innovation is investigated. The results and conclusion of the essays provide a valuable insight into how to harmonize between traditional pro-market industry policy and systemic innovation policy.

In terms of an academic contribution, the essays implement a novel empirical approach (various kinds of structure equations including expanded NEIO method) and introduce new concepts (e.g. patented knowledge). The essays deal with the questions that could hardly be answered using the traditional empirical approach. The approaches used in this dissertation are easy and simple to handle because they require industry-level aggregate data. This feature can encourage further empirical research on the important topics in this field. The approaches demonstrated and the results obtained in this dissertation will hopefully stimulate future research on related topics.

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Appendix

Appendix I

Table I-A1: R&D expenditures by industries in Korea (average)

Industry	1991 – 1996		1997 – 2002		2003 – 2008	
	Basic	Applied	Basic	Applied	Basic	Applied
1. Food, Beverages and Tobacco	19,564	112,620	16,010	110,043	26,936	184,683
2. Textiles, Leather and Footwear	10,874	75,565	4,747	43,312	6,085	40,159
3. Pulp and Paper	1,762	16,762	1,831	13,766	1,397	11,394
4. Printing and Publishing	355	12,322	927	23,302	1,082	14,226
5. Coke, Refined petroleum and Nuclear fuel	3,602	87,566	12,104	118,827	6,187	118,174
6. Chemicals and Chemical products	64,790	496,301	64,216	587,918	158,581	1,119,181
7. Rubber and Plastics	8,413	88,362	9,006	125,551	8,918	246,520
8. Other non-metallic minerals	9,297	67,742	8,450	73,246	10,056	100,288
9. Basic metals	12,160	148,315	8,207	119,434	28,163	286,521
10. Fabricated metals	3,702	82,064	4,055	54,067	8,442	106,440
11. Machinery	14,438	269,840	18,656	378,809	56,009	907,129
12. Office, Accounting and Computing machines	9,852	112,788	27,829	393,666	5,496	208,287
13. Electrical machinery and Apparatus	8,363	138,116	11,885	182,213	23,320	325,791
14. Radio, Television and Communication equipment	158,953	1,871,377	349,877	3,477,709	1218,561	6,818,655
15. Medical, Precision and Optical instruments	2,681	51,477	5,967	101,017	13,989	273,062
16. Motor vehicles, Trailers and Semi-trailers	109,578	1,166,575	76,963	1,426,647	211,828	2334,698
17. Other transport equipment	11,671	177,789	13,577	364,220	39,553	349,606
18. Other Manufacturing and Recycling	1,304	20,570	2,427	45,633	2,977	42,341

Note: Unit is million won.

Table I. A-2: Survey on previous studies about spillover of R&D of Korea

Studies	Sample & period	output	Elasticity to output / results
Song (1994)	10 manufacturing industries 1985 - 1990	TFP	0.37% ~ 2.15%
Kim (1999)	11 manufacturing industries 1980 – 1996	TFP	2.2%
Cho (2004)	Manufacturing firms 1979 - 2002	TFP	Result of large firms; 2.63% (internal) 3.06% (external)
Yang (2005)	Manufacturing firms 1991 - 2002	TFP	1.3% (small & medium firms) 0.53% (large firms)
Shin (2004)	Korea economy	GDP	13.9%
Whang (2008)	6 manufacturing industries 1993-2005	TFP	Basic R&D is important in chemical and machinery industries Chemical and machinery industries are affected from other industries' R&D stock

Table I-B1 results based on same depreciation rate R&D stock (Lag 1 year models)

		Lag 1 year		
Depreciation rate		15%	20%	25%
Equation 1 Dependent variable: *lnY*	*lnK*	0.218***	0.215***	0.213***
		(0.029)	(0.028)	(0.028)
	lnL	0.057	0.058	0.058
		(0.042)	(0.042)	(0.042)
	lnR^b	0.361***	0.382***	0.389***
		(0.055)	(0.053)	(0.052)
	lnR^a	-0.093	-0.116**	-0.125**
		(0.059)	(0.056)	(0.054)
	lnR^{ob}	-0.351	-0.245	-0.183
		(0.262)	(0.231)	(0.208)
	lnR^{oa}	0.377	0.249	0.181
		(0.367)	(0.323)	(0.291)
	constant	9.117***	9.940***	10.309***
		(2.645)	(2.308)	(2.078)
Equation 2 Dependent variable: lnE^b	*lnY*	0.554***	0.589***	0.611***
		(0.078)	(0.076)	(0.074)
	lnR^a	0.886***	0.880***	0.878***
		(0.041)	(0.039)	(0.038)
	lnR^{ob}	-0.275	-0.172	-0.138
		(0.434)	(0.380)	(0.340)
	lnR^{oa}	0.187	0.076	0.054
		(0.604)	(0.528)	(0.472)
	constant	-11.257***	-11.218***	-11.556***
		(4.177)	(3.646)	(3.282)
Equation 3 Dependent variable: lnE^a	*lnY*	-0.205***	-0.228***	-0.236***
		(0.072)	(0.069)	(0.066)
	lnR^b	0.930***	0.953***	0.965***
		(0.033)	(0.032)	(0.030)
	lnR^{ob}	1.492***	1.144***	0.903***
		(0.356)	(0.304)	(0.267)
	lnR^{oa}	-2.333***	-1.783***	-1.398***
		(0.495)	(0.421)	(0.370)
	constant	23.455***	19.251***	16.288***
		(3.453)	(2.947)	(2.609)

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses.

Table I-B2 results based on same depreciation rate R&D stock (Lag 2 year models)

		Lag 1 year		
Depreciation rate		15%	20%	25%
Equation 1 Dependent variable: *lnY*	*lnK*	0.233***	0.232***	0.233***
		(0.029)	(0.029)	(0.029)
	lnL	0.039	0.042	0.044
		(0.044)	(0.044)	(0.044)
	lnR^{b}	0.288***	0.311***	0.321***
		(0.056)	(0.055)	(0.053)
	lnR^{a}	-0.005	-0.031	-0.044
		(0.060)	(0.058)	(0.056)
	lnR^{ob}	-0.347	-0.232	-0.164
		(0.269)	(0.237)	(0.213)
	lnR^{oa}	0.369	0.23	0.152
		(0.372)	(0.326)	(0.293)
	constant	8.672***	9.539***	9.948***
		(2.645)	(2.301)	(2.066)
Equation 2 Dependent variable: lnE^{b}	*lnY*	0.532***	0.571***	0.601***
		(0.088)	(0.086)	(0.085)
	lnR^{a}	0.852***	0.840***	0.830***
		(0.046)	(0.045)	(0.044)
	lnR^{ob}	0.029	0.127	0.153
		(0.479)	(0.420)	(0.376)
	lnR^{oa}	-0.246	-0.346	-0.356
		(0.659)	(0.576)	(0.515)
	constant	-7.389	-7.500*	-7.998**
		(4.514)	(3.940)	(3.549)
Equation 3 Dependent variable: lnE^{a}	*lnY*	-0.129	-0.159**	-0.171**
		(0.083)	(0.080)	(0.079)
	lnR^{b}	0.880***	0.907***	0.921***
		(0.039)	(0.037)	(0.036)
	lnR^{ob}	1.741***	1.389***	1.138***
		(0.409)	(0.353)	(0.312)
	lnR^{oa}	-2.682***	-2.125***	-1.728***
		(0.563)	(0.484)	(0.427)
	constant	25.110***	20.909***	17.875***
		(3.905)	(3.361)	(2.994)

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses.

Table I-B3 results based on same depreciation rate R&D stock (Lag 3 year models)

		Lag 1 year		
Depreciation rate		15%	20%	25%
Equation 1 Dependent variable: *lnY*	*lnK*	0.236***	0.237***	0.238***
		(0.030)	(0.030)	(0.030)
	lnL	0.021	0.026	0.029
		(0.045)	(0.045)	(0.045)
	lnR^b	0.236***	0.256***	0.267***
		(0.057)	(0.056)	(0.054)
	lnR^a	0.066	0.041	0.027
		(0.061)	(0.059)	(0.057)
	lnR^{ob}	-0.327	-0.213	-0.142
		(0.274)	(0.241)	(0.216)
	lnR^{oa}	0.342	0.205	0.125
		(0.375)	(0.328)	(0.294)
	constant	8.543***	9.352***	9.749***
		(2.649)	(2.298)	(2.061)
Equation 2 Dependent variable: lnE^b	*lnY*	0.573***	0.603***	0.629***
		(0.095)	(0.093)	(0.092)
	lnR^a	0.815***	0.807***	0.798***
		(0.050)	(0.049)	(0.048)
	lnR^{ob}	0.577	0.602	0.58
		(0.507)	(0.444)	(0.397)
	lnR^{oa}	-0.968	-0.961	-0.902*
		(0.691)	(0.602)	(0.537)
	constant	-3.212	-4.042	-4.993
		(4.718)	(4.114)	(3.710)
Equation 3 Dependent variable: lnE^a	*lnY*	0.003	-0.033	-0.049
		(0.093)	(0.091)	(0.089)
	lnR^b	0.810***	0.841***	0.857***
		(0.044)	(0.043)	(0.042)
	lnR^{ob}	2.019***	1.649***	1.383***
		(0.454)	(0.395)	(0.350)
	lnR^{oa}	-3.058***	-2.479***	-2.063***
		(0.618)	(0.535)	(0.473)
	constant	26.055***	21.759***	18.639***
		(4.291)	(3.719)	(3.332)

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses.

Table II-A1 Sub-categories of the industries.

Source: ISIC rev.3

Chemical Industry	Electronics Industry	Machinery Industry
C24: Chemicals and chemical products	C30: Office, accounting and computing machinery C31: Electrical machinery and apparatus, nec C32: Radio, television and Communication equipment C33: Medical, precision and optical instruments	C29: Machinery and equipment, nec C34: Motor vehicles, trailers and semi-trailers C35: Other transport equipment

Table II-A2 Bivariate correlation coefficients for the value-added equation in the chemical industry.

Variable	*VA*	*K*	*L*	*RDS20*	*IPR*	*IPR2*
VA	1.000					
K	0.9871	1.000				
L	0.9528	0.9463	1.000			
RDS20	0.9614	0.9441	0.8780	1.000		
IPR	0.4055	0.3782	0.2712	0.5185	1.000	
IPR2	0.3845	0.3522	0.2563	0.5002	0.9954	1.000

Table II-A3 Bivariate correlation coefficients for the value-added equation in the electronics industry.

Variable	*VA*	*K*	*L*	*RDS20*	*IPR*	*IPR2*
VA	1.000					
K	0.9866	1.000				
L	0.9679	0.9543	1.000			
RDS20	0.9490	0.9525	0.8675	1.000		
IPR	0.4375	0.4309	0.3117	0.5667	1.000	
IPR2	0.4206	0.4094	0.2996	0.5510	0.9954	1.000

Table II-A4: Bivariate correlation coefficients for the value-added equation in the machinery

Variable	*VA*	*K*	*L*	*RDS20*	*IPR*	*IPR2*
VA	1.000					
K	0.9819	1.000				
L	0.9521	0.9589	1.000			
RDS20	0.9795	0.9534	0.9548	1.000		
IPR	0.5382	0.4351	0.3728	0.5526	1.000	
IPR2	0.5213	0.4132	0.3607	0.5412	0.9954	1.000

Table II-A5 : Bivariate correlation coefficients for the R&D equation in the chemical industry.

Variable	*RDI*	*IPR*	*IPRPK*	*VA*	*RDS0*
RDI	1.000				
IPR	0.5178	1.000			
IPRPK	-0.6105	-0.1110	1.000		
VA	0.9614	0.4055	-0.5137	1.000	
RDS0	0.9579	0.5254	-0.5937	0.9171	1.000

Table II-A6: Bivariate correlation coefficients for the R&D equation in the electronics industry.

Variable	*RDI*	*IPR*	*IPRPK*	*VA*	*RDS0*
RDI	1.000				
IPR	0.5596	1.000			
IPRPK	-0.3711	0.0572	1.000		
VA	0.9567	0.4375	-0.3892	1.000	
RDS0	0.9657	0.5657	-0.3452	0.9185	1.000

Table II-A7 : Bivariate correlation coefficients for the R&D equation in the machinery industry.

Variable	*RDI*	*IPR*	*IPRPK*	*VA*	*RDS0*
RDI	1.000				
IPR	0.5555	1.000			
IPRPK	-0.6857	-0.2421	1.000		
VA	0.9818	0.5382	-0.6309	1.000	
RDS0	0.9635	0.5575	-0.6723	0.9516	1.000

Table II- B1 Value Added and R&D Investment with time lag variable for the chemical industry.

Variable	Value Added Model			Variable	R&D Model		
	m1	m2	m3		m1	m2	m3
K	0.610*** (0.04)	0.607*** (0.04)	0.600*** (0.04)	*IPR*	0.172*** (0.04)		
L	0.260*** (0.04)	0.269*** (0.04)	0.279*** (0.05)	*IPR (n-1)*		0.092* (0.04)	
RDS20	0.158*** (0.02)	0.153*** (0.02)	0.148*** (0.02)	*IPR (n-2)*			0.013 (0.03)
IPR	0.019 (0.01)			*IPRPK*	-0.008*** (0.00)		
IPR (n-1)		0.025 (0.02)		*IPRPK (n-1)*		-0.005*** (0.00)	
IPR (n-2)			0.036* (0.02)	*IPRPK (n-2)*			-0.002* (0.00)
				VA	0.496*** (0.05)	0.275*** (0.06)	0.048 (0.06)
				RDS0	0.369*** (0.05)	0.617*** (0.06)	0.869*** (0.06)
Obs.	124	112	100	Obs.	124	112	100
R^2	0.999	0.999	0.999	R^2	0.999	0.999	0.999

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses.

Table II-B2 Value Added and R&D Investment with time lag variable for the electronics industry.

Variable	Value Added Model			Variable	R&D Model		
	m1	m2	m3		m1	m2	m3
K	0.404*** (0.05)	0.402*** (0.06)	0.382*** (0.06)	*IPR*	0.148** (0.05)		
L	0.518*** (0.05)	0.536*** (0.05)	0.564*** (0.06)	*IPR (n-1)*		0.050 (0.04)	
RDS20	0.142*** (0.02)	0.127*** (0.02)	0.121*** (0.03)	*IPR (n-2)*			-0.015 (0.04)
IPR	0.034 (0.02)			*IPRPK*	-0.019*** (0.00)		
IPR (n-1)		0.036 (0.02)		*IPRPK (n-1)*	-	-0.003** (0.00)	
IPR (n-2)			0.045* (0.02)	*IPRPK (n-2)*	-		-0.002* (0.00)
				VA	0.305*** (0.04)	0.168*** (0.05)	0.053 (0.04)
				RDS0	0.583*** (0.05)	0.743*** (0.05)	0.875*** (0.05)
Obs.	115	104	93	Obs.	115	104	93
R^2	0.999	0.999	0.999	R^2	0.999	0.999	0.999

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses.

Table II-B3 Value Added and R&D Investment with time lag variable for the machinery industry.

Variable	Value Added Model			Variable	R&D Model		
	m1	m2	m3		m1	m2	m3
K	0.686*** (0.04)	0.662*** (0.04)	0.651*** (0.05)	*IPR*	0.095* (0.04)		
L	0.223*** (0.05)	0.269*** (0.05)	0.297*** (0.06)	*IPR (n-1)*		0.066 (0.04)	
RDS20	0.071** (0.02)	0.052* (0.02)	0.036 (0.02)	*IPR (n-2)*			0.037 (0.03)
IPR	0.150*** (0.02)			*IPRPK*	-0.026*** (0.00)		
IPR (n-1)		0.159*** (0.02)		*IPRPK (n-1)*	-	-0.004*** (0.00)	
IPR (n-2)			0.166*** (0.02)	*IPRPK (n-2)*	-		-0.003** (0.00)
				VA	0.475*** (0.05)	0.228*** (0.05)	0.097 (0.05)
				RDS0	0.419*** (0.06)	0.675*** (0.06)	0.815*** (0.06)
Obs.	115	104	93	Obs.	115	104	93
R^2	0.999	0.999	0.999	R^2	0.999	0.999	0.999

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses.

Table II-B4 Value Added and R&D Investment with IPRGP and RDS15 variable for the chemical industry.

Variable	Value Added Model				Variable	R&D Model			
	m1	m2	m3	m4		m1	m2	m3	m4
K	0.610*** (0.04)	0.610*** (0.04)	0.504*** (0.03)	0.502*** (0.03)	*IPR*	0.172*** (0.04)	0.171*** (0.04)		
L	0.260*** (0.04)	0.264*** (0.04)	0.389*** (0.04)	0.393*** (0.04)	*IPRGP*			0.271* (0.13)	0.273* (0.13)
RDS20	0.158*** (0.02)		0.108*** (0.02)		*IPRPK*	-0.008*** (0.00)	-0.008*** (0.00)		
RDS15		0.153*** (0.02)		0.104*** (0.02)	*IPRGPPK*			-0.013*** (0.00)	-0.013*** (0.00)
IPR	0.019 (0.01)	0.020 (0.02)			*VA*	0.496*** (0.05)	0.494*** (0.05)	0.479*** (0.05)	0.478*** (0.05)
IPRGP			0.304*** (0.05)	0.309*** (0.05)	*RDS0*	0.369*** (0.05)	0.371*** (0.05)	0.390*** (0.05)	0.390*** (0.05)
Observations	124	124	117	117	Observations	124	124	117	117
R^2	0.999	0.999	1.000	1.000	R^2	0.999	0.999	0.999	0.999

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses. IPRGP and IPRGPPK variables are Ginarte-Park version of IPR and IPRPK.

Table II-B5 Value Added and R&D Investment with IPRGP and RDS15 variable for the electronics industry.

Variable	Value Added Model m1	m2	m3	m4	Variable	R&D Model m1	m2	m3	m4
K	0.404*** (0.05)	0.390*** (0.05)	0.257*** (0.06)	0.254*** (0.06)	*IPR*	0.148** (0.05)	0.148** (0.05)		
L	0.518*** (0.05)	0.527*** (0.05)	0.663*** (0.06)	0.664*** (0.06)	*IPRGP*			0.155 (0.17)	0.158 (0.17)
RDS20	0.142*** (0.02)		0.112*** (0.02)		*IPRPK*	-0.019*** (0.00)	-0.019*** (0.00)		
RDS15		0.147*** (0.02)		0.116*** (0.02)	*IPRGPPK*			-0.030*** (0.01)	-0.030*** (0.01)
IPR	0.034 (0.02)	0.148** (0.05)			*VA*	0.305*** (0.04)	0.307*** (0.04)	0.291*** (0.04)	0.292*** (0.04)
IPRGP			0.355*** (0.08)	0.340*** (0.08)	*RDS0*	0.583*** (0.05)	0.580*** (0.05)	0.615*** (0.06)	0.613*** (0.06)
Observations	115	115	108	108	Observations	115	115	108	108
R^2	0.999	0.999	0.999	0.999	R^2	0.999	0.999	0.999	0.999

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses. IPRGP and IPRGPPK variables are Ginarte-Park version of IPR and IPRPK.

Table II-B6 Value Added and R&D Investment with IPRGP and RDS15 variable for the machinery industry.

Variable	Value Added Model m1	m2	m3	m4	Variable	R&D Model m1	m2	m3	m4
K	0.686*** (0.04)	0.687*** (0.04)	0.522*** (0.05)	0.524*** (0.05)	*IPR*	0.095* (0.04)	0.095* (0.04)		
L	0.223*** (0.05)	0.224*** (0.05)	0.308*** (0.06)	0.307*** (0.06)	*IPRGP*			-0.023 (0.13)	-0.023 (0.13)
RDS20	0.071** (0.02)		0.126*** (0.02)		*IPRPK*	-0.026*** (0.00)	-0.026*** (0.00)		
RDS15		0.068** (0.02)		0.124*** (0.02)	*IPRGPPK*			-0.047*** (0.01)	-0.047*** (0.01)
IPR	0.150*** (0.02)	0.151*** (0.02)			*VA*	0.475*** (0.05)	0.473*** (0.05)	0.519*** (0.06)	0.518*** (0.06)
IPRGP			0.471*** (0.06)	0.469*** (0.06)	*RDS0*	0.419*** (0.06)	0.420*** (0.06)	0.407*** (0.06)	0.408*** (0.06)
Observations	115	115	108	108	Observations	115	115	108	108
R^2	0.999	0.999	0.999	0.999	R^2	0.999	0.999	0.999	0.999

Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level; standard errors in parentheses. IPRGP and IPRGPPK variables are Ginarte-Park version of IPR and IPRPK.

Appendix III-A

We modeled the quantity competition behavior among electricity-generating firms .Firm i's profit function is

$$\pi_i = p(Q,Z)q_i - c(q_i,w) \qquad \text{(A. 1)}$$

where, π is profit, p is price which depends on total quantitiy(Q) and other exogeneous variables(Z) and, q_i is quantity of firm i, c is cost which depends on quantity(q_i) and other exogeneous variables(w) .

First order condition for profit maximization is

$$\begin{aligned}\frac{\partial \pi_i}{\partial q_i} &= \frac{\partial}{\partial q_i}\left(p(Q,Z)q_i - c(q_i,w)\right)\\ &= \frac{\partial Q}{\partial q_i}\frac{\partial p(Q,Z)}{\partial Q}q_i + p(Q,Z) - \frac{\partial c(q_i,w)}{\partial q_i} \qquad \text{(A. 2)}\\ &= \frac{\partial Q}{\partial q_i}\frac{\partial p(Q,Z)}{\partial Q}q_i + p(Q,Z) - MC(w) \equiv 0\end{aligned}$$

We introduce $\theta \equiv \frac{q_i}{Q}\frac{\partial Q}{\partial q_i}$ and substitute it into Eq. (A.2). Then we obtain

$$\frac{\partial \pi_i}{\partial q_i} = \theta\frac{\partial p(Q,Z)}{\partial Q}Q + p(Q,Z) - MC(w) \equiv 0 \qquad \text{(A .3)}$$

Appendix III-B. Data
1. Liberalization index

OECD International Regulation Database provides a group of indicators measuring regulatory restrictions in energy, transportation, and communication. The indicators cover transmission, distribution, and supply in the electricity industry. They include the following low-level measures in the electricity industry: barriers to entry, public ownership, and vertical integration.

The indicators for entry regulation focus on terms and conditions for third party access (TPA) and the extent that consumers may choose their suppliers. Regulated TPA, free consumer choice, and a liberalized wholesale power market presumably promote competition. The indicator for public ownership records the prevailing ownership structure, which ranges from fully private to fully public. The indicators for vertical integration reflect the status of electricity generation and supply compared to natural monopoly activities. The degree of separation ranges from full integration to mere legal/accounting separation to separation into different companies owned by different shareholders. The assumption, reflecting industrial organization theory, is that the scope for anticompetitive behavior is largest when an electricity or gas company simultaneously controls the network and operates in upstream or downstream competitive markets (Conway and Nicoletti, 2006).

We use three kinds of liberalization index: entry liberalization, privatization, and vertical separation based on the weighted averages of the lower components of each category. Note that the value of them ranges from 0 to 6 along with the degree of liberalization increases. The specific contents and weights are given in Table III- B.1

Table III-B.1 Indicators for liberalization in electricity industry

<table>
<tr><th>Liberalization Measures</th><th>Questions</th><th colspan="6">Liberalization Degree</th></tr>
<tr><td rowspan="6">Entry Regulation</td><td rowspan="2">How are the terms and conditions of third party access (TPA) to the electricity transmission grid determined?</td><td colspan="2">Regulated TPA</td><td colspan="2">Negotiated TPA</td><td colspan="2">No TPA</td></tr>
<tr><td colspan="2">6</td><td colspan="2">3</td><td colspan="2">0</td></tr>
<tr><td rowspan="2">Is there a liberalized wholesale market for electricity (a wholesale pool) ?</td><td colspan="3">yes</td><td colspan="3">No</td></tr>
<tr><td colspan="3">6</td><td colspan="3">0</td></tr>
<tr><td rowspan="2">What is the minimum consumption threshold that consumers must exceed to be able to choose their electricity supplier? (Gigawatts)</td><td>No Threshold</td><td>< 250</td><td>250-500</td><td>500-1000</td><td>>1000</td><td>No Consumer Choice</td></tr>
<tr><td>6</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>Privatization</td><td>What is the ownership structure of the largest companies in the generation, transmission, distribution, and supply segments of the electricity industry?</td><td colspan="6">% of shares owned by government / 100 * 6</td></tr>
<tr><td rowspan="2">Vertical Separation</td><td rowspan="2">What is the degree of vertical separation between the transmission and generation segments of the electricity industry?</td><td>Ownership seperation</td><td>Legal seperation</td><td colspan="2">Accounting separation</td><td colspan="2">No separation</td></tr>
<tr><td>6</td><td>3</td><td colspan="2">1.5</td><td colspan="2">0</td></tr>
</table>

2. Knowledge stocks

To build knowledge stock data, we adopt the method of Popp (2002). The R&D activity does not directly affect the present outcome, but it slowly diffuses and becomes utilizable over time. However, the R&D also grows increasingly obsolete. These two effects are expressed as the R&D diffusion and R&D decay rates, respectively. Unlike Popp (2002), who used patent numbers to determine knowledge stock, we used R&D investment.

$$\mathrm{PRI\_ST}_{it} = \sum_{s=0}^{t-1} e^{-\beta_1(s)}(1-e^{-\beta_2(s+1)})RnD_{i(t-s)} \tag{B.1}$$

$$GOV\_ST_{it} = \sum_{s=0}^{t-1} e^{-\beta_1(s)}(1-e^{-\beta_2(s+1)})GovRnD_{i(t-s)} \tag{B.2}$$

The coefficients, β_1 and β_2 for the energy industry are given in Popp (2001). Older knowledge constitutes a greater share of the total knowledge stock, $\lim_{s\to\infty}\left(1-e^{-\beta_2(s+1)}\right)=1$, but loses its novelty, $\lim_{s\to\infty} e^{-\beta_1(s)} = 0$, over time. It is explicitly assumed that the net addition of such knowledge from R&D to knowledge stock follows a life cycle as observed in (Popp (2001)). The net contribution increases rapidly during the initial years, peaks within a short time, and then shows a steep decrease followed by a modest decline. For this reason, changes in knowledge stock are significantly affected by the way the stock is initially assigned. As almost all contributions of R&D investment in a certain year last 10 years as knowledge stock, previous R&D observations are important components in the analysis such that data should not merely include the first R&D observation for the initial stock. Therefore, the time range of R&D observations is extended to the years preceding the observation.

Appendix III-C. Trend of government and private R&D in the electricity industry

Private R&D investment expenditures were obtained from "Business enterprise R&D expenditure (BERD)" in OECD structure analysis data (OECD STAN). The private R&D investment data was aggregated from electricity, gas, and water sectors (excluding sewage) by ISIC 4(International Standard Industrial Classification Rev.4). Note that the private R&D of U.S. is approximated values because it was not provide by same aggregation level.

Government R&D investment budgets were obtained from "Energy technology R&D budgets" of IEA. The budget categories which have more relation to the generation, transmission, and distribution of electricity were selected, which are 1) fossil fuel combustion & conversion, 2) renewable energy sources, 3) nuclear, 4) electric power conversion and electricity transmission & distribution.

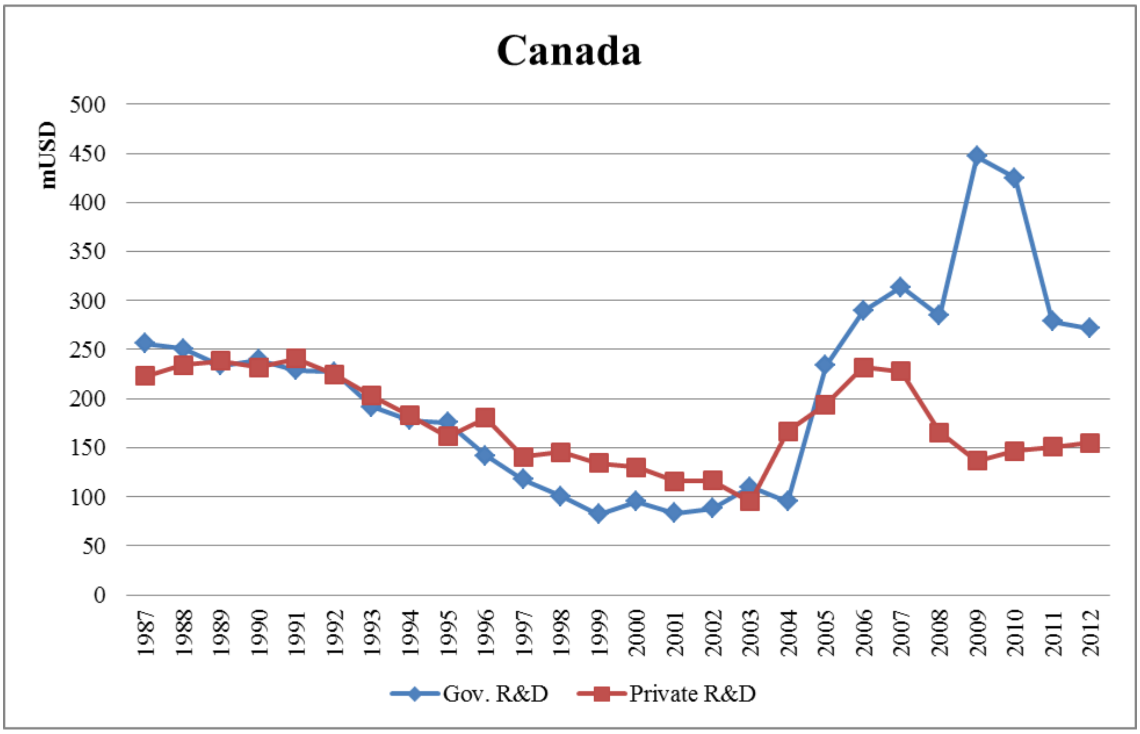

Figure III – C.1 : Government and private R&D of Canada

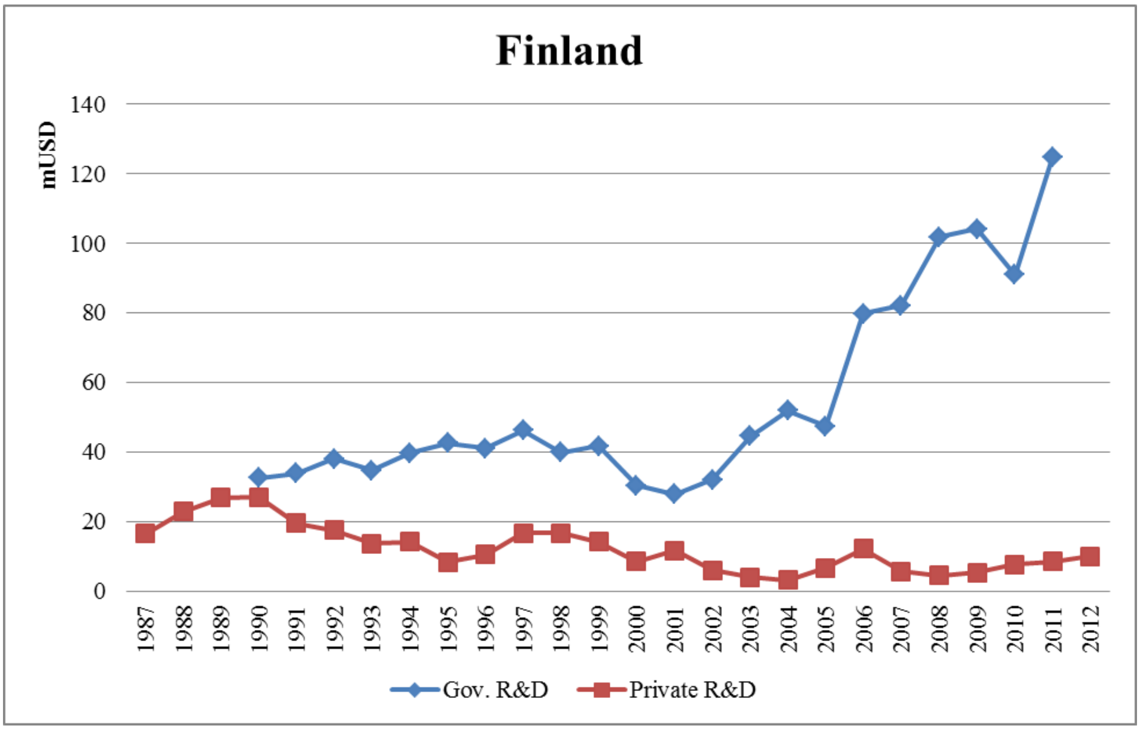

Figure III – C.2 : Government and private R&D of Finland

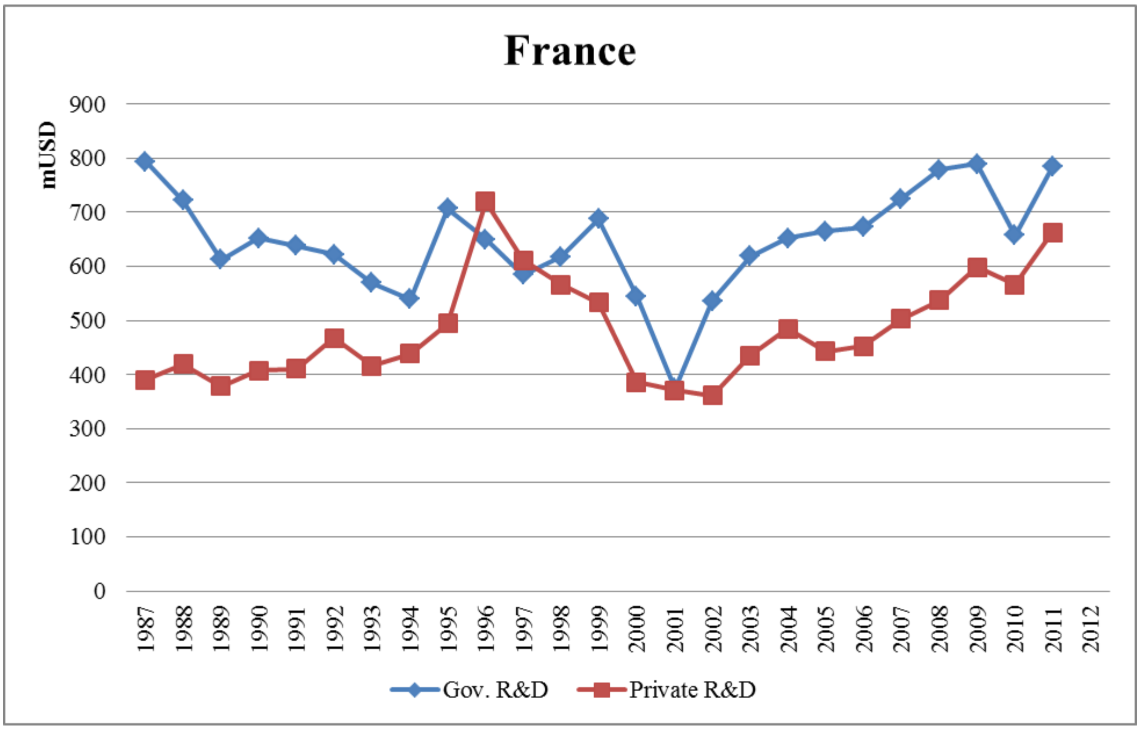

Figure III – C.3 : Government and private R&D of France

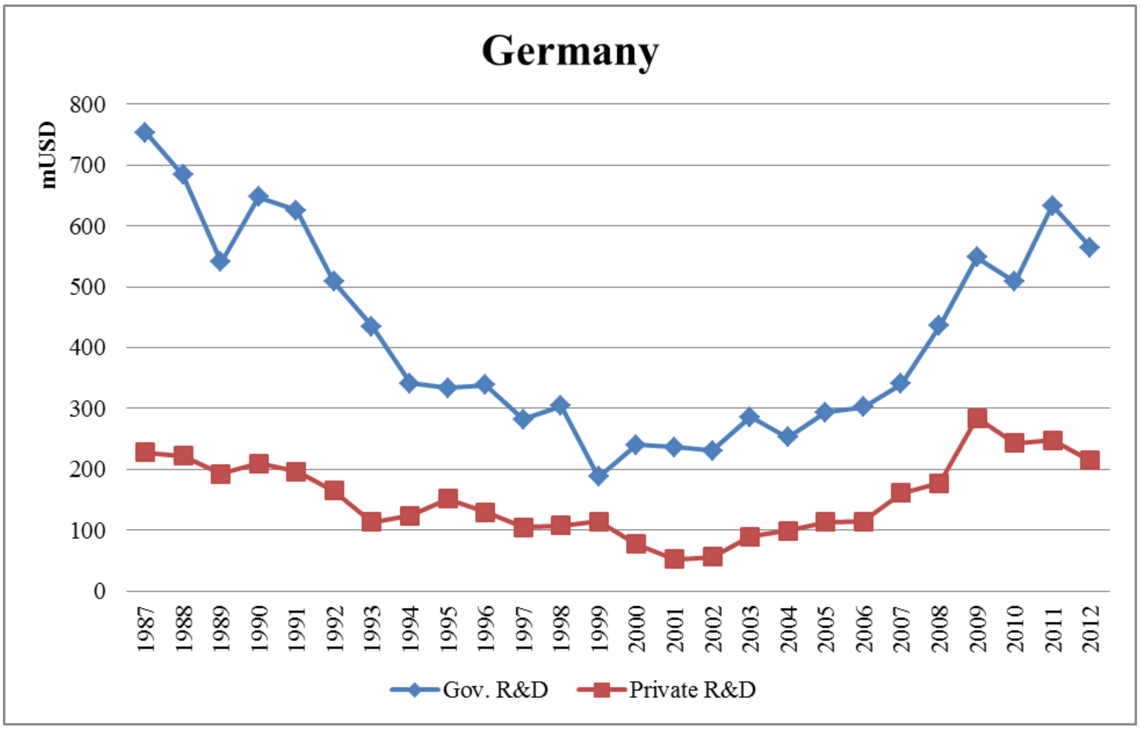

Figure III – C.4 : Government and private R&D of Germany

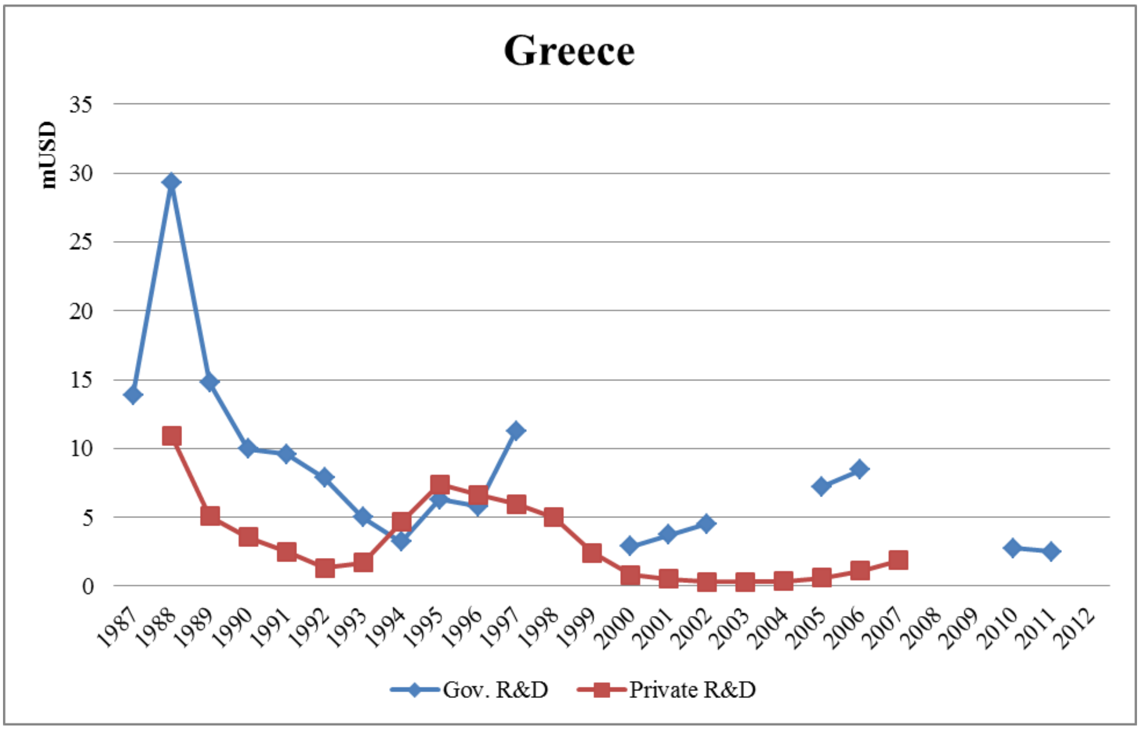

Figure III – C.5 : Government and private R&D of Greece

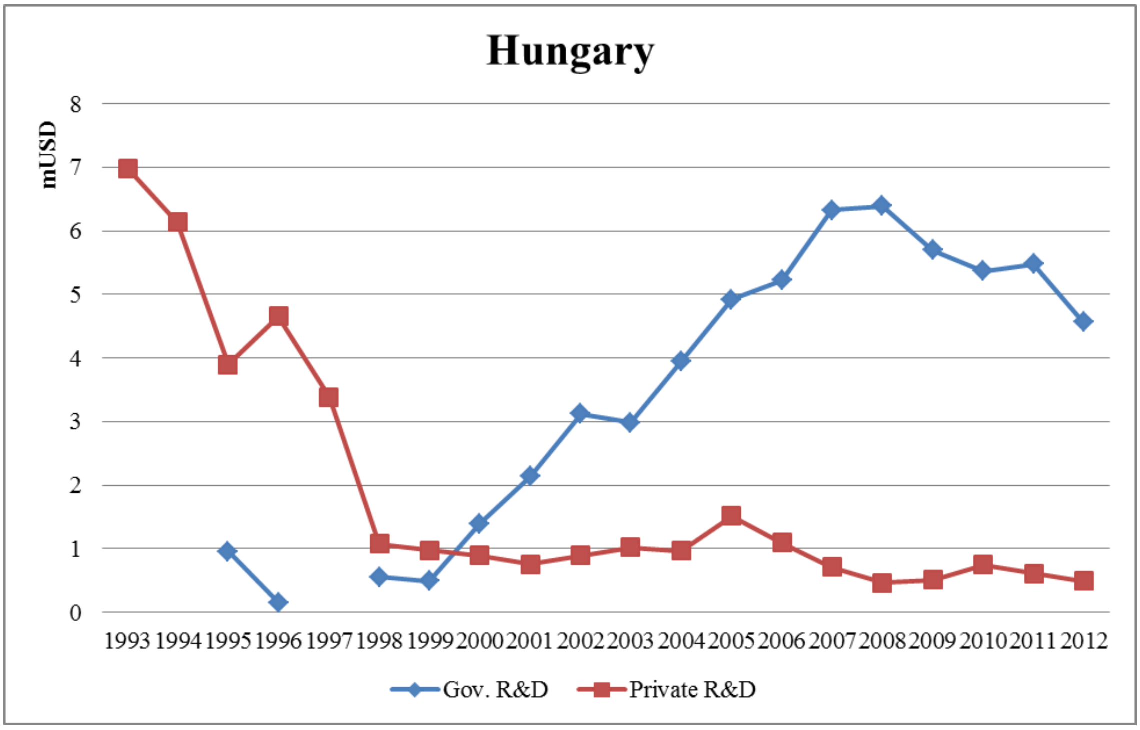

Figure III – C.6 : Government and private R&D of Hungary

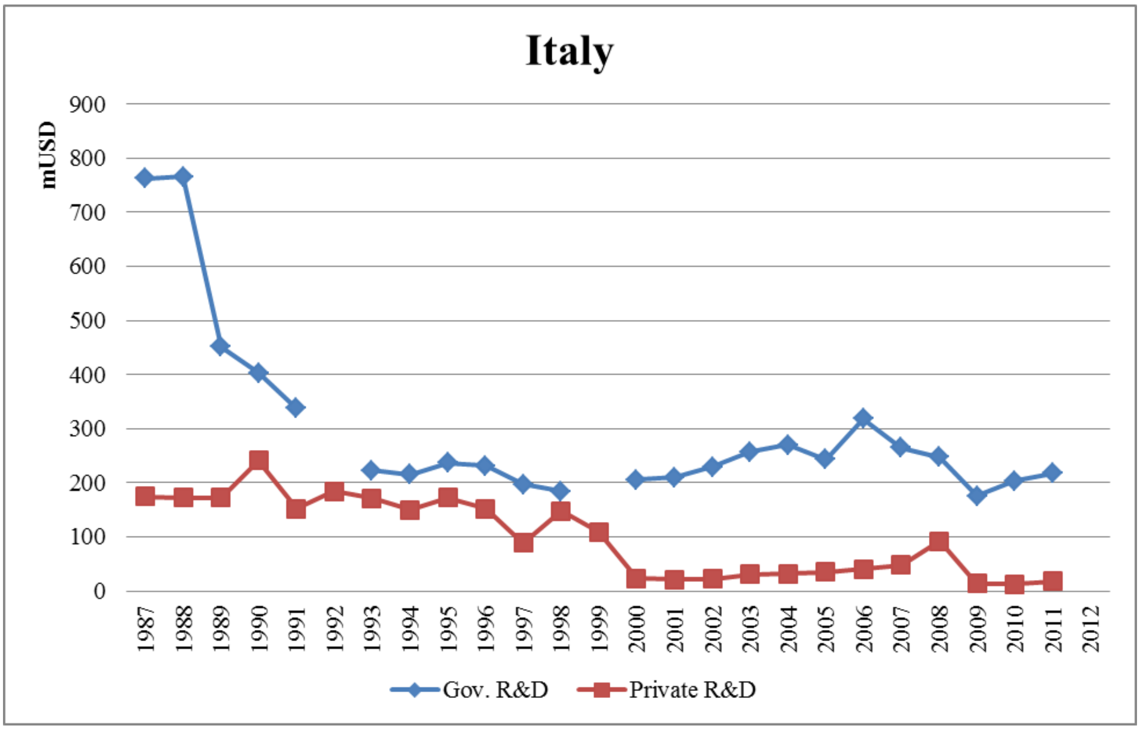

Figure III – C.7 : Government and private R&D of Italy

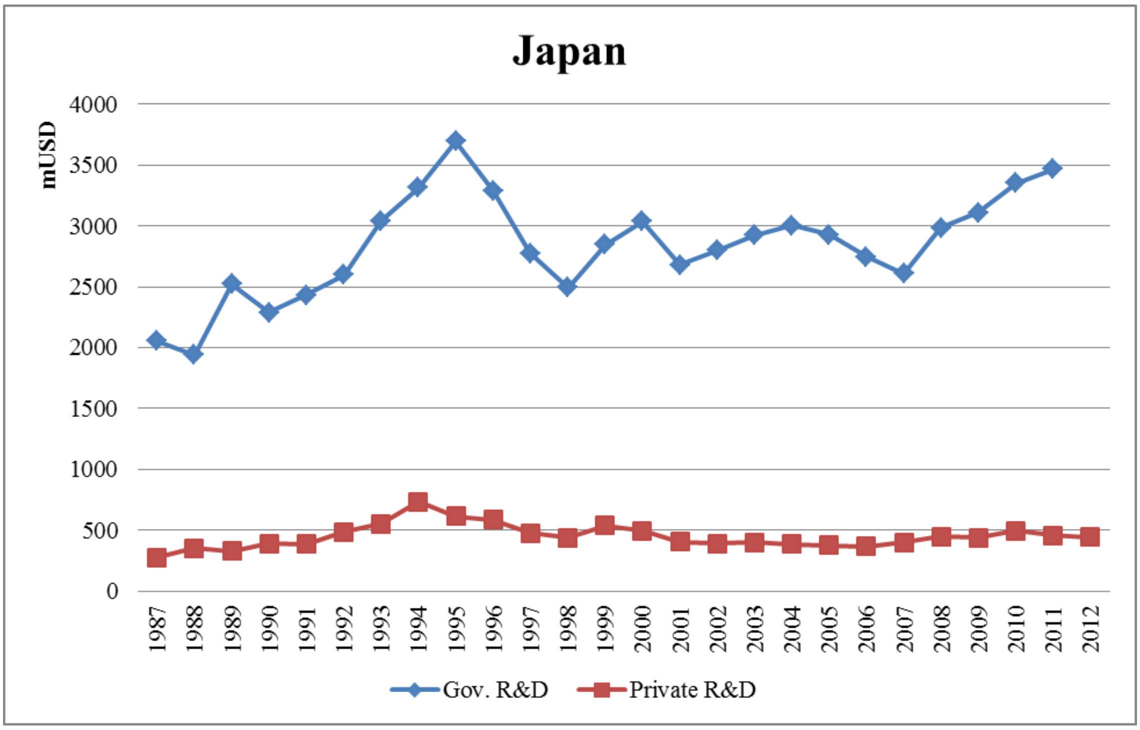

Figure III – C.8 : Government and private R&D of Japan

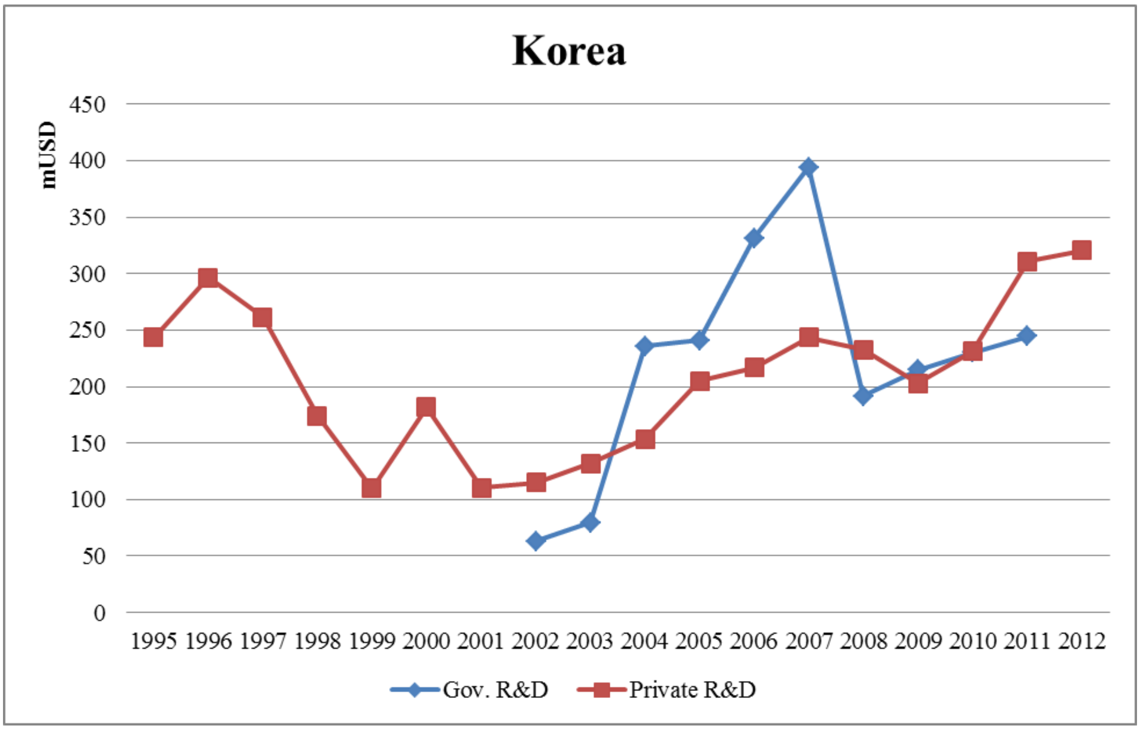

Figure III – C.9 : Government and private R&D of Korea

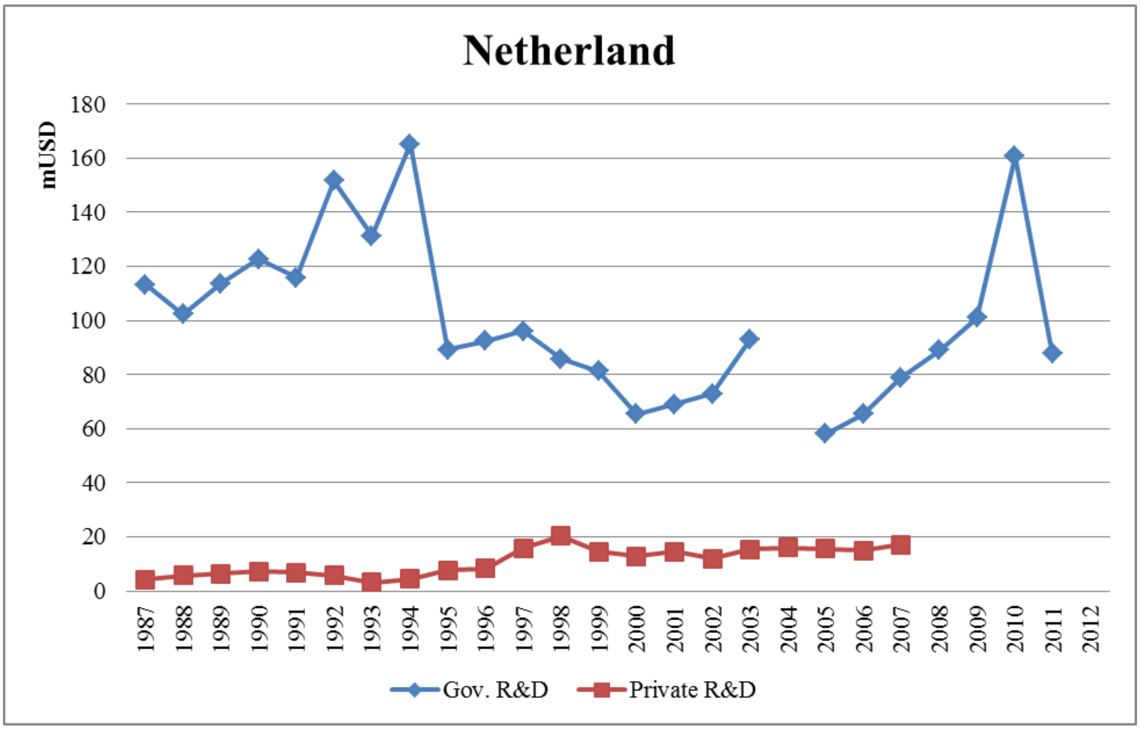

Figure III – C.10 : Government and private R&D of Netherland

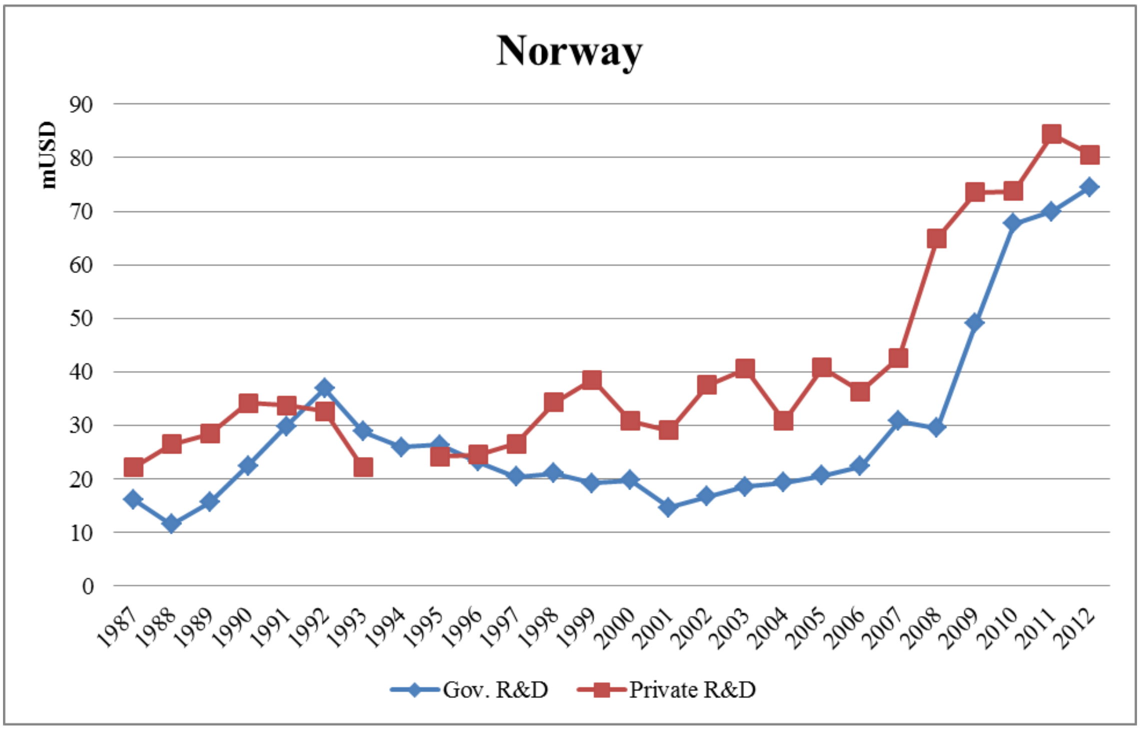

Figure III – C.11 : Government and private R&D of Norway

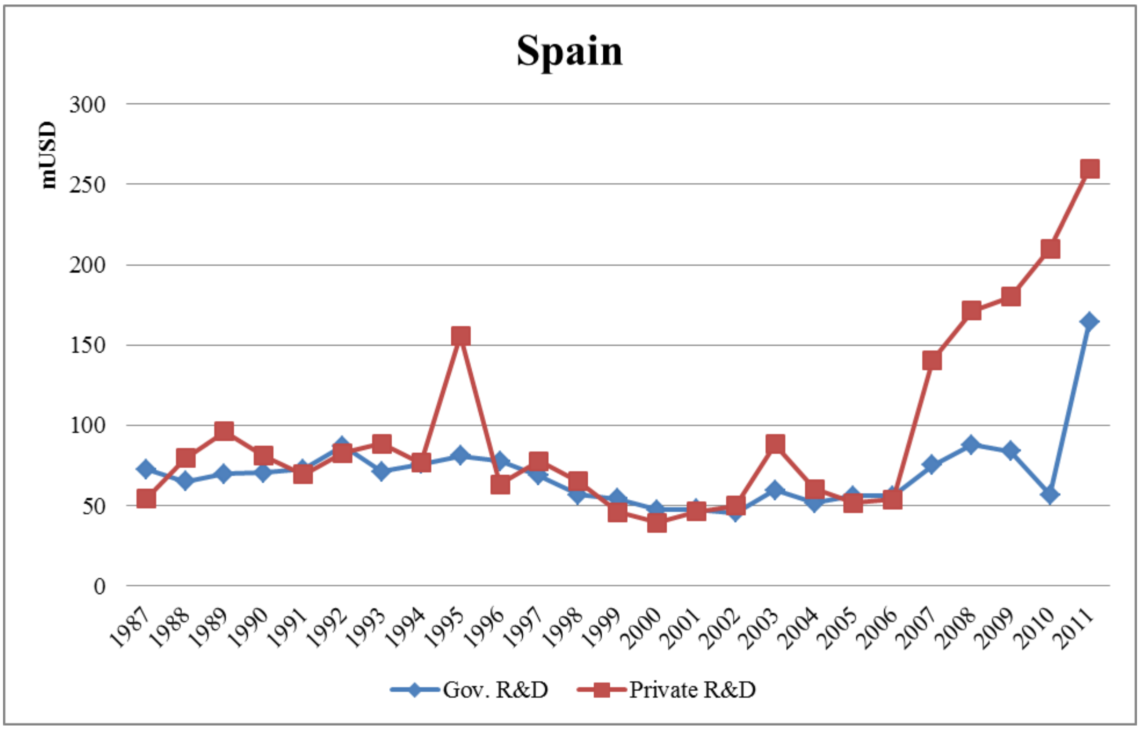

Figure III – C.12 : Government and private R&D of Canada

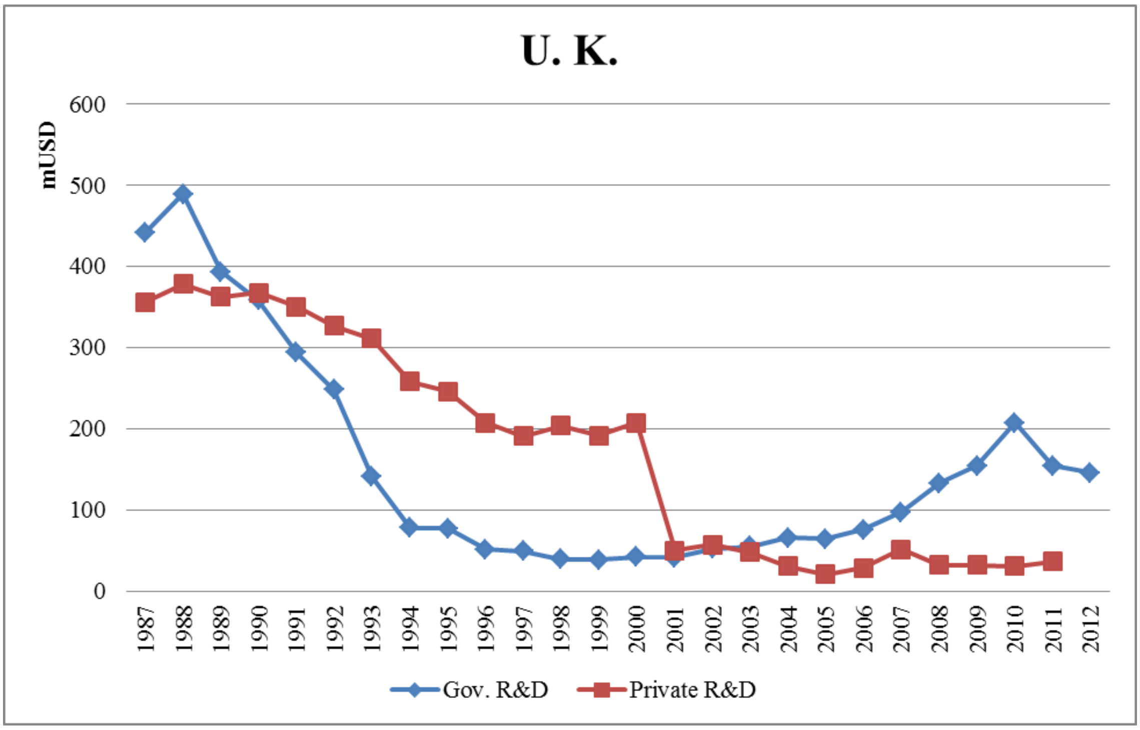

Figure III – C.13 : Government and private R&D of U.K.

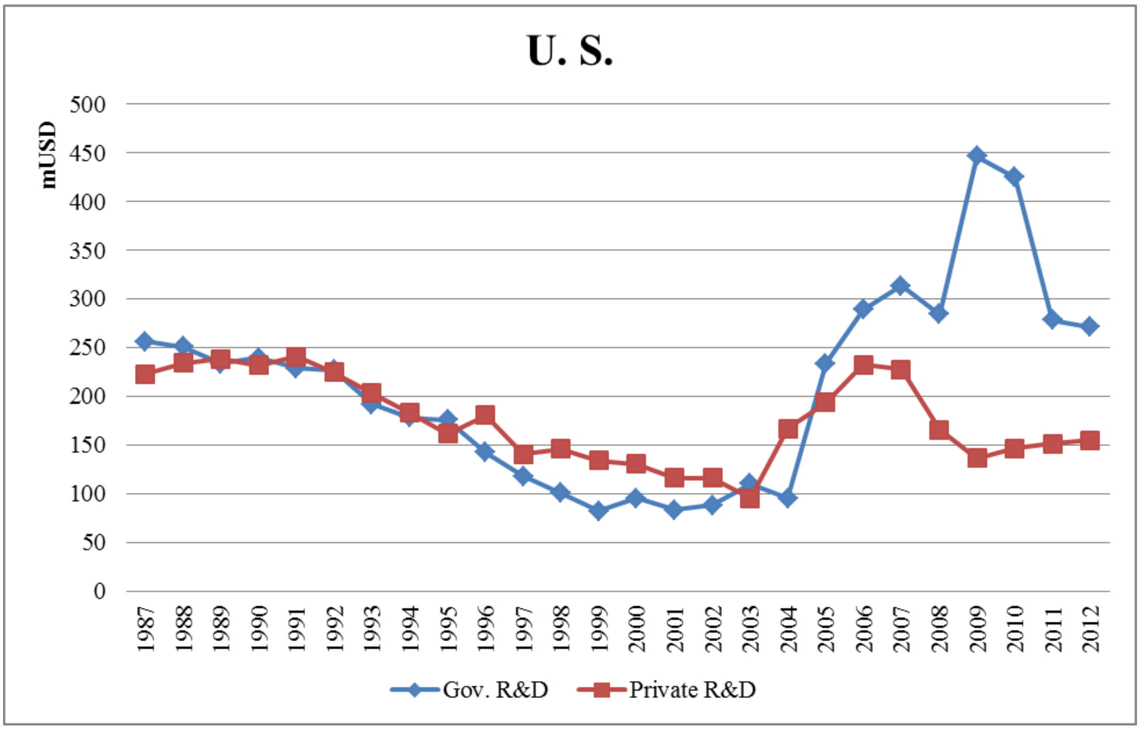

Figure III – C.14：Government and private R&D of U.S.

Abstract (Korean)

본 학위논문은 R&D와 제도적 변화가 산업의 경제적 성과에 주는 영향을 분석한 세 개의 에세이로 구성되어 있다. 이 주제는 지난 수 십 년간 많이 논의되어온 주제이지만, 본 논문들은 그 간 간과되어왔거나 탐구되지 못한 미답(未踏)의 주제들에 대하여 새로운 방법론을 적용하여 분석하고 있다. 첫째, 혁신주도성장의 기반이자 혁신의 시장실패의 원인이 되는 산업간 지식의 확산이 연구개발단계에 따라 어떻게 다른지 분석한다. 둘째, 혁신을 촉진하기 위한 기술에 특허권을 부여하는 지식재산제도가 혁신에 미치는 긍정적 부정적 영향을 분석한다. 셋째, 전력산업에 시장경쟁을 도입하는 전력산업 자유화가 혁신에 미치는 영향을 분석한다. 이 에세이들은 혁신의 내생적 특성을 고려하여 산업 경제성과를 평가하기 위한 통합적 모형을 수립하려는 일련의 연구흐름에 기여하고, 전통적 산업정책과 혁신시스템 정책의 조화를 이루는데 기여하는데 목적이 있다.

첫 번째 에세이는 기초연구와 응용연구가 산업 생산성과 혁신에 미치는 영향을 지식의 확산효과(spillover effect)에 초점을 맞추어 분석하였다. 지식의 확산적 성격은 혁신주도성장의 주요한 바탕이 됨과 동시에 혁신 창출에 있어서 시장실패를 일으키는 원인이 된다. 여기서는 생산함수와 연구개발투자식의 구조방정식을 통해서 기초연구와 응용연구가 자 산업 및 타 산업에 어떤 확산효과를 가지는 지를 분석하였으며 분석대상은 한국 제조업 18개 산업 1991~2009년 패널 자료를 사용하였다. 기존 연구들의 경우 기초연구 및 응용연구의 장기적 효과를 비교하는 연구들이 있지만 서로 다른 산업간의 확산효과의 차이를 다루고 있지는 않다. 기초연구와 응용연구의 산업간 확산 분석에 대해서 최초의 실증 연구이다. 분석결과 기초연구가 응용연구보다 훨씬 큰 산업간 확산 효과를 가지는 것으로 나타났다. 이는 기초연구의 중요성으로 보여주며, 확산효과를 고려하여 기초연구를 지원하는 혁신정책이 필요함을 보여준다.

두 번째 에세이는 지식재산권의 강화가 혁신과 산업성과에 미치는 영향을 분석

한 것으로서, 지식재산권이 강화됨에 따라 산업성과에 어떤 영향을 미치는지 그리고 혁신 유인이 증가하여 연구개발 투자가 증가하는 측면과, 지식의 활용에 독점권을 부여하여 추가적 혁신(sequential innovation)이 저해되는 측면을 비교 분석하였다. 산업별 특성에 따라 달라지는 효과를 관찰하기 위해 화학, 전자, 기계 세가지 산업에 대하여 분석하였으며, 12개국 1995~2005년의 패널자료를 구축하여 분석하였다. 분석결과 지식재산권은 일반적으로 산업 성과와 연구개발투자증가에 긍정적인 영향을 미치는 것으로 나타났지만, 더 많은 지식이 특허화될수록 지식재산권의 강화는 연구개발 투자를 감소시키는 것으로 나타났다. 지식재산권의 긍정적 효과는 비교적 이산산업으로 분류되는 화학산업에서 크게 나타났으며, 복잡산업으로 분류되는 기계 및 전자산업에서는 부정적 효과가 크게 나타났다.

세 번째 에세이는 전력산업 자유화의 장단기적인 효과를 비교 분석한 것이다. 대부분의 기존 연구들이 전력시장 자유화에 의한 단기적 가격 변화만을 분석하거나, 연구개발투자에만 초점을 맞추고 분석한데 반하여 시장경쟁체제의 도입으로 인한 시장지배력의 변화에 따른 정태적 효율성의 변화와 연구개발투자 변화에 따른 동태적 효율성 변화를 비교 분석하였다. 신경험적 산업조직론 방법론(New Empirical Industrial Organization, NEIO)을 확장하여 전력산업 자유화 지표들이 시장지배력과 연구개발투자에 미치는 영향과 장단기적 가격변화를 추정하였으며 분석대상은 1987~2011년 사이의 OECD 17개국이다. 분석결과 전력산업 자유화 과정에서 시장지배력과 혁신유인간의 상충관계가 발생하여, 자유화 정책의 부작용을 보완하는 혁신정책이 수반될 필요가 있는 것으로 나타났다.

주요어 : 혁신, 경제성과, 제도, 확산효과 , 지식재산권 , 전력산업 자유화

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