Ph. D. Dissertation in Economics

Macroeconomic Spillover Impact of Innovation Capability by Firm Size

기업규모에 따른 혁신역량의 거시경제적 파급효과

February 2015

Graduate School of Seoul National University

Technology Management, Economics, and Policy Program

Chanyoung Hong

Macroeconomic Spillover Impact of Innovation Capability by Firm Size

지도교수 이정동

이 논문을 경제학박사학위 논문으로 제출함

2015 년 2 월

서울대학교 대학원
협동과정 기술경영경제정책 전공
홍찬영

홍찬영의 경제학박사학위 논문을 인준함

2015 년 2 월

위 원 장 ____________________(인)

부위원장 ____________________(인)

위 원 ____________________(인)

위 원 ____________________(인)

위 원 ____________________(인)

Abstract

Macroeconomic Spillover Impact of Innovation Capability by Firm Size

Chanyoung Hong
Technology Management, Economics, and Policy Program
College of Engineering
Seoul National University

Small and medium enterprises (SME) have a key role in Korean economy; hence there have been many policy efforts to enhance the innovation capabilities of SMEs. However, it is not clear whether these policies had enough positive influence on the national economy. The degree of policy impact also has hardly been estimated. One of the main reasons for this is the absence of an appropriate analysis tool that quantitatively measures the effects of policy in terms of industry and national economic levels.

This study aims to find the analysis framework which enables the policy assessment regarding the promotion of innovation capability by firm size. The computable general equilibrium (CGE) model deals with macroeconomic phenomena including both the supply part of industry and the demand part of household and the government, thus it is expected to be useful for research goal if the innovation capability is introduced in the model.

In this respect, the knowledge-based CGE model, in which the innovation capability is reflected as a form of knowledge, is proposed and validated. In the model, knowledge is regarded as one of main factor inputs for production, and is treated as having a spillover effect on other sectors. The proposed model is proved to fit the past 15 years' real data better than standard model.

Then the policy for the enhancement of innovation capability is evaluated by firm size. For the analysis by firm size, the production section in the social accounting matrix is classified by firm size, and the R&D efficiency term is added to equation system. The policy is designed to decrease tax rate for research and development of firm. The results show that the support for large enterprises is better for economic growth in the case of applying the same percentage discount of tax rate, while the support for SMEs is better in the case of deducting the same volume of tax.

The second result implies that the priority of SMEs for the tax benefit is more efficient in terms of national economic growth, when policymakers have constraint in the amount of fiscal benefit by firm size. This result is derived mainly because SMEs have more linkage effect in knowledge enhancement and spillover than large enterprises. As a result, the policy for promoting innovation capability of SME can be said to cause better economic benefit through the increase in production and consumption. The proposed knowledge-based model is successful in deriving the macroeconomic impact quantitatively.

Keywords: Small and medium enterprise, Innovation capability, Spillover effect,

Tax incentive for R&D, Knowledge-based CGE model

Student Number: 2010-30274

Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1 Research background

Although there exist several criteria — in terms of sales, employees, and industry — to define Small and Medium Enterprise (SME) according to administrative standards, a firm with under 300 employees are generally referred to as SME. SMEs are important to consider when dealing with macroeconomic analysis, because they have major portion in national economics.

Based on a statistical perspective, SMEs account for 99% of total number of firms, 32% of exports, and 46% of production in the South Korean economy. In the perspective of its industrial role, SME comprises a basis of industry as a producer of components and materials. In the perspective of national economy, SMEs offer 88% of total jobs, which means that they are the sources of earned income and purchasing power.

Therefore, policy-makers may believe that SME deserves public support because of its importance in national economy. In reality, the new South Korean presidential administration that started in 2013 decided it as one of main policy projects to enhance the support for SME. As a part of this trend, the rate of budget increase for Small & Medium Business Administration was decided as 12.6% for 2015, which is double the average increase rate. The budget amount, 7.9 trillion won, is the highest one ever. The South Korean government expects that this policy result in the revitalization of economy through the enhancements of business activity and purchasing power.

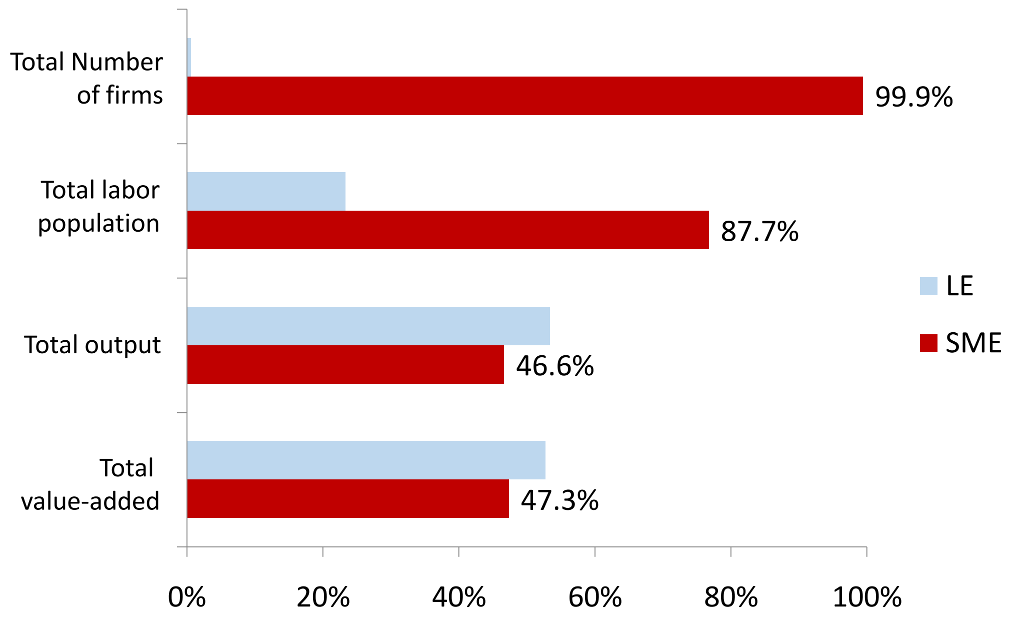


Figure 1. Status of SMEs in Korea

On the other hand, however, one may insist that the support for SME is not necessary and promoting large enterprise (LE) is more effective. Accordingly, pro-LE policies can be often found in some countries. For example, the South Korean government in the 1970s and 1980s experienced great success in economic development via intensive pro-LE industrial policies, and the belief in LE-oriented policy tends to be strong. The supporters of pro-LE policies think that LE has more effective technology than SME, thus the pro-LE policy can result in bigger and faster national outcomes.

Of course, that idea has reasonable grounds. Schumpeter (1942) pointed out that LE has the advantage in possessing resources for innovation, and Chandler (1990) argued that the economy of scale and scope acquired by mass production of LE brings the expansion of the market and national economy. It is true that the advantages of LE are more highlighted as globalization accelerates the effect of the scale and scope economy.

However, the decision between LE- and SME-oriented policies needs to be considered under the premise that the agent of business activity is the firm itself, not the government. The past industrial policy, especially in developing economies, assumed that government is an important agent in the growth of a firm and the industry. This perspective on government as a main agent has been losing its position, because it can restrict autonomous adjustment and the consequent progress of the market.

Even though environments such as institution, policy, and geography are regarded as the main factors in firm growth, as Acemoglu et al. (2001) argued, the role of government in business environment setup is only indirect. Since the operation of a firm is based on an entrepreneur's judgment, the direct and leading role in management is the firm's own. Therefore, the policy by firm size is eventually a matter of supporting which side of firm activity.

Among various aspects of firm activity, this study focuses on innovation capability. Innovation capability refers to the skill or knowledge through which one can absorb the existing technology and improve it to create a new one, as Lall (1992) summarized. In conventional analysis on industry, labor and physical capital were primary input factors, and firm growth was explained by the changes of these factors or their factor productivities. As industry advances, however, those factors are not enough to explain firm growth, whereupon skill or knowledge is regarded as another major factor for production. After Romer (1992) explained the endogenous growth of total factor productivity with knowledge, innovation capability has been recognized as a key factor for the growth of a firm and a country.

In this respect, the policy by firm size needs to be evaluated in terms of its impact on assisting the increase in firms' innovation capability. Many previous papers found that the characteristics of innovation capability are different by firm size, hence this study aims to investigate the macroeconomic impact of business-supporting policy by firm size, especially in the perspective of innovation capability. Even though SMEs occupy important portion of the national economy, they experience relatively more difficulties in forming innovation capability because of limits in resources. Accordingly, the relationship between innovation capability and its economic impacts is more doubtful in the case of SMEs. This paper analyzes the impact of policy by firm size, particularly focusing on SMEs.

1.2 Motivation

The South Korean government has continued policy efforts to enhance innovation capability of a firm. Since innovation capability is closely related to research and development (R&D), the statistics on R&D is a good measure for the effort in innovation capability. Governmental support for R&D can be classified by being direct (through providing subsidy) and indirect (through tax credit).

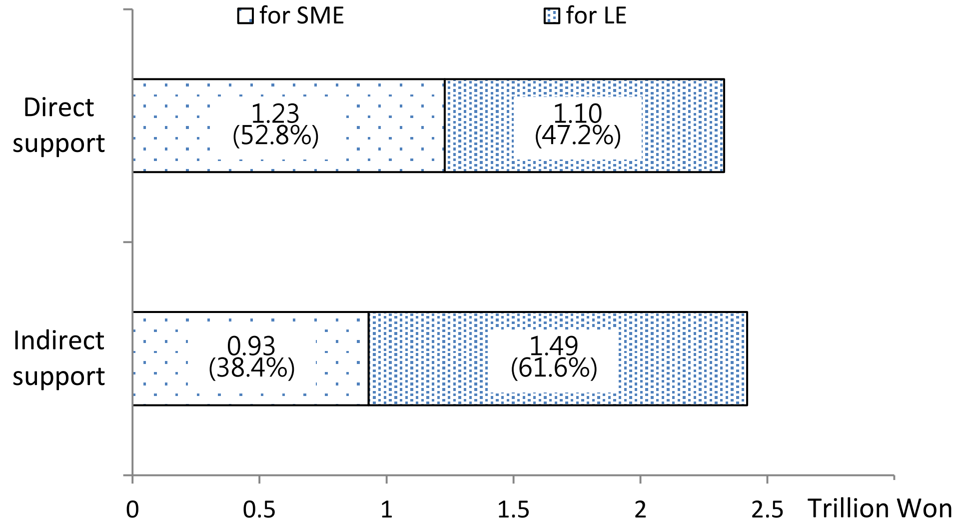


Figure 2. Governmental support by firm size in 2011

The direct effort for innovation capability can be estimated by using the annual data in Survey of Research and Development in Korea. According to the survey in 2011, the government spent a total of 13 trillion won for R&D activity, and 18% (2.33 trillion won) of that was subsidized for private firms. Of the 13 trillion won, 9.5% (1.23 trillion won) was for SMEs, while 8.5% (1.10 trillion won) was for LE.

The indirect effort for innovation capability can be found in *Statistical Yearbook of National Tax* by the National Tax Service. According to the data in 2011, total tax reduction was 29.6 trillion won, and 8.2% (2.42 trillion won) of that was for R&D activities. Of the tax reduction, 3.2% (0.93 trillion won) and 5.0% (1.49 trillion won) were beneficial for SMEs and LEs, respectively.

It cannot be said that the indirect tax credit was biased toward LEs, though they obtained more of tax credit. Total private R&D expenditure in 2011 was 38.18 trillion won, and the SMEs' share was only 25.5% (9.72 trillion won). This means that governmental tax credit policy is rather friendly to SMEs (Kim, 2013)

However, the effect of governmental support for innovation capability needs to be judged by its achievement in public interests. Even though current policy is relatively friendly to SMEs, it needs to be expanded if more benefit to SMEs is expected to bring more gains to the whole economy. If providing more benefits to LEs is expected to cause more growth in the entire economy, it would be better alternative. Therefore, the redirection of support policy for innovation capability needs to be evaluated based on its expected macroeconomic impacts.

Despite various methods of assessment, the policy by firm size tends to be considered under the characteristics by firm size. For example, SMEs usually have difficulties in financing, networking, and information-collecting, and thus the policy assessment for SMEs tends to focus on resolving the target problems. Surely, resolving the inevitable difficulties that originated from firm size may be policy means, but it needs not to be a final goal of policy. Because government is not an agent or assistor of a specific business group, the final goal of policy should be to address the interests of the entire economy although the policy may target specific groups.

In this perspective, it is necessary to suggest public criteria for the evaluation of a policy by firm size. As a solution for the policy of innovation capability, this study proposes a macroeconomic standard in the level of industry and national economy. This standard includes considerations of inter-industry relations.

The inter-industry relation is based on the mutual transactions among industries in the nation. As a car is composed of various electrical and mechanical components made from steel, plastics, and semiconductors, the final goods industry demands raw material or intermediate goods from other industries. Accordingly, the development of an industry is not just an issue of its own but an issue of other linked industries in the national economy. The analysis on an industrial level needs to incorporate this linkage effect.

As a result, when I analyze the effect of policies that promote innovation capability by firm size, it is necessary to introduce the criterion in macroeconomic level and significant to reflect inter-industry relations. It is because the internal and external characteristics of industry are the basis of a sound analysis of the national production system. Since it would be preferable if the analysis could incorporate the consumption aspect as a demand system, the computable general equilibrium (CGE) model may be a good solution that satisfies the above requirements.

The CGE model has the advantage of incorporating macroeconomic variables and agents, such as production, consumption, investment, savings, household, government etc. Moreover, it is a practical tool that enables *ex ante* simulation of macroeconomic variables by giving exogenous shocks to policy variables. However, the CGE model has been applied to specific areas such as trade, energy, and taxation; hence, it is relatively uncommon to incorporate innovation capability by firm size. This study will investigate whether the application of the CGE framework to the assessment of policy by firm size is feasible.

1.3 Research purpose

As mentioned in Section 1.1 and 1.2, the policy for the enhancement of innovation capability may be applied by the target firm's size, and the effect of the policy needs to be assessed in the macroeconomic scope. Accordingly, this study aims to analyze the macroeconomic impact of innovation-promoting policy for SMEs through the knowledge-based CGE model. The result will show whether the pro-SME policy is desirable for national economy, and whether the policy is beneficial to individual firms. The goal of this study according to the development of logic can be organized as follows.

First, the macroeconomic model for the innovation capability policy is constructed and validated. Though the CGE model is a proper tool for the research goal, practical implication can be acquired only from the model having good correspondence with real world. Therefore, the proposed model will be validated before its application to policy analysis.

Second, the macroeconomic impact of innovation-promoting policy by firm size is estimated. The results will quantitatively show the impacts in whole production and utility compared to those from counter policy. Because the role and status of SMEs will be varied by industry, the policy impact by industry will be also different. Therefore, the impacts on the industry level will be analyzed also.

The paper is organized as follows. Chapter 2 presents the previous studies on industrial policy, R&D by firm size, and the CGE model. Chapter 3 describes the detailed structure of a knowledge-based model, then Chapter 4 validates whether the proposed model is appropriate for the explanation of real economy, compared to the standard form of CGE model. Chapter 5 estimates the impact of R&D policy by firm size, according to the scenarios on tax incentives. Chapter 6 summarizes the above discussions and concludes with policy implications.

Chapter 2. Previous literature

2.1 Firm size and policy intervention

2.1.1 Historical context of industrial policy

Mainstream modern economy is based on the philosophy of laissez-faire. This means that demand and supply are naturally balanced by the principle of competition without any intervention. According to the theory, policy intervention for industries or enterprises had been regarded as needless in the academic field for a long time. But in many practical cases of developed countries, the examples of policy intervention for industry development can be easily found (Landes, 1970; Chang, 2002). After the Second World War, some developing countries also participated in adopting industrial policy, and academia began to have more in-depth discussion about the issue.

Since the 1950s, some developed countries implemented the industrial policy which led the mergers and acquisitions in order to promote growth and competitiveness in global market (Levicki, 1984). The efforts targeted firms whose sizes were more than certain degree. The principle was supported by classical logic of industrial organization theory which insists that firms over a minimum efficient scale are more productive. For example, French governments, until 1981 when President V. Giscard d'Estaing resigned, strongly pushed the industrial policy to raise national champions like Elf-Aquitaine and Air France.

The governmental interventions in developing countries were mainly done through import protection or export subsidy to protect their own infant industries. In the stage of entry to new industry, firms generally should endure large amounts of fixed cost, while there is insufficient demand yet. Accordingly, they are unable to expect profits and are reluctant to enter the industry. In this situation, the government can select some promising firms and make them enter the market through reducing actual costs along with offering subsidies. For example, in the 1970s, the Korean government made large investments to firms in heavy chemical industry. The national concentration on capital-intensive industry resulted in the establishment of a foothold for a leapfrog in economy afterward.

Those kinds of governmental policies were the targeted interventions that specified certain industries or a few firms in them. However, counterarguments for the targeted intervention were also raised. One of main reasons argues that the government cannot guarantee its choice of target industry or firm (Pack and Saggi, 2007). Government, just like an individual person, cannot obtain perfect information about market, so that government investment has a risk of failure. ICL in the UK, Bull in France, and Olivetti in Italy were publicly funded by government in order to compete against IBM, the dominator of computer market. However, now these companies are known as typical examples of failure (OECD, 2009). Moreover, in the case of developing countries, the government investment may act as a rent, so private firms have an aptitude to have rent-seeking behavior (Krueger, 1990)

As a result, many policy-makers and scholars after early 1980s agreed that non-targeted intervention is more desirable than targeted intervention (Aghion, 2011). The non-targeted intervention is related to the construction of circumstances where firms can freely behave. It also includes the encouragement of investment, reinforcement of patents, and liberalization of the market. In other words, it is related to the indirect support for all firms, not for some specified firms. This type of intervention is expected to cause a competition through the participation of multiple firms, while the targeted intervention intends to increase market concentration.

The intervention with passive meaning was largely supported in the 1990s and became the basis of the “Washington consensus.” However, the current worldwide recession raises a question about the rationale of it, and debates about it have been revived. Nevertheless, there exists a general consensus on the role firms as leading agents of economic activities and the necessity of competition among firms. Consequently, policy intervention is related to the coordination problem to assure the sound operation of the competitive environment.

2.1.2 Rationale of policy intervention

When dealing with the problem of competition among firms, it is important to remind that firms are heterogeneous. The heterogeneity covers several issues including firm age, productivity, and technology. Like in biology, the fittest survives through the competition among the firms with those varieties. As a result, a small number of firms are successful in gaining much profit and grow up to large sizes, while most other firms are operated with relatively small profit and size. If the principle of market competition works well, that status is said to be a natural result after optimal distribution of resources.

In reality, however, there exist some distortions of the competition principle with respect to firm size. The premise of the market economy is that the resources are distributed efficiently through the mechanism of price. However, the characteristics according to firm size may cause market failures that break this premise. In general, imperfect competition, externality, and uncertain information are mentioned as major reasons for market failure.

Imperfect competition is a situation when a few firms with market power can affect the level of the market price. That monopolistic or oligopolistic situation can be made not only by institutional system like patent, but also by natural process under economy of scale. When the minimum efficient scale, the threshold of lowering average cost, is formed with high level, the large firms having enough production capacity can artificially increase their production in order to drive out small firms. That is one reason why various kinds of regulations for large firms exist.

Externality and uncertain information are factors especially related to SME (Storey, 2003). For the externality, it is pointed out that there is no incentive to provoke positive externality. Even when it is obvious that there is positive externality, people do not want to participate because there is no reward for it. That results in smaller production than what is socially optimal. In this context, SMEs as main source of innovative ideas need to be encouraged, in order to gain a positive external effect in the national economy (Holtz-

Eakin, 2000).

The problem of uncertain information can be found in the capital market. Usually, individuals cannot have confidence in the success of a new business, and financial institutions are also careful with the returns from small business loans, which are riskier than loans to large firms. These kinds of insufficient information cause an unfair environment where investment is biased to large firms.

These reasons justify policy intervention by firm size. In particular, policy for SME is usually required more often than that for LE whose capacity for growth is already secured. Hence, many countries adopt policy for SMEs, but the degree of intervention differs by country. In the case of the U.S., despite the existence of public organizations (e.g., Small Business Administration) and programs (e.g., Small Business Innovation Research), the government claims not to intervene in business affairs including SMEs' (Dennis, 1999). That is, the U.S. government only supports indirect forms of intervention such as the protection of market rule.

Europe tends to be more generous with SME policy. The European Union regards the SME as a source of job creation and competitiveness enhancement. France and Scandinavian countries think that active policy intervention to support SME is necessary (Storey, 2003). This tendency is also found in the budget expansion of SME support projects under the Entrepreneurship and Innovation Programme after pro-SME policy agenda (Small Business Act for Europe) in 2008.

Korea has positively accepted SME policy. Total government support to SME was

13.7 trillion won in 2008, and the increase of tax incentive to SME jumped up more than 10 times during last 10 years (from 0.29 trillion won in 1998 to 3.46 trillion won in 2008). Particularly, the new government from 2013 promised to enlarge policy support for SME and have it as one of main governmental endeavors. Notwithstanding those policy efforts for SME, there are several ways of support having pros and cons respectively, thus the target area and method of support are still in the middle of discussions.

2.1.3 Types of policy intervention

Policy intervention for SME can be classified in various criteria such as goal, form, and properties. The Small and Medium Business Administration of the Korean government classifies the SME support program in nine categories: startup, technology, human resource, funds, export outlet, mutual growth, knowledge service, micro-enterprise, and other. According to this standard, the budget and ratio of the SME support policy of Korea can be summarized in Table 1 (NABO, 2012).

According to the budget in 2012, the policies with the biggest share are those related to funds (52.5%), technology (16.9%), and human resources (4.2%) (except “other”). They correspond to practical barriers of SMEs. In other words, SMEs in Korea have difficulties with funding, technology, and human resources. It is worth noting that “funds” has the highest percentage. Support of funding is divided into loans (4.9 trillion won) and credit guarantee funds (0.4 trillion won).

Table 1. Governmental projects for SME by support types

(Unit: million won, %, unit)

	Settlement in 2011		Budget in 2012		Budget in 2013		Variation	
	Amount (ratio)	Number of project	Amount (ratio) (A)	Number of project	Amount (ratio) (B)	Number of project	B-A	(B-A)/A
Startup	246,292 (2.5)	10	422,788 (4.2)	10	461,475(4.4)	16	38,687	9.2
Technology	1,618,930 (16.4)	40	1,705,627 (16.9)	39	1,666,253(15.8)	39	-39,374	-2.3
Human resource	602,729 (6.1)	23	637,199 (6.3)	24	452,441 (4.3)	15	-184,758	-29.0
Funds	5,406,364 (54.6)	42	5,295,612 (52.5)	41	4,976,750 (47.1)	39	-318,862	-6.0
Export outlet	146,679 (1.5)	27	155,884 (1.5)	26	271,300 (2.6)	30	115,416	74.0
Mutual growth	189,212 (1.9)	11	207,367 (2.1)	12	191,086 (1.8)	14	-18,281	-8.7
Knowledge service	138,304 (1.4)	17	142,808 (1.4)	17	68,586 (0.7)	9	-74,222	-52.0
Micro-enterprise	291,289 (2.9)	8	303,066 (3.0)	6	1,205,725 (11.4)	10	902,659	297.8
Other	1,260,519 (12.7)	27	1,214,389 (12.0)	28	1,273,343 (12.1)	28	58,954	4.9
Total	9,900,318 (100.0)	205	10,086,741 (100.0)	203	10,566,959 (100.0)	200	480,218	4.8

Here, when assorting the loans into operating and facility fund, it is seen that the share of operating fund is consistently increasing (Table 2). NABO (2013) pointed out that the share of operating fund surpasses that of facility fund in 2013. Operating fund is used for managing production processes, while facility fund is for constructing land or equipment. Therefore, Table 2 shows that public loans tend to be used for the short-term goals.

Table 2. Use of budget for SME Promotion Fund by government

(Unit: 10 million won, %)

	2010	2011	2012	End of Sep. 2013
Facility fund	20,606 (66.5)	19,314 (65.3)	18,917 (60.1)	12,857 (46.3)
Operation fund	10,377 (33.5)	10,251 (34.7)	12,576 (39.9)	14,936 (53.7)
Total	30,984 (100.0)	29,565 (100.0)	31,493 (100.0)	27,793 (100.0)

Note: numbers in parentheses are proportions

Resource: Small and Medium Business Administration (Oct. 2013)

The effect of financial support with short-term goal is negative in general. One may say that the trend reflects the weakness of the private financing system in Korea. Nevertheless, the role of the government as a financing institute is limited because the majority of financing is raised in the private sector. Moreover, the side effect, such as moral hazard of a beneficiary firm, is also reported. This means that a beneficiary from public financial support tends to be satisfied with the present condition and be dependent on the government. Finally, the performance of the beneficiary firm is not better than a non-beneficiary firm.

Therefore, the support for SME needs to be handled in the perspective of long-term vision. Here, long-term vision means the construction of an environment where firms survive independently through the enhancement of innovation capability and productivity. Among the nine categories of policy tools, the support for technology and human resources can be classified for it. In the case of Germany, most of public funds by the federal government are for technology innovation and educational training (Kim, 2014). Particularly, the support for technology is important for the following reasons.

R&D investment for the enhancement of innovation capability has characteristics of fixed and sunk cost. It is a big burden for the SMEs in the early phase of business, and may act as an entry barrier. The R&D activity and its commercialization is a very risky process, so that SME cannot help feeling difficulty in external funding. This is regarded as a reason for public support, together with the phenomenon of market failure.

Nevertheless, there are some opinions which oppose the direct support for R&D investment. First, the public funding for R&D may crowd out the private R&D activity of a firm (Howe & McFetridge, 1976). The R&D activity of a firm is subjected to a beneficiary project by the government, thus other research projects are constrained. Second, the selection problem can be found in the process of selecting beneficiary firms.

The original goal of public support is to strengthen the firms with low innovation capability and productivity. However, the government becomes to select relatively stronger firms in those characteristics among numerous applicant firms, and it contradicts the original purpose of support policy (Guellec & Van Pottelsberghe de la Potterie, 2003).

Therefore, the tax incentive began to attract attention as governmental R&D support policy. Tax incentive can be applied to all firms who perform R&D, so that a greater number of firms can be beneficiaries without discrimination. Because the policy of tax incentive does not require an evaluation process, the beneficiary firms do not feel the burden of administrative procedures. Of course, there is a disadvantage in the tax incentive system: it is *ex post* support after R&D activity. Accordingly, the firms who want R&D activity but do not have initial capital may be excluded. In spite of this disadvantage, the tax incentive is evaluated as an efficient policy because it is basically a market-oriented system since it induces the voluntary activity of a firm without any direct intervention (Hall & Van Reenen, 2000). As a result, the tax incentive for R&D activity is broadly adopted in many countries, including the U.S. and European countries.

2.2 Firm size and innovation capability

2.2.1 Firm size and R&D effort

Schumpeter (1942) triggered a discussion on the relationship between firm size and R&D when he presented the hypothesis that larger firms are more likely to invest in R&D.

He thought that larger firms have an advantage in R&D investment and technology innovation. As a result, he anticipated that most of innovative R&D would be conducted by large firms, while small firms are involved only in imitation work with low-technology. Though he emphasized the role of the entrepreneur as a creative destroyer, he thought that the ability of an entrepreneur can be most efficiently realized in a large firm with high market power.

Galbraith (1952) is another supporter of large firm with regard to innovation. He suggested some reasons why large firms are advantageous for innovation. He insisted that it is easy for large firms to obtain the economy of scale and scope. In addition, sufficient funding enables risk-spreading, and large firms usually have enough complementary assets like research organizations or facilities. As a result, he concluded that the role of large firms is relatively bigger in the economic growth of a nation (Galbraith, 1967).

Large firms are advantageous in innovation capability for the following specific reasons. First, the property of fixed cost in R&D investment causes economy of scale. In general, huge amounts of money are necessary in the early stage of development, so that a large amount of product can lead to profit margin through cost reduction. Second, the diversification of products and business cause the economy of scale and risk spreading. Various development projects naturally raise the probability of success. Innovation success in one product may be applied to another product as well. Furthermore, in large firms that produce many kinds of products, success in one project can compensate for the losses from other projects' failures (Acs & Audretsch, 2003). A high level of market power is also advantageous in controlling market uncertainty for innovative products. Third, organizational power causes complementary asset. Large firms usually not only have independent research institute with professional researchers, but also have service facilities that assist marketing or commercialization of innovative outputs. Those kinds of professional organizations facilitate innovation (Teece, 1986; Rothaermel, 2001).

As a counterargument for those opinions, the advantage of small firm in innovation capability is also insisted. First, bureaucratic environment in large firm is considered as a barrier to innovation. This environment lengthens the communication line in firm, and it may result in the preoccupation with incremental improvement rather than radical innovation (Link & Rees, 1990; Henderson & Clark, 1990). Second, personal payoffs for innovators are not big enough in large firms, which results in weak motivation for innovation (Sah & Stiglitz, 1988). Large firms inevitably are confronted with the agency problem which needs much cost to be resolved. In contrast, SME has enough personal incentive from innovation, thus more active R&D effort is often observed. Third, large firm don’t often want new innovation. In many cases, large firms are enjoying monopoly rents from previous success in innovation. Therefore, paradigm-shifting innovation has a risk to obsolete existing benefit (Arrow, 1962).

As the theoretical discussions about innovation capability and firm size progress, the empirical research has been studied since the 1960s. If larger firm has more advantages in innovation capability, the advantage of scale in R&D is expected to exist. Scholars have used regression analysis in order to find the relationship between R&D investment and sales. If the result says that R&D investment grows more than proportional to firm size, then it can be argued that there is an advantage of scale in R&D. In contrast, if R&D investment increases just proportionally to firm size, then it means that there is no special relationship between them.

Early studies reported mixed results. Horowitz (1962) and Hamberg (1964) reported a disproportional relationship between R&D and firm size. However, other studies found just proportional relationship between them (Worley, 1961; Scherer, 1965; Comanor, 1967). This means that Schumpeter's hypothesis is unrealistic. Nevertheless, some research discovered disproportionality in specific industries: the chemical industry is more than proportional (Mansfield, 1964), and the pharmaceutical industry is less than proportional (Grabowski, 1968), and some industries are more or less proportional (Soete, 1979).

However, about those reports, it was pointed out that the small sample size of data may cause selection bias. After the criticism on statistical limitation, research afterward extended the data size and controlled the industry effect. As a result, the majority of empirical studies showed similar results that there is proportional relationship between firm size and R&D effort, at least over certain threshold (Kamien & Schwartz, 1982; Bound et al., 1984; Baldwin & Scott, 1987; Cohen et al., 1987; Scherer & Ross, 1990).

Bound et al. (1984) used a panel data set covering about 2,600 firms in the U.S. manufacturing sector for about 20 years. They found that an elasticity of R&D with respect to sales is close to unity, meaning that the relationship between R&D and firm size is just proportional.

Cohen et al. (1987) used U.S. firm data that includes 2,494 business units in 244 manufacturing lines of business operated by 345 firms. They take into account both fixed industry effects and measured industry characteristics in their analysis. The results said that business unit size has little effect on the R&D intensity of the business units.

After a close review of previous papers on firm size and R&D, Cohen (2010) concluded that the proportionality between the two was robustly found in most studies. In summary, empirical studies are converged to conclude that there is no advantage of scale in R&D, in contrast to the hypothesis of Schumpeter and Galbraith.

2.2.2 Firm size and R&D efficiency

The relationship between firm size and R&D efficiency is about the question whether larger firm presents more innovative outputs. Innovative output means the number of patent or innovation obtained as a result of R&D activity. Research on the relationship was conducted in a similar context with former studies in Section 2.2.1. That is, there were two streams of discussion on the advantage by firm size.

One opinion insists that larger firm enjoys more return from R&D. This idea is derived from the economy of scale that spread the cost in R&D. Another reason is related with complementarities regarding R&D (Cohen, 1995). Large firms possess functional activities such as marketing and manufacturing capacity, which contribute to the return from R&D. In other arguments, large firms dominate in process innovation, which helps the increase in return from R&D (Legge, 2000).

Empirical studies supporting the logic above were also published. Link (1981) conducted regression analysis with data on U.S. manufacturing firms, and found the positive relationship between firm size and return from R&D. Henderson and Cockburn (1997) analyzed pharmaceutical firms and also found positive correlation. Tsai (2005) empirically studied Taiwanese manufacturing firms and reported a U-type relationship between firm size and R&D productivity. Focusing on the result from large firm data, he interpreted his result to mean that firm size is beneficial to R&D return.

However, the majority of empirical studies reported that the efficiency of R&D decreases with firm size (Cohen & Klepper, 1996). That is, the number of patent or innovation per unit dollar of R&D investment was estimated to be lower in larger firms (Bound et al., 1984; Acs & Audretsch, 1991). Moreover, many studies reported that small firms have disproportionally larger numbers of patent and innovation (Gellman, 1982; Pavitt et al., 1987; Acs & Audretsch, 1988; Graves & Langowitz, 1993).

The research by Pavitt et al. (1987) used a large dataset in the U.K. They investigated 4,378 significant innovations over a period of fifteen years, and classified them according to the number of employees in each firm. They found that the firms with fewer than 1,000 employees showed much larger shares in the commercialization of innovation compared to R&D expenditures. Innovation per employee was above average in the case of firms with fewer than 1,000 and also more than 10,000 employees.

Acs and Audretsch (1988) used a patented invention of the U.S. in 1982. They identified 4,476 innovations in manufacturing industries, and classified them by firm size and employee number. They found that the number of innovations increased with industry R&D expenditures, but at a decreasing rate. After some more test, they also concluded that industry innovation tends to decrease as the level of concentration rises.

Graves and Langowitz (1993) focused on the pharmaceutical industry. They used the innovative output of 16 pharmaceutical firms over 19 years. Their proposition was that increasing levels of R&D spending is counterproductive in terms of innovative output. The analysis result supported the proposition. They found decreasing returns to scale in R&D as the level of R&D expenditures rises.

There were also various discussions about the reasons for high efficiency in small business. One of most general views is related to pioneering entrepreneurship in SME. It is more distinctive in the sectors with high level of technological opportunity or appropriability. Other researchers explained the reason with informal R&D activity which is not counted in official statistics (Kleinknecht, 1987), or less bureaucratic environment (Link & Bozeman, 1991). Cohen and Klepper (1996) used the concept of cost spreading in order to offer a logical explanation for the inverse proportional relationship between R&D efficiency and firm size. In other words, larger firms can make more R&D investments because they can afford it through spreading the cost over large outputs, but this results in lowering the return from R&D per unit cost.

Though this kind of deductive reasoning may be helpful, the final conclusion needs to rely on empirical results because the logical theory has the limitation of being unable to perfectly explain firm behavior. Based on past empirical studies, the majority of scholars regard the decrease of R&D efficiency by firm size as a stylized fact (Rothwell & Dodgson, 1994; Cohen & Klepper, 1996; Ortega-Argilés et al., 2009).

2.3 Knowledge-based CGE model

2.3.1 Innovation capability and economic growth

The microeconomic analysis about R&D activity has been broadly discussed since the mention of technology innovation by Schumpeter (1912), but its relationship with macroeconomic analysis has a relatively short history. The theory of Romer (1990), which was called the new growth theory afterwards, became a milestone in growth theory; however, macroeconomic studies before him had focused on the explanation of technological progress.

Academic societies have been raised a question about the explanation of sustained economic growth with classical input factors of labor and capital. It naturally results in the effort of revealing productivity enhancement or, in other terms, technological progress. The basic explanation is that technology is assumed to be embodied in input factors. If a new technology is embodied in an input factor, the factor becomes different one in quality, hence the adoption of new technology means the substitution of a new input factor. The vintage model by Solow (1959) is based on this assumption.

Another simple explanation is that technology is assumed not to be embodied in input factors. Disembodied technology does not change the factor in quality. This means the change in total factor productivity (TFP), which enables more production output with the same factor input. The Solow model, the typical growth theory in the neoclassical school, explains the sustained economic growth only with technological progress. However, the models with embodied or disembodied technology assume technological progress to be exogenous, which is not a clear answer for the cause of technological progress.

The technological progress from endogenous reason was proposed in the “AK model” or its modified version, the “learning by doing” model (Arrow, 1962). The former incorporated human capital as a factor input other than physical capital and assumed the two channels of capital accumulation. The latter assumed the production function whose labor productivity is increased through production experiences in the past. With these methods, marginal return is not decreased, and economic growth is described endogenously.

In contrast with those explanations, Romer accounted for the technological progress of TFP in terms of R&D activity. His endogenous growth theory assumes the R&D sector which is separated from final and intermediate goods. In the R&D sector, new knowledge is developed to create new varieties of intermediate products. Here, TFP increases through knowledge spillover which assumes higher knowledge growth in more knowledge stock. In short, the process of knowledge creation and the spillover of knowledge are described in detail in the new growth theory, which is the difference between former growth theories.

Romer’s argument broke the typical assumption of technological progress as an exogenous one, and demonstrated it as a result of intentional effort. In this aspect, active effort on R&D became to have an important implication. The logic of technological progress and economic growth caused by knowledge from R&D activity has a more important meaning in this era of knowledge-based society.

2.3.2 CGE model and innovation capability

The CGE model is a macroeconomic explanation for the economic activities in a region or among nations through sets of simple equations. CGE analysis assumes the current economy is a result of specified system in the model. The current economic condition here refers to the input-output table which records annual transactions between industry producers. The CGE model uses the social accounting matrix (SAM), the extended version of the input-output table. In the CGE framework, the transactions in SAM represent the general equilibrium point in the target economy.

The CGE model has some of following characteristics. First, the CGE model assumes “equilibrium.” The equilibrium means the perfect balance in demand and supply in markets, and the maintenance of the state under no external disturbance. Although many modern economic theories do not agree with the concept of equilibrium, the typical theory on equilibrium has an advantage in its strict mathematical description. Under predefined assumptions, the equilibrium model in CGE assures the objectivity in analysis through its logical description and quantitative calculations.

Second, the CGE model assumes the “simultaneous equilibrium” in multiple markets. In the framework of partial equilibrium analysis, only the specified market is the target to analyze. In general equilibrium analysis, however, all commodities and factors including price system affect one another. Nevertheless, the affecting path of economic shock is not clearly appeared, and it is difficult to separate individual causes of an overlapped calculation. These difficulties are because multiple calculations coincide in the equation system, but the simultaneous reflection of multiple equations is a unique advantage in the macroeconomic modeling.

Third, CGE model involves comparative static analysis. In the perspective of the equilibrium framework, the economy in the equilibrium relocates to another equilibrium point when external shock is applied. According to this principle, one can look into the economic conditions that change after intentional economic shock such as a new governmental policy. To be specific, some policy variables are incorporated as exogenous terms in the equation system and then change the values of the variables. After recalculation for a new equilibrium point, one can evaluate the effect of policy change by comparing the values of target variables with past ones. Like this procedure, a researcher can conduct various simulations with multiple conditions in policy variables. It is regarded as one of the main advantages to select the best policy among many alternatives.

The above characteristics of the CGE model have turned out to be favorable in such fields as energy, environment, trade, and tax. However, the applications of the CGE model to the field of innovation capability were attempted since the end of 1990s. In those studies, there are two issues with determining how to incorporate knowledge or R&D as a proxy of innovation capability to the CGE model. One is the extraction of knowledge transaction in SAM, and the other is the equation system which relates knowledge to productivity.

The simplest method for the extraction of knowledge transaction in SAM is the assumption proposed by Terleckyj (1974). He assumed that the R&D expenditure is included in the transaction amounts in commodities or services. Therefore, he distributed the R&D expenditure of one industry according to the ratio of its sales to other industries. This reflects that the knowledge conducted in one industry can spill over to another industry.

Another method of extraction was proposed by Goulder and Schneider (1999) and Sue Wing (2003). They regarded the total output of some high-technology industries as the total value of knowledge in the economy, and they estimated the amount of knowledge investment. In their papers, the return from knowledge stock is represented by the return from high-technology asset, and the effort of enhancing knowledge stock is represented by the investment to high-technology asset.

The two methods above do not need additional data about knowledge, but Garau and Lecca (2007) proposed a more elaborate way to extract the amount of knowledge flow in the inter-industry transaction matrix. Referring to Evenson et al. (1988), they used the Yale technology matrix (YTM) which is based on patent data. In their model, they regarded YTM as a proxy of knowledge transaction, and estimated the amount by multiplying total industry R&D expenditure to each cell in YTM.

Besides the extraction of knowledge transaction, the logic of linking the transaction to macroeconomic system was more deeply discussed. Goulder and Schneider (1999) dealt with policy-induced technological changes as a main feature of their model despite a theme of climate change. They divided knowledge stock built by R&D into two classes: spillover knowledge (like public goods) and appropriable knowledge (like private goods). TFP was defined as a function of the former, but it was a simple linear function that changed into a constant in the long run.

The research that concentrated on R&D in the CGE model originated from Diao and his colleagues. They proposed a method of placing R&D into the CGE model based on the endogenous growth theory of Romer (1990). Their model separated differentiated capital, similar concept to knowledge, as an input factor produced through activity in the R&D sector. Preliminary work by Diao et al. (1996) made the productivity coefficient a constant. However, subsequent research by Diao et al. (1999) made the productivity change by the spillover effect, although it was limited to the R&D sector. This setup was in line with Coe and Helpman (1995); the embodied technology in imported goods induces international spillover of R&D, so that productivity grows. This method is also adopted by others like Ghosh (2007) and Lecca (2009).

Since Diao, research concerning the R&D-based CGE model have focused more on the implementation of TFP, with a few exceptions such as Bye et al. (2009) and Bor et al. (2010) who introduced exogenous factor-augmenting productivity. Visser (2007) assumed that the TFP change was affected by various elements in the R&D version of the Worldscan model from the Netherlands Bureau for Economic Policy Analysis. That is, TFP is changed by exogenous and endogenous causes, and the latter is a function of spillovers from three ranges: intrasectoral, intersectoral, and international spillovers. This model tried to accept multiple channels of spillover propagation from its own sector, other domestic sectors, and foreign sectors. Verbic et al. (2009) expressed TFP change with a regression equation using two variables: the share of nationally produced R&D in GDP and the share of foreign trade in GDP. This setup allows TFP to get positive effects directly from R&D production and foreign trade.

Zürn et al. (2007) did not express TFP with an explicit coefficient. However, they nested knowledge stock at the top level of the production tree, which means that the increase of knowledge augments the productivity of other input factors. This was a Hicks-neutral type of technology progress, which was also adopted in the R&D-based CGE model of Křístková (2012). In her following work, Křístková (2013) sorted the private and public R&D sectors. The R&D commodity in the public R&D sector was designed not only to improve the TFP of its own sector, but also to have spillover effects on private R&D sector.

The foregoing studies individually proved that R&D-related policy can be analyzed by incorporating R&D as an element in the CGE model. The researchers had different ways of implementing R&D. For example, some did not separate the R&D account in SAM, while others designed their own channel of the spillover effect to production technology. Whatever the differences are, those methods showed that it is possible to analyze R&D issue in the framework of general equilibrium. In this respect, dealing with R&D in the CGE model is novel because most analyses on the economic impact of R&D belong to partial equilibrium approach.

Particularly, the R&D-based model has advantage in explaining TFP growth. Recent discussions on economic growth accept that TFP is one of main reasons for economic growth. TFP is a residual that cannot be explained by input factors and represents the productivity of the production process. TFP covers all possible explanations, including industrial structure, law, and institutions. However, Griliches (1973) and Terleckyj (1974) proposed a relationship between TFP growth and R&D activity. Later empirical studies have reported a positive correlation between R&D activity and TFP growth. This means that countries eager to invest in R&D show long-term increases in their TFP. Figure 1 exhibits the last 20 years of TFP trends for certain Organization for Economic Cooperation and Development (OECD) members, based on calculations from the OECD Productivity Database[1].

---

[1] This productivity calculation is based on all other factors except labor and capital. Detailed methodology is described in OECD (2004).

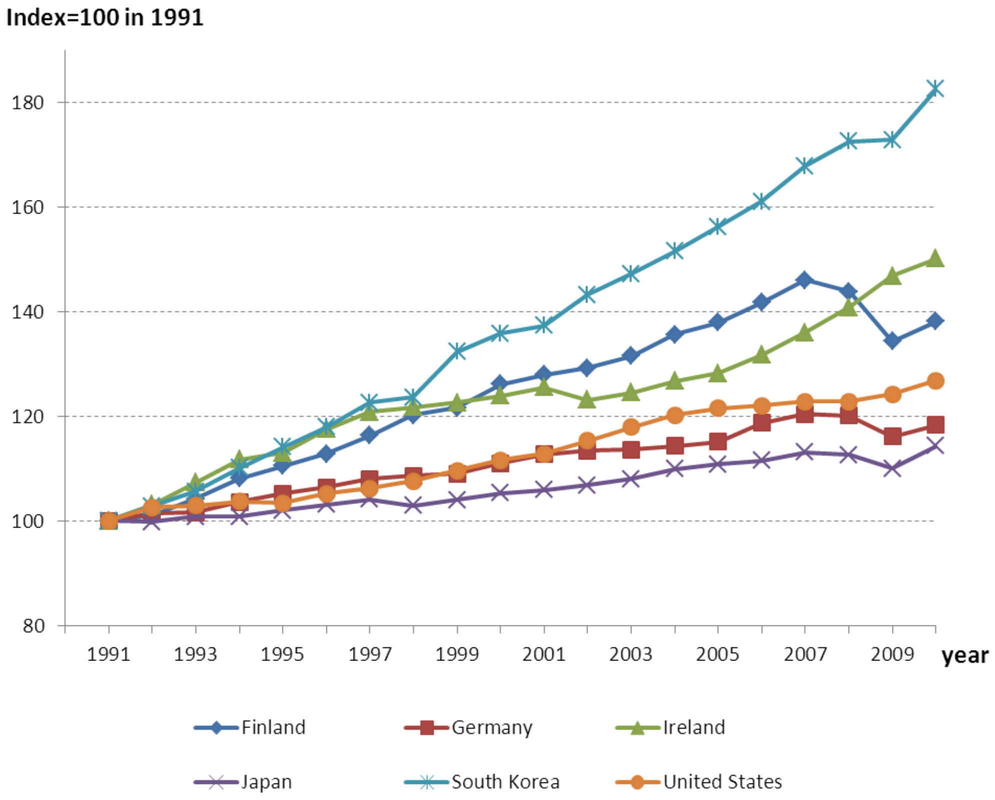


Figure 3. Trends in TFP growth

Although TFP is growing from a long-term perspective, ordinary CGE models assume the TFP coefficient as a fixed number in the process of calibration. This is appropriate in either the case of nations with relatively low TFP growth or the case of analysis with short-term impacts. However, if one faces other cases, such as fast TFP growth or long-term analysis, neglecting TFP changes could lead to a distortion in the results of the analysis.

Eventually, for the countries with high degree of knowledge economy, the description of R&D in the macroeconomic model can be regarded as an essential part for the feasibility of analysis.

2.4 Contribution of this study

In Section 2.1, the needs for policy intervention for SMEs were discussed. In particular, the support for innovation capability, in terms of long-term perspective, is more significant than short-term financial support. Because of its small size, SMEs usually have several restrictions in conducting R&D: lacks of financing, technological resources, and support service. Among the restrictions, the limited investment in R&D due to its high cost is considered to be one of main barriers to technological development of SME. Therefore, tax incentive can be an effective way to enhance innovation capability, because it benefits all R&D-performing firms without discrimination. Nevertheless, it is questionable whether R&D investment for SMEs is more effective in the national level compared to LEs.

Accordingly, Section 2.2 investigated two stylized facts; there is no advantage of scale in R&D effort, and the return of R&D is inversely proportional to firm size. The two findings imply that the R&D activity of SMEs is not inferior to that of LEs. Rather, R&D effort of SMEs is important and indispensable when considering both SMEs' contributions to the continuity of innovation through challenging entrepreneurship and their roles as suppliers in the industrial value chain (Torres-Fuchslocher, 2010). The innovation capability of SME vitalizes the national economy and reinforces the internal structure of industry. However, even though the innovation capability of SME is expected to be positive for national economic growth, it is still unclear how much the effect will be.

Section 2.3 showed that the CGE model is a suitable tool for quantitatively investigating the effect of policy shocks on the macro-economy. The CGE model can explain the interrelation among macroeconomic variables in the national economy system covering transactions of economic agents, industries and international trade. If R&D terms can be incorporated into the CGE model, the process of driving industrial and national economic growth by firm's innovation capability can be formalized. The so-called knowledge-based CGE model is expected to numerically calculate the effect of policy for enhancing SMEs' innovation capability on economic growth.

Although some kinds of knowledge-based CGE models have been discussed in recent years, they have some problems that need to be resolved before using them to measure the effect of innovation-supporting policy. First, it has not been verified whether the knowledge-based CGE model is adequate to explain real economic phenomena. Although some research attempted to verify the standard form of the CGE model, the knowledge-based CGE model has not been targeted. Verification of a CGE model has to precede in order to guarantee practical meaning of policy effects, so the verification of the knowledge-based model is prerequisite to subsequent discussions with the model.

Second, the distinction by firm size has not been adopted in CGE models. The CGE model is based on the input-output table which classifies the production part by industry sector. Although some papers tried to subdivide the industry sectors by firm size according to their research goals, they stayed at input-output analysis, not applying it to CGE analysis.

Therefore, this dissertation constructs a knowledge-based CGE model and verifies it with real data. The model is then varied in order to be applied to analysis by firm size. Finally, the macroeconomic impact of support policy that enhances innovation capability is analyzed according to firm size. In particular, tax incentive for R&D activity will be designed to be biased to either SME or LE, and the consequent results will be compared.

Chapter 3. Structure of knowledge-based CGE model

3.1 Knowledge-based SAM

R&D activity has generally been regarded as an investment because it is conducted to create future income. However, the capitalization of R&D expenditure requires asset valuation, depreciation rate, time lag, and double counting as prerequisites. These practical difficulties made the 1993 version of system of national accounts (SNA) treat R&D spending as a current expenditure that is used up in the production process. In contrast, the new 2008 SNA expands the range of fixed assets[2] and clarifies how to handle R&D spending for fixed-capital formation.

The SAM used in this study accepts the recommendation of the 2008 SNA to have an additional account for knowledge capital. While there are some previous studies that include a knowledge account in the SAM, they had assumptions on R&D due to the limitations of extracting knowledge transaction. For example, Sue Wing (2003) chose some industries with high R&D intensities and assumed these to be the only sectors conducting R&D. While Ghosh (2007) assumed that the transaction structure of knowledge capital is the same as that of physical capital, Lecca (2008) indirectly estimated knowledge transactions based on the Yale technology matrix built with patent

[2] The 2008 SNA enhances the concept of fixed assets by including intellectual-property products like software, R&D, entertainment, and literary and artistic originals.

data.

The reason for these specific assumptions is that the researchers had trouble identifying the sector for R&D commodity production. Hence, their attempts have the limitation of probable distortions in the real transaction of knowledge. This study adopts a knowledge-based SAM made by the method of Yang et al. (2012) which needs no specific assumptions for the knowledge transaction.

The South Korean official input-output table by Bank of Korea (the central bank of South Korea) also treats R&D expenditure as intermediate consumption according to the 1993 SNA. However, Yang et al. (2012) found that the Korean input-output table separates the R&D production sector from other sectors when looking at the most-detailed sector classifications (402 kinds) in the table. This enabled the researchers to identify the inter-industry knowledge transaction between the R&D production sector and the others. Therefore, the knowledge capital account can be extracted without any assumptions about the sector for R&D commodity production.

Table 4 shows the final form of the knowledge-based SAM that is used in the knowledge-based CGE model presented in this study. The cells with diagonal stripes include values, while the white cells do not. Compared to the standard SAM, this type of SAM has two additional accounts: “knowledge” in production factors and “knowledge capital formation” in investment (green-shaded cells). The latter is subdivided into private and public capital. While the 2008 SNA defines the intangible asset of intellectual property to be included in the existing account of physical capital formation, this study separates the knowledge capital account from the physical capital account in order to measure the economic effect of R&D investment.

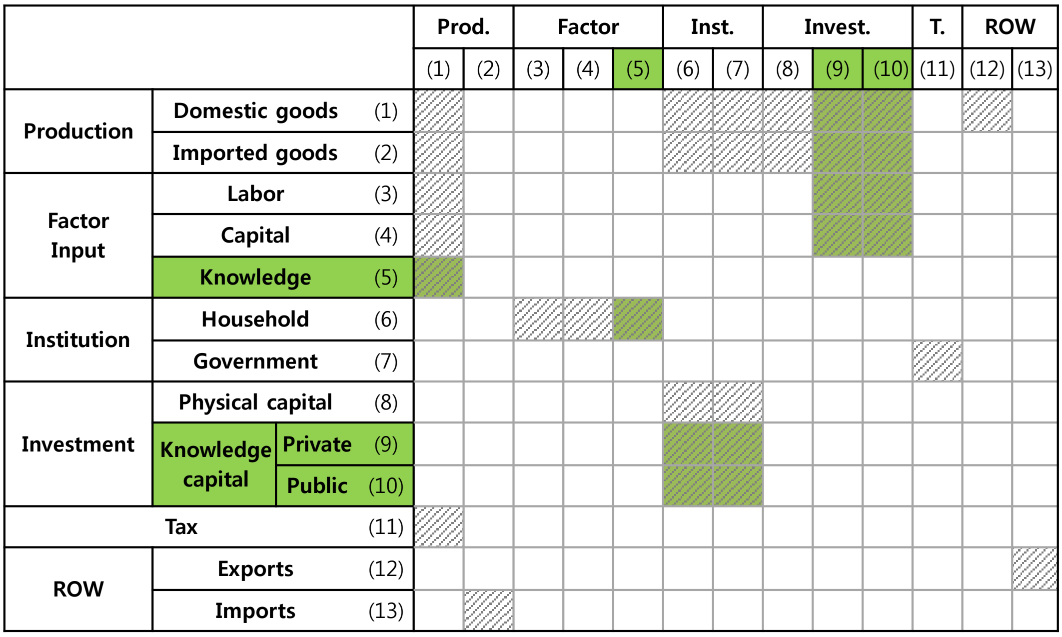


Figure 4. Structure of knowledge-based SAM

Transfer of R&D transactions

There are two stages for the procedure of allocating proper values in newly added accounts. In the first stage, the rows of R&D sector, which were originally contained in the partial matrix of production, are moved to the account in factor input. R&D was handled as intermediate goods before, but, according to this process, now it is regarded as factor input for the creation of value added. In the second stage, the columns of R&D sector, which were contained in the partial matrices of production and physical capital investment, are moved to the new account in knowledge capital investment. R&D was handled as a consumer of other sectors' commodity before, but now it is regarded as an investment to accumulate knowledge stock. These procedures are briefly described in Figure 5.

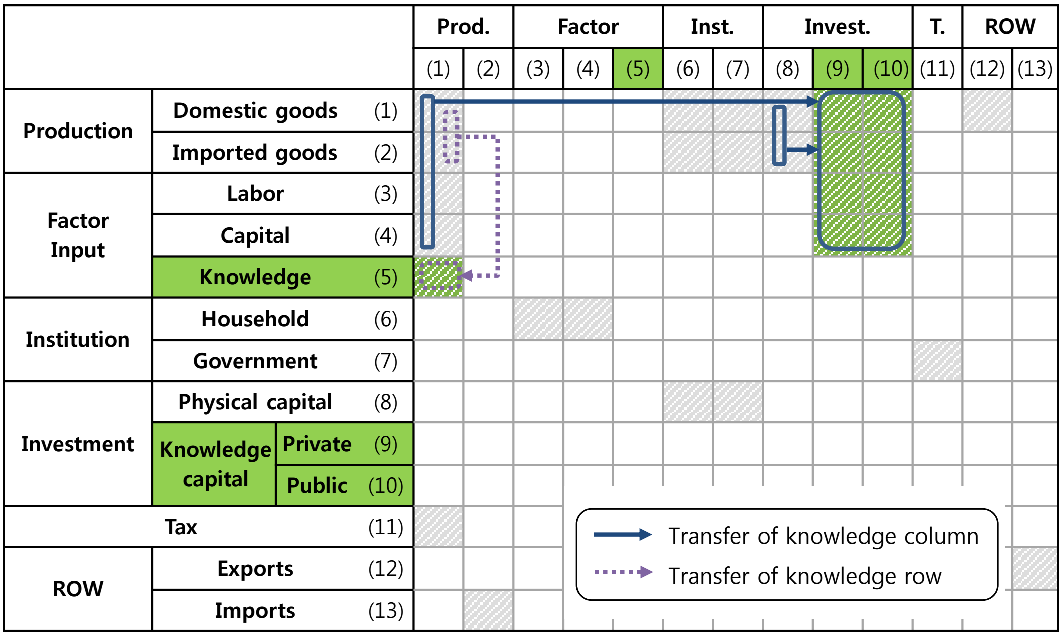


Figure 5. Transfer of rows and columns related to knowledge

In the first stage, the sectors which are related to knowledge are identified. In the third level of classification of the Korean input-output table, "Research institute" (#148) and "R&D in enterprise" (#149) are separated as independent accounts. The input-output table regards these two sectors as industries that produce R&D commodity. Accordingly, the values in the rows indicate R&D expenditures of other sectors. In the perspective of knowledge-based SAM, the values are payments for the input factor called “knowledge.”

However, the recognition of the final amount of the values depends on the agent who spent it: the market producer (private) or the non-market producer (public). In the case of market producer, the entire transaction amount is recognized as paying for value added. In the case of the non-market producer, however, only the depreciation of knowledge is regarded as paying for value added. This occurs because there is no operating surplus in the public sectors. According to the fourth (most-detailed) level of classification in the input-output table, non-market producers include 13 sectors: “research institute” (#357), “non-profit research institute” (#358), “central government” (#372), “local government” (#373), “public educational institute” (#374), “non-profit educational institute” (#375), “public medical institute” (#377), “non-profit medical institute” (#378), “public social welfare service” (#380), “non-profit social welfare service” (#381), “public sanitation service” (#382), “public culture service” (#386), and “non-profit other social organization” (#394). The sectors other than those are recognized as market producers.

In the second stage, the transactions of knowledge are identified based on those of “Research institute” (#148) and “R&D in enterprise” (#149) just as in the first stage. The values in those columns indicate the use of other sectors’ products in research activity. Therefore, they can be regarded as utilization for the capitalization of knowledge.

However, not all the values are recognized as capitalization, because 2008 SNA recommends that expenditure for the sake of sales or profit is regarded as intermediate consumption. Accordingly, among the expenditures of the two sectors, the expenditure by the market producer needs to remain in intermediate transaction. According to the fourth level classification of the input-output table, “research institute” (#148) is subdivided into “public research institute” (#357), “non-profit research institute” (#358), and “commercial research institute” (#359), while “R&D in enterprise” (#149) is reclassified into “R&D in enterprise” (#360). Therefore, only three sectors (#357, #358, #360), not including the “commercial research institute” (#359), are moved to the new account of “knowledge capital.” Among the three, “R&D in enterprise” (#360) is allocated in “private”, while “public research institute” (#357) and “non-profit research institute” (#358) is allocated to “public” knowledge capital.

Moreover, there are spending for physical capital even in R&D expenditure. The amount is already counted in existing account of “physical capital.” Therefore, some portions of the physical capital account, which is related to R&D, need to be extracted and moved to the knowledge capital account. Physical capital is classified into three types: “machinery”, “land and building”, and “computer software.” The R&D expenditure for each type needs to be estimated.

For the “machinery”, it is assumed that R&D expenditures include five sectors: “general machinery and equipment”, “electronic and electrical equipment”, “precision instruments”, “transport equipment”, and “furniture and other manufactured products.” For those sectors, the Survey of Research and Development in Korea by the Korean government offers the data on R&D expenditure. The R&D expenditure in “machinery” type of physical capital can be obtained by multiplying the obtained ratio with the values in physical capital.

The same method is applied to the two other physical capital types of “land and building” and “computer software.” “Land and building” is identified by the “construction” sector, while “computer software” is done by the “real estate and business service” sector. The estimated values in the three types are subtracted from the physical capital account and added to the knowledge capital account.

Additional terms

The adoption of the accounts related to knowledge leads to the addition of new terms in SAM. Basically, the knowledge account in factor input means paying for the provision of knowledge. It causes the additional income of the household. Moreover, the knowledge capital account in the column indicates a new type of investment. It causes the corresponding savings in the row.

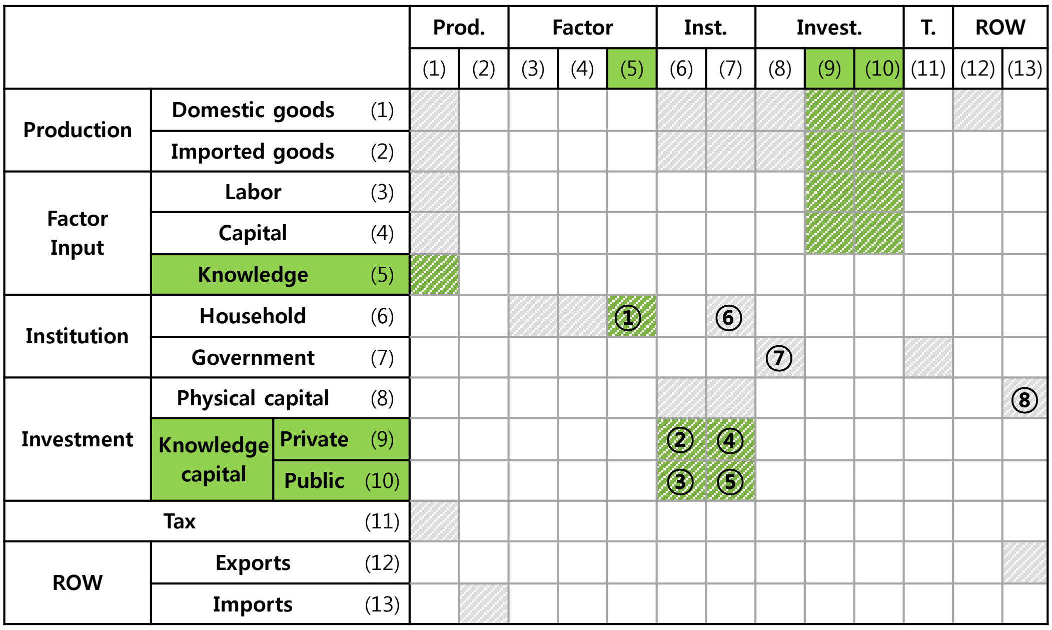


Figure 6. Additional terms after the adoption of knowledge accounts in SAM

The transfer of the knowledge return to household can be represented by one term, so the value of that term can be calculated by summing up the value added of knowledge in all sectors (① in Figure 6). The savings which is equal to knowledge investment can be done by either the private or public sector, hence additional statistics on each ratio are necessary. The statistics in the Survey of Research and Development in Korea are used in this research. The terms ②~⑤ in Figure 6 mean the investment from households to private R&D agents, from household to public R&D agent, from the government to private R&D agent, and from the government to public R&D agent, relatively. Those ratios can be found in the statistics.

Moreover, some balancing terms are also needed. The terms ⑥~⑧ in Figure 6 indicate the transfer to household, government deficit, and trade balance, respectively. These terms are necessary because the row sum should equal the column sum, according to the logic of SAM matrix. The values for the terms can be calculated from the transaction differences between household and the government, and also between imports and exports. The small deviations between row and column sums after the balancing process are calibrated by the method of cross entropy.

3.2 Equation system in knowledge-based model

The CGE model is organized with multiple equations that define the relationship between macro variables. The equations are classified into the supply part which describes the production of final goods with input factors, and the demand part which describes the consumption of goods by each type of agent. Moreover, the values of supply and demand are equal in all markets of commodities and factors according to Warlas's law. The overall structure of the equation system is described in Figure 7. In the knowledge-based CGE model, compared with the standard CGE model, there are additional descriptions with respect to the handling of knowledge.

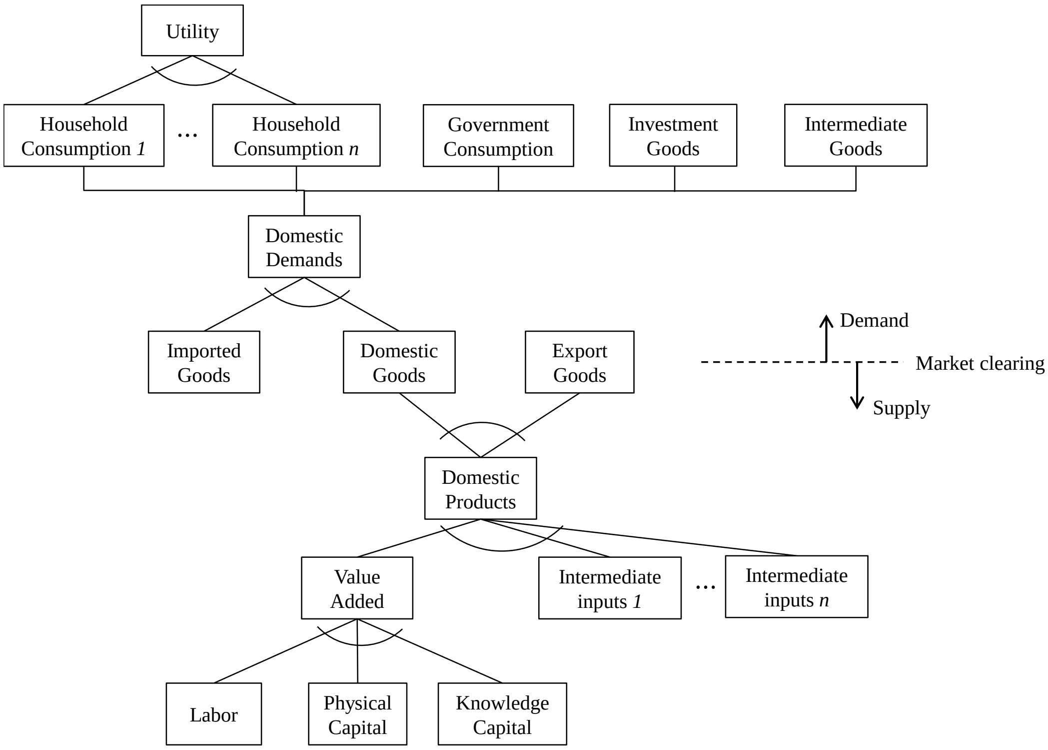


Figure 7. Overall structure of knowledge-based CGE model

The equation system of the knowledge-based CGE model is classified into eight blocks. The eight blocks are referred to as production, institution, investment & saving, trade, R&D, market clearing, gross production & utility, and dynamics. The equations in each block are explained in the following sections. The number of equations should be equal to the number of endogenous variables for the solvability of simultaneous equations. Therefore, some variables are regarded as exogenous in order to adjust the number of endogenous variables. The macro variables in the CGE model are handled as value which means a product of quantity and price. Accordingly, the CGE model generally has a large number of variables. The endogenous variables in the equation system are listed in table 3.1. The variables are written in capital letters, and variables starting with "P" indicate the price variables.

Table 3. Symbols of variables

Indices	
i	Sectors and goods
rdt	Type of R&D
Activity variables	
L_i	Labor of sector i
K_i	Physical capital of sector i
H_i	Knowledge capital of private sector i
$X_{j,i}$	Intermediate goods of sector i produced in sector j
VA_i	Value-added composite of sector i
Z_i	Final output of sector i
D_i	Domestic goods of sector i
E_i	Export of sector i
M_i	Import of sector i
Q_i	Armington composite goods of sector i
XP_i	Private consumption of sector i
XG_i	Government consumption of sector i

XV_i	Investment demand of sector i
DP_i	Depreciation in physical capital of sector i
$INVRD_i$	Demand for R&D investment of sector i
RLS_{rdt}	Labor in R&D investment of sector rdt
RKS_{rdt}	Physical capital in R&D investment of sector rdt
RVA_{rdt}	Knowledge capital in R&D investment of sector rdt
$XRD_{rdt,i}$	Intermediate goods in R&D investment produced in sector i
RDZ_{rdt}	R&D investment in sector rdt
AVA_i	Value-added requirement coefficient of sector rdt
SPC_i	Spillover coefficient in sector i
HG	Knowledge capital of government
$HOTHER_i$	Interindustry spillover in sector i
$INVK$	Demand for capital investment
$INVRES$	Investment resource
SP	Private saving
SG	Government saving
IFR	Foreign investment
Price variables	
PL	Factor price of labor
PK	Factor price of physical capital
PRD_i	Factor price of knowledge capital

PVA_i	Price of value-added composite in sector i
PZ_i	Price of final output in sector i
PD_i	Price of domestic goods in sector i
PE_i	Price of export in sector i
PM_i	Price of import in sector i
PQ_i	Price of Armington composite goods in sector i
$PRDZ_{rdt}$	Price of R&D composite
$PINVK$	Price of capital investment
$PINVRD_i$	Price of R&D investment
Tax and income variables	
TZ_i	Production tax
TL_i	Tax for labor
TK_i	Tax for physical capital
TH_i	Tax for knowledge capital
TM_i	Import tariff
TRD_{rdt}	Tax for R&D activity
HLINC	Household income from labor
HKINC	Household income from physical capital
HRINC	Household income from knowledge capital
GINC	Government income

Production

In the production block, the process of making final goods is formulated with value added composites and intermediate goods. At first, value added composites are assumed to be created with three primary input factors — labor, physical capital, and knowledge capital — through the Cobb-Douglas function (Eq. (3.1)). Labor indicates the number of people working for the industry, so that the wage difference by industry is reflected through an additional term ($wdist_i$). Because it is also assumed that firms want maximization of profit with their inputs, the optimal input quantities are determined in the level where the price of input is equal to the value of marginal product (Eq. (3.2) ~ Eq. (3.4)).

$$VA_i = b_{CD} \cdot L_i^{\beta_i^L} \cdot K_i^{\beta_i^K} \cdot H_i^{\beta_i^H} \qquad \text{Eq. (3.1)}$$

$$L_i = \frac{\beta_i^L \cdot PVA_i \cdot VA_i}{\left[\left(1+\tau_i^L\right) \cdot PL \cdot wdist_{\mathrm{i}}\right]} \qquad \text{Eq. (3.2)}$$

$$K_i = \frac{\beta_i^K \cdot PVA_i \cdot VA_i}{\left[\left(1+\tau_i^K\right) \cdot PK\right]} \qquad \text{Eq. (3.3)}$$

$$H_i = \frac{\beta_i^H \cdot PVA_i \cdot VA_i}{\left[\left(1+\tau_i^H\right) \cdot PH\right]} \qquad \text{Eq. (3.4)}$$

The value added is then combined with intermediate goods through the Leontief function to become final goods. In the Leontief function, the input factors are used with fixed ratio, which means no substitution among the factors. In the CGE model, the ratio of input factors are obtained from input coefficients in SAM. The demand of intermediate goods can be calculated through multiplying intermediate input coefficients by the final product (Eq. (3.5)), while the demand of value added is available through multiplying the value added input coefficient by the final product (Eq. (3.6)). In the market of perfect competition, firms can only get profits that exceed zero. This principle of zero profit leads to the equality of the value of the final product to the values of value added and intermediate goods. In this study, the ratio of indirect tax is adopted because it is necessary to consider the decrease in the value of the final product by tax (Eq. (3.7)).

$$X_{j,i} = ax_{j,i} \cdot Z_i \qquad \text{Eq. (3.5)}$$

$$VA_i = AVA_i \cdot Z_i \qquad \text{Eq. (3.6)}$$

$$\left(1-\tau_i^Z\right)\cdot PZ_i = AVA_i \cdot PVA_i + \sum_j ax_{j,i} \cdot PQ_i \qquad \text{Eq. (3.7)}$$

Institution

The institution identifies household and government, and the income and expense of each agent are assumed to be equal. The source of government income is taxes. This CGE system defines four types of tax: indirect tax imposed on the production of a firm (Eq. (3.8)), direct tax imposed on the return of input factors (Eq. (3.9) ~ Eq. (3.11)), tariff from imports, and tax for R&D investment (Eq. (3.12)). The amount of each tax is calculated by multiplying a certain level of tax ratio to the value of target variables (Eq. (3.13)).

$$TZ_i = \tau_i^Z \cdot PZ_i \cdot Z_i \qquad \text{Eq. (3.8)}$$

$$TL_i = \tau_i^L \cdot PL \cdot L_i \qquad \text{Eq. (3.9)}$$

$$TK_i = \tau_i^K \cdot PK \cdot K_i \qquad \text{Eq. (3.10)}$$

$$TH_i = \tau_i^H \cdot PRD_i \cdot H_i \qquad \text{Eq. (3.11)}$$

$$TM_i = \tau_i^m \cdot PWM_i \cdot M_i \qquad \text{Eq. (3.12)}$$

$$TRD_{rdt} = \tau_{rdt}^{RD} \cdot PRDZ_{rdt} \cdot RDZ_{rdt} \qquad \text{Eq. (3.13)}$$

The total income of the government is the sum of the taxes and additional transfer from household (Eq. (3.14)). The latter means the amount that is not captured by tax, and may include debt from the private sector. The government spends the income by buying goods from private industries, and it saves the rest (Eq. (3.15)). The governmental consumption of industry products are calculated by multiplying the consumption ratio by industry to the total consumption.

$$Ginc = \sum_i TZ_i + \sum_i TL_i + \sum_i TK_i + \sum_i TH_i + \sum_i TM_i + \sum_{rdt} TRD_{rdt} + HT \qquad \text{Eq. (3.14)}$$

$$XG_i = \mu_i \cdot \left(Ginc - SG\right) / PQ_i \qquad \text{Eq. (3.15)}$$

Total income of household is the sum of the return from primary factor inputs. Wage is a reward from offering labor to the production and R&D sector (Eq. (3.16)). Capital income is a reward from lending physical capital to the production and R&D sector (Eq. (3.17)). Knowledge income is from offering knowledge that is demanded in the production sector (Eq. (3.18)). Total household income is the sum of those three sources (Eq. (3.19)). Household purchases necessary goods with disposable income, which remains after saving and transfer to the government (Eq. (3.20)). The commodity demand of household by industry is determined through multiplying the ratio of consumption goods.

$$HLINC = \sum_{i} L_i \cdot PL + \sum_{rdt} RL_{rdt} \cdot PL \qquad \text{Eq. (3.16)}$$

$$HKINC = \sum_{i} K_i \cdot PK + \sum_{rdt} RK_{rdt} \cdot PK \qquad \text{Eq. (3.17)}$$

$$HRINC = \sum_{i} H_i \cdot PRD_i \qquad \text{Eq. (3.18)}$$

$$HINC = HLINC + HKINC + HRINC \qquad \text{Eq. (3.19)}$$

$$XP_i = \alpha_i \cdot \left(HINC - SP - TP \right) / PQ_i \qquad \text{Eq. (3.20)}$$

Investment and savings

Investment is classified into two kinds of stocks: physical capital and knowledge capital, while saving is a classified by two sources: household and government. As a macro closure of each period, two kinds of savings are designed to meet the investment demand. The investment demands in knowledge capital are determined according to the principle of Tobin's Q (Eq. (3.21)). This means that the allocation of sectoral investment is decided by the fraction of return to capital and the user cost of capital. The investment for physical capital is allocated according to the ratio in the base year (Eq. (3.22)). The price of investment for physical capital is designed to be a sum of the prices of the Armington composite, weighted by the ratio of investment demand (Eq. (3.23)). The price of investment for knowledge capital is that of R&D investment goods but affected by the tax ratio (Eq. (3.24)). The resource of total investment is equal to the sum of two values of physical and knowledge capital (Eq. (3.25)).

$$INVRD_i = H_i \cdot r\zeta \cdot \left(\frac{PRD_i}{PINVIRD_i \left(rhdep + intrate \right)} \right)^{r\xi} \qquad \text{Eq. (3.21)}$$

$$XV_i = \lambda_i \cdot INVK \qquad \text{Eq. (3.22)}$$

$$PINVK = \sum_i \left(\lambda_i \cdot PQ_i \right) \qquad \text{Eq. (3.23)}$$

$$PINVIRD_i = \left(1 + \tau_{RDC}^{RD}\right) \cdot PRDZ_{RDC} \qquad \text{Eq. (3.24)}$$

$$INVRES = INVK \cdot PINVK + \sum_{rdt} RDZ_{rdt} \cdot \left(1 + \tau_{rdt}^{RD}\right) \cdot RDZ_{rdt} \qquad \text{Eq. (3.25)}$$

The R&D investment goods are sourced by savings in the private and public sectors (Eq. (3.26) ~ Eq. (3.27)). The coverage ratios (rp_{rdt}, rg_{rdt}) are obtained from external statistics. Total saving consists of private saving, public saving, and depreciation by industry (Eq. (3.28)). The foreign investment makes up the gap between total saving and total investment (Eq. (3.29)).

$$RDZ_{RDC} \cdot \left(1+\tau_{RDC}^{RD}\right) \cdot PRDZ_{RDC} = SP \cdot rp_{RDC} + SG \cdot rg_{RDC} \qquad \text{Eq. (3.26)}$$

$$RDZ_{RDG} \cdot PRDZ_{RDG} = SP \cdot rp_{RDG} + SG \cdot rg_{RDG} \qquad \text{Eq. (3.27)}$$

$$TOTSAV = SP + SG + \sum_i DP_i \qquad \text{Eq. (3.28)}$$

$$IFR = TOTSAV - INVRES \qquad \text{Eq. (3.29)}$$

International trade

In the trade section, the prices of exports and imports vary depending on the exchange rate. In the case of exports, the domestic price of export goods is equal to the multiplication of the world price and the exchange rate (Eq. (3.30)). Similarly, the domestic price of import goods is calculated by multiplying the world price by exchange rate, but the distortion by tariff is added (Eq. (3.31)). The values of imports and exports are defined as products of the prices and each quantity, and the difference between two values is a trade balance. In the equation system, the trade balance is regarded as a foreign investment, hence the sum of exports and foreign investment equals to imports (Eq. (3.32)).

$$PE_i = \mathrm{ex} \cdot PWE_i \qquad \text{Eq. (3.30)}$$

$$PM_i = \mathrm{ex} \cdot \left(1 + \tau_i^m\right) \cdot PWM_i \qquad \text{Eq. (3.31)}$$

$$\sum_i PWE_i \cdot E_i = \sum_i PWM_i \cdot M_i + IFR \qquad \text{Eq. (3.32)}$$

For the explanation of intra-industry trade, the general assumption by Armington is adopted, which admit the product differentiation by country. If the constant elasticity of substitution (CES) form of function is adopted, Armington composite goods can be defined, which is a virtual commodity composed by domestic and imported goods (Eq. (3.33)). The optimal levels of input in domestic and imported goods in order to produce output with minimum cost are determined at the point where the relative price of the commodities is equal to the marginal rate of substitution between them. According to this logic, the ratio of demand in domestic and imported goods can be found (Eq. (3.34)). The value of Armington goods should be equal to the sum of values for imported and domestic goods (Eq. (3.35)).

$$Q_i = \gamma_i \left[\delta_i M_i^{\chi} + \left(1 - \delta_i\right) D_i^{\chi} \right]^{1/\chi} \qquad \text{Eq. (3.33)}$$

$$\frac{M_i}{D_i} = \left[\frac{PD_i}{PM_i} \cdot \frac{\delta_i}{\left(1 - \delta_i\right)} \right]^{1/(1-\chi)} \qquad \text{Eq. (3.34)}$$

$$PQ_i \cdot Q_i = PM_i \cdot M_i + PD_i \cdot D_i \qquad \text{Eq. (3.35)}$$

Regarding export parts, the concept of transformation is adopted. In other words, the products of a firm can either be exported or consumed in the domestic market, and this is explained with a virtual technology of transformation between domestic and export goods. If the technology is expressed with the transformation function of CES form, the output product can be changed to export and domestic goods by that function (Eq. (3.36)). The output level of domestic and export goods for maximum profit are determined at the point where the relative price of the commodities is equal to the marginal rate of transformation. According to this logic, the ratio of demand in domestic and export goods can be found (Eq. (3.37)). The value of final output should be equal to the sum of values for export and domestic goods (Eq. (3.38)).

$$Z_i = \theta_i \left[\psi_i E_i^{\varphi} + \left(1-\psi_i\right) D_i^{\varphi} \right]^{1/\varphi} \qquad \text{Eq. (3.36)}$$

$$\frac{E_i}{D_i} = \left[\frac{PD_i}{PE_i} \cdot \frac{\psi_i}{\left(1-\psi_i\right)} \right]^{1/(1-\varphi)} \qquad \text{Eq. (3.37)}$$

$$PZ_i \cdot Z_i = PE_i \cdot E_i + PD_i \cdot D_i \qquad \text{Eq. (3.38)}$$

R&D sector

In the R&D sector, the production of knowledge investment is described, separated from the production of tangible commodities. The Cobb-Douglas production function is used for the process, and labor and physical capital are adopted as input factors of the process (Eq. (3.39)). The levels of inputs are calculated from the first order condition in profit maximization (Eq. (3.40) ~ Eq. (3.41)). That is, the quantity of input demand is determined at the point where the value of marginal product is equal to the price of the input factor. In addition, the value of R&D investment goods are set to equal to the sum of the values of value added and intermediate goods in the R&D sector (Eq. (3.42)).

$$RVA_{rdt} = rs_{rdt} \cdot RL_{rdt}^{\nu_{rdt}^{RL}} \cdot RK_{rd}^{\nu_{rd}^{RK}} \qquad \text{Eq. (3.39)}$$

$$RK_{rdt} = \nu_{rdt}^{RK} \cdot PRVA_{rdt} \cdot RVA_{rdt} / PK \qquad \text{Eq. (3.40)}$$

$$RL_{rdt} = \nu_{rdt}^{RL} \cdot PRVA_{rdt} \cdot RVA_{rdt} / \left(PL \cdot wdist_{rdt} \right) \qquad \text{Eq. (3.41)}$$

$$PRDZ_{rdt} = avard_{rdt} \cdot PRVA_{rdt} + \sum_{i} axrd_{rdt,i} \cdot PQ_{i} \qquad \text{Eq. (3.42)}$$

The input coefficients for value added and intermediate goods are used to determine their individual demands. The demands are calculated by multiplying the coefficients by the final product of R&D investment (Eq. (3.43) ~ Eq. (3.44)). The value of R&D investment is determined as a certain ratio of GDP, and the distortion of price by is considered (Eq. (3.45)).

$$XRD_{rdt,i} = axrd_{rdt,i} \cdot RDZ_{rdt} \qquad \text{Eq. (3.43)}$$

$$RVA_{rdt} = avard_{rdt} \cdot RDZ_{rdt} \qquad \text{Eq. (3.44)}$$

$$RDZ_{rdt} \cdot \left(1 + \tau_{rdt} \right) \cdot PRDZ_{rdt} = rdi_{rdt} \cdot GDP \qquad \text{Eq. (3.45)}$$

The spillover effect is represented by the spillover coefficient. The spillover coefficient is affected by knowledge stocks in other industries and the government (Eq. (3.46)). At this point of the process, the knowledge stocks of other private sectors are reflected with the weights of intermediate goods transactions (Eq. (3.47)). Then the input coefficient for value added (AVA_i) is designed to be decreased when the spillover increases (Eq. (3.48)). This results in the growth in total factor productivity. The detailed explanation for this logic will be presented in the next chapter.

$$SPC_i = aspc_i \cdot \left(HOTHER_i\right)^{rdes_i} \cdot \left(HG\right)^{grdes_i} \qquad \text{Eq. (3.46)}$$

$$HOTHER_i = \sum_{j,j\neq i} intindwt_{j,i} \cdot H_j \qquad \text{Eq. (3.47)}$$

$$AVA_i = ava0_i \,/\, SPC_i \qquad \text{Eq. (3.48)}$$

Market clearing

The market clearing condition needs to be satisfied in the domestic goods market and the input factor market. The Armington goods supplied in the domestic market are consumed as household (XP_i) and government consumption (XG_i), investment goods (XV_i), and intermediate goods (Eq. (3.49)). In the proposed model, the intermediate goods are those in final goods production and in the R&D sector ($X_{i,j}$, $XRD_{rdt,i}$). The endowments of input factors in the economy are equal to the sum of each factor in the production and the R&D sectors (Eq. (3.50) ~ Eq. (3.51)).

$$Q_i = XP_i + XG_i + XV_i + \sum_i X_{i,j} + \sum_{rdt} XRD_{rdt,i} \qquad \text{Eq. (3.49)}$$

$$\sum_i L_i + \sum_{rdt} RL_{rdt} = LS \qquad \text{Eq. (3.50)}$$

$$\sum_i K_i + \sum_{rdt} RK_{rdt} = KS \qquad \text{Eq. (3.51)}$$

Gross product and consumer utility

Gross domestic product is defined as a sum of value added, so the values of labor, physical and knowledge capital are added to constitute gross product (Eq. (3.52)). Household maximizes its utility by full consumption within budget constraint. The Cobb-Douglas form is used as a utility function (Eq. (3.53)). Therefore, the sum of the exponents (α) of each industry is one.

$$GDP = LS \cdot PL + KS \cdot PK + \sum_i H_i \cdot PRD_i \qquad \text{Eq. (3.52)}$$

$$Maximize \quad U = \prod_i \left(XP_i \right)^{\alpha_i} \qquad \text{Eq. (3.53)}$$

Dynamics

The proposed model is time-recursive dynamic model which is suitable for observing the trend of change in variables. For the dynamization, the change of factor endowment over time needs to be described. The labor increases according to the natural population growth rate (Eq. (3.54)). The statistics on population growth are obtained in national statistics on population. The physical and knowledge stock is assumed to follow the logic of the perpetual inventory method (Eq. (3.55) ~ Eq. (3.57)). It describes the annual depreciation and addition in stock.

$$LS_{t+1} = (1+g_t)\cdot LS_t \qquad \text{Eq. (3.54)}$$

$$KS_{t+1} = (1-rkdep)\cdot KS_t + INVK_t \qquad \text{Eq. (3.55)}$$

$$H_{i,t+1} = (1-rhdep)\cdot H_{i,t} + INVRD_{i,t} \qquad \text{Eq. (3.56)}$$

$$HG_{t+1} = (1-rhdep)\cdot HG_t + RDZ_{GOV,t} \qquad \text{Eq. (3.57)}$$

Chapter 4. Validation of knowledge-based CGE model

4.1 Background: Validation of CGE model

As Dixon and Jorgenson (2013) pointed out, tests of goodness-of-fit for the CGE model were not investigated enough after early studies (Johansen, 1960; Taylor et al., 1980; Dixon et al., 1978; Cook, 1980). This is possibly because CGE modelers have been mainly interested in comparative analysis between baseline and political-impact scenarios, which was a reason for other modelers to raise doubts about how well the CGE model fit.

It was Kehoe who offered a detailed report on the validation issue of the CGE model. Kehoe et al. (1995) made a CGE model of the Spanish economy to analyze the impact of fiscal reform in 1986, which was related to Spain's entry into the European Community, and compared the estimations with actual data for 1985–87. The results showed that the model tracked the actual value of major macroeconomic variables relatively well when it accepted both policy changes (i.e., changes in tax and tariff rates) and exogenous shocks (i.e., changes in food and energy prices).

Kehoe (2005) also tried to evaluate multi-sectoral CGE models for changes in Canada, Mexico, and the United States after the North American Free Trade Agreement (NAFTA). The three target models, however, did not fit well with actual data. The authors thought that one of the reasons was a long-term TFP change. They modified the model by exogenously assigning TFP and trade balance changes, which resulted in a better fit.

On the other hand, some researchers have tried to enhance the validity of the model with elasticity parameters. Valenzuela et al. (2007) tested the price volatility of agricultural products using the Global Trade Analysis Project (GTAP) model of Hertel (1997). He found that differences between actual and estimated data were caused by incomplete transmission of world-wheat price signals to the domestic markets of importing countries. Measurement of price-transmission elasticities from the real world could improve correlation between the model and reality. Furthermore, Beckman et al. (2011) detected that the price volatility of energy was not estimated as much in the energy-environmental extension of the GTAP model (GTAP-E) by Burniaux and Truong (2002). He could estimate similar price volatility to real world through a re-parameterization of demand and supply elasticities from the original model. The two validation researches above revised the original model for a short period of less than five years and focused only on price volatility.

Dixon and Rimmer (2010) used special techniques to make the model conform to reality. They divided simulation stages into two: “historical” and “forecast” simulations. In the first stage, the model was forced to track observed data from the past seven years in input, output, and final demand. In this stage, changes in preferences, technologies, and the demand curve were extracted and passed on to the second stage to predict the data for the next seven years. This method, which was also used in Bor et al. (2010), emphasized more on historical data than the structure of the model’s equations. The model could reflect observed characteristics from past data, but the dependence on many exogenous variables could obscure interrelationships among the variables.

Among various attempts to make improvements to the validity of the model, as described above, Kehoe’s works had important implications in two respects. He presented the comparison between estimated and actual data in order to show the explanatory power for past events. He also pointed out that secular trends like TFP changes were essential for long-term analysis.

Despite the various tries on validation above, the knowledge-based CGE model has not been targeted yet. The reason seems to be that the introduction of knowledge in CGE model has not enough time to be discussed in academic field. Main focuses of papers listed in Section 2.3 were the feasibility of adopting knowledge factor in the model and the availability of applying it to R&D policy analysis. Therefore, if the fact that the adoption of knowledge can contribute to tracking real data in the past is presented, the macroeconomic design with knowledge can be widely accepted. Moreover, the validation will prove that the simulation result with knowledge-based model is more reliable than that of conventional model.

4.2 Difference between standard and knowledge-based model

4.2.1 Design of SAM

This study investigates whether introduction of R&D as an additional aspect in the CGE model contributes to a better fit with reality. Therefore, the standard model adopts the typical form of the CGE model generally used, while the R&D-based model adds R&D descriptions to the standard one. In other words, the R&D-based model utilizes the R&D-based SAM which has knowledge-related accounts extracted from the standard SAM. It also comprises extra equations to treat the new accounts. Except for these additional setups, the two types of CGE model have the same structure and parameters.

Basic SAM in standard model identifies 27 sectors in production according to the classification of input-output table, and regard labor and physical capital as input factors. The values for labor account are referred from “Compensation of employees” account in input-output table, while the values for capital account are from the sum of “Operating surplus” and “Depreciation of fixed capital” accounts. Tax account is divided into 4 categories: indirect tax, corporation tax, income tax, and tariff. The sectoral values in each account are estimated from industry ratio data in “Statistical Yearbook of National Tax” by Korean government.

Knowledge-based SAM has same form with basic SAM, except for the introduction of new accounts on knowledge. The way how to add the accounts are already explained in Chapter 3. One thing to notice is that the knowledge-based SAM is reorganized from the basic SAM by moving R&D expenditure in intermediate-goods transactions to additional accounts. Therefore, two kinds of SAM have consistency in data.

4.2.2 Production of final and investment goods

The standard model assumes that final goods (Z) are aggregated with value added (VA) and intermediate goods (X). Value added is produced with labor (L) and physical capital (K) as the primary input factors. The difference between the R&D-based model and the standard model is an additional primary factor of knowledge capital (H) as described in Eq. (4.1). This is a sector-specific asset that is accumulated through R&D investment in the sector. Production sectors are classified into 27 kinds[3] according to the industrial classification standard in South Korean input-output table.

$$
\begin{gathered}
Z_i = g\left(VA_i, X_i\right) = \min\left(\frac{VA_i}{AVA_i}, \frac{X_{j,i}}{ax_{j,i}}\right) \\
VA_i = f\left(L_i, K_i, H_i\right) = b_{CD} \cdot L_i^{\beta_i^L} \cdot K_i^{\beta_i^K} \cdot H_i^{\beta_i^H} \\
where\ i = 1, 2, \cdots, 27
\end{gathered}
\qquad \text{Eq. (4.1)}
$$

The suggested R&D-based model has a detailed description for R&D investment. R&D investment goods of RDZ, defined below, are generated through a separate process. Some researchers (Visser, 2007; Křístková, 2013) isolated the R&D sector as an independent industry, but this study assumes two kinds of R&D composite (RDZ) in the

[3] Original categories of Korean input-output table are 28 kinds, but the last one is "dummy sector". Authors merged it into 27th sector.

private and public sector, respectively. This is in line with the classification of R&D investment accounts in the R&D-based SAM. The private and public sector each aggregates RDZ with value added (RVA) and intermediate goods (XRD) for R&D, while RVA is produced with labor (RL) and physical capital (RK) for R&D:

$$
\begin{aligned}
RDZ_{rdt} &= g'\left(RVA_{rdt}, XRD_{rdt,i}\right) = min\left(\frac{RVA_{rdt}}{avard_{rdt}}, \frac{XRD_{rdt,i}}{axrd_{rdt,i}}\right) \\
RVA_{rdt} &= f'\left(RL_{rdt}, RK_{rdt}\right) = rs_{rdt} \cdot RL_{rdt}^{v_{rdt}^{RL}} \cdot RK_{rdt}^{v_{rdt}^{RK}} \qquad \text{Eq. (4.2)} \\
& where\ \ rdt = PRI, GOV
\end{aligned}
$$

In addition, the CGE models here are designed to have recursive dynamics, which means that motion equations are necessary for the formation of physical and knowledge capital. Accordingly, investment activity also has two types: physical investment and knowledge investment. Physical investment ($INVK$) is accumulated to make physical stock through the perpetual inventory method with a constant depreciation rate ($kdep$):

$$K_{t+1} = \left(1 - kdep\right) \cdot K_t + INVK_t \qquad \text{Eq. (4.3)}$$

The knowledge investment that is added to the R&D-based model has two kinds of knowledge stocks (private and public) owing to the setup in Eq. (4.2). The accumulation is done through the same method as with the physical investment case, except for a different depreciation rate ($rdep$). The knowledge stock in the public sector is built by public R&D investment (RDZ_{GOV}), while the knowledge stock in the private sector is sourced from private R&D investment (RDZ_{PRI}). RDZ_{PRI} is gross expenditure on R&D in the private sector, so it is distributed into investments by individual industry (IR_i) to build their own respective knowledge stock:

$$\begin{aligned} HG_{t+1} &= \left(1-rdep\right)\cdot HG_t + RDZ_{GOV,t} \\ H_{i,t+} &= \left(1-rdep\right)\cdot H_{i\ t} + IR_{i\ t} \end{aligned} \qquad \text{Eq. (4.4)}$$

The allocation of private investment to each industry follows the logic of Tobin's Q in Eq. (4.5) below (Jung and Thorbecke, 2003; Lemelin and Decaluwe, 2007; Křístková 2012). That is, the investment allocation is decided by the fraction of return to capital and user cost of capital:

$$\frac{IR_i}{H_i} = \zeta_i \left(\frac{PH}{PIR\left(rdep + intrate\right)} \right)^{\xi_i} \qquad \text{Eq. (4.5)}$$

where the fraction in large parentheses means Tobin's Q ratio. PH is a return to knowledge stock, PIR is a price for R&D investment, $rdep$ is the depreciation ratio, and $intrate$ is the interest rate. ζ_i is the calibrated-scale parameter and ξ_i is the elasticity parameter. The production structure of final and investments goods is depicted in Figure 8 below. The structure in a dotted box is an additional part for the R&D-based model.

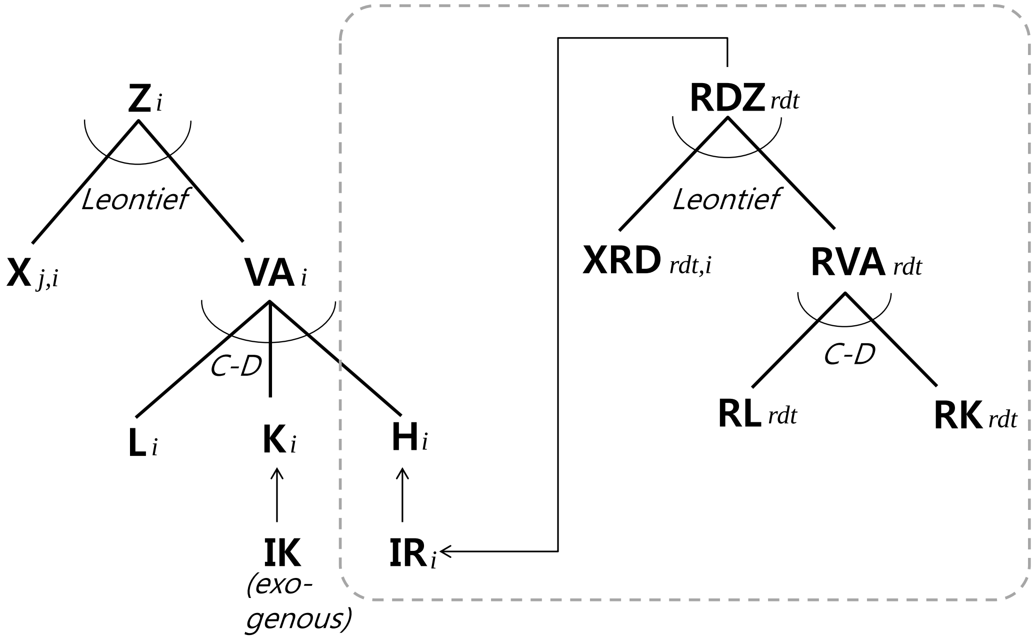


Figure 8. Production of final and R&D investment goods

4.2.3 Implementation of TFP growth with a knowledge spillover effect

Knowledge spillover means a phenomenon that one's improvement of an idea creates a positive externality even when unintended for others. Therefore, the price for knowledge transfer is not considered. The one-nation model of this paper aims to take a close look at the effect of R&D in the private and public sectors, so that TFP change is modeled with spillovers from these two sectors.

The public and private sectors have different characteristics. Public R&D bases like university and governmental institutes conduct basic research, and their outcomes are non-excludable and non-rival. In contrast, firms usually carry out applied research as private R&D, and the outcomes are sector-specific and appropriable. This context of two types of R&D is in common with Goulder and Schneider (1999) and also Křístková (2012). The details on TFP in this study are implemented as Eq. (4.6):

$$\begin{aligned} VA_{i,t} &= AVA_{i,t} \cdot Z_{i,t} \\ AVA_{i,t} &= AVA_{i,t-1} / spl_{i,t} \end{aligned} \qquad \text{Eq. (4.6)}$$

where AVA is the fraction of value added to produce final output. If AVA gets small, less value added is required for the same output, and hence it means technical progress. AVA is defined as a function of the spillover coefficient (SPC). The larger the spillover effect, the more technical progress is accomplished.

The SPC term is defined as a function of governmental knowledge stock (HG) and other industry sectors' knowledge stock ($HOTHER$). A sector's own knowledge stock is used as a primary input factor in production, so it is not added in this spillover equation.

$$\begin{aligned} SPC_i &= aspc_i \cdot \left[HG \right]^{grdes} \cdot \left[HOTHER_i \right]^{rdes_i} \\ HOTHER_i &= \sum_{j \neq i} intindwt_{j,i} \cdot H_j \end{aligned} \qquad \text{Eq. (4.7)}$$

where $aspc_i$ is calibrated coefficient, while $grdes$ and $rdes_i$ are elasticities of public and private knowledge stock, respectively. The equation (4.7) expresses that spillover is transferred from others' knowledge, including government and other industries. The spillover between industries is weighted by the parameter $intindwt$, which is defined as a ratio of inter-industry transactions to total intermediate goods turnover. Total industry turnover includes both domestic and imported goods, so spillover from foreign technology is also considered. This weight parameter is determined in the input-output table of base year. The values of elasticity owe the official reports of South Korean national institutes: $grdes$ is assumed to be 0.25 based on the estimated rage of elasticity in Hwang et al. (2008), and $rdes_i$ are cited from estimations by Korea Institute for Industrial Economics and Trade (Cho, 2003). The values of $rdes_i$ are listed in Table 4.

Table 4. Elasticity of industry knowledge stock

Sector ID	$rdes_i$	Sector ID	$rdes_i$
S01	0.013	S15	0.124
S02	0.010	S16	0.140
S03	0.013	S17	0.100
S04	0.152	S18	0.100
S05	0.073	S19	0.010
S06	0.061	S20	0.010
S07	0.008	S21	0.010
S08	0.060	S22	0.150
S09	0.076	S23	0.010
S10	0.037	S24	0.010
S11	0.074	S25	0.010
S12	0.087	S26	0.010
S13	0.097	S27	0.010
S14	0.074		

4.2.4 Other common structures

The demand structure is common to both the standard and the R&D-based models. Final output splits into domestic and export goods by a constant elasticity of transformation (CET) function under Armington's assumption. The domestic and imported goods constitute total demand by a constant elasticity of substitution (CES) function. Total demand is spent in the form of intermediate goods, investment, and household and government consumption.

The utility of a household (U) is defined with the Cobb-Douglas function of commodity consumption and maximized in every period as in Eq. (4.8). The 12 final consumption commodities (COM)[4] are redefined from 27 household consumption goods (XP). It is more practical for a household to use final consumption commodities than industrial final goods, such as "non-metallic minerals." The conversion from Xp to COM used a 12×27 transformation matrix based on matching information between 78 detailed industries and 12 commodities.

$$\begin{gathered} Maximize U = \prod_{c} \left(COM\left(c\right) \right)^{\alpha(c)} \\ where \quad c = 1, \quad \cdots \end{gathered} \qquad \text{Eq. (4.8)}$$

Macro closure is satisfied by the manner in which household and government savings meets investment demand. Trade balance is also taken into account in the case of physical capital. In each nested hierarchy, demand equals supply as income does expenditure. Furthermore, all common parameters are set to be the same in both the standard and R&D-based models.

---

[4] Korean national statics of "Household Income and Expenditure Survey" define 12 final consumptions as follows: (1) Food and non-alcoholic beverages, (2) Alcoholic beverages and tobacco, (3) Clothing and footwear, (4) Housing, water, electricity, gas, (5) Furnishings, household equipment, (6) Health, (7) Transport, (8) Communications, (9) Recreations and culture, (10) Education, (11) Restaurant and hotels, (12) Miscellaneous goods and services.

4.3 Empirical results in the baseline scenario

To check the fit with actual data, each model has the base year of the 1995 South Korean economy and estimates 15 years of change until 2010, respectively. The models do not employ a policy-shock scenario but calculate industry changes in the baseline scenario. The models follow a recursive dynamics process whose growth determinant is saving or investment in the current period. The endogenous decision logic for the physical investment is obviously meaningful for the completeness of the model, but this research exogenously provides the real value of past physical investment because its concern is the effect of adding R&D as an additional element in the CGE model. The actual values, which are time-series data for gross investment from 1995 to 2010, are obtained from statistics by the Bank of Korea, and adjusted by a GDP deflator. The physical and knowledge stock in base year are estimated data by Korea Productivity Center (a public corporation) and Bank of Korea, respectively.

Two CGE models calculate the final output value of each industry by multiplying output quantity (Z_i) and relative price (PZ_i). Actual output data values are obtained from official input-output tables from the Bank of Korea. Because an input-output table was not tabulated every year, values for missed years (1996, 1997, 1999, 2001, 2002, and 2004) are proportionally estimated according to the real GDP growth rate.

The indices used to measure the goodness-of-fit are mean absolute deviation (MAD) and mean absolute percentage error (MAPE). The two measures calculate the degree of error in time-series data as defined in Eq. (4.9), so the smaller value means closer estimation to actual data. Moreover, slopes of the approximated linear regression for industrial time-series data are identified to compare these values with the growth trends. Therefore, the closer value to actual slop means more accurate estimation. The results are described in Table 5:

$$\begin{aligned} &\text{MAD}: \quad \frac{1}{n}\sum_{t=1}^{n}\left|Y_t - \hat{Y}_t\right| \\ &\text{MAPE}: \quad \frac{1}{n}\sum_{t=1}^{n}\left|\frac{Y_t - \hat{Y}_t}{Y_t}\right| \times 100 \\ &\text{Regression}: \quad \hat{Y}_t = at + b \end{aligned} \qquad \text{Eq. (4.9)}$$

$where \quad Y_t: Real\ value\ of\ industry\ output$

$\hat{Y}_t : Estimated\ value\ of\ industry\ output\ through\ CGE\ model$

$a : Slope\ of\ regressed\ equation$

Table 5 enables us to compare the performance of the two models by each index. Bold characters with shaded cells in the table indicate closer results with actual data. The R&D-based model shows better results in 16 or 17 industries out of 27, but those industries occupy about 75.5 percent (in 1995) of total output. Thus, the estimations for total industry are displayed as Figure 9, which shows that the R&D-based model can be said to be more accurate in general.

Table 5. Fitness of industrial output estimates from models

ID	Sector description	MAD		MAPE		Slope		
		STD	R&D	STD	R&D	Actual	STD	R&D
S01	Agriculture, forestry, and fisheries	**1,478.8**	3,508.0	**33.3**	79.3	121.2	**355.3**	644.4
S02	Mining and quarrying	**203.0**	357.7	**63.6**	110.2	3.4	**25.9**	49.9
S03	Food, beverages and tobacco prod.	**958.2**	3,799.0	**12.3**	50.2	334.9	**517.1**	928.7
S04	Textile and apparel	**676.9**	1,313.3	**14.4**	29.5	40.7	**64.2**	309.0
S05	Wood and paper products	**270.8**	862.9	**13.3**	41.6	86.4	**121.3**	207.6
S06	Printing and publishing	**523.1**	972.4	**67.9**	121.3	-3.1	**102.1**	167.3
S07	Petroleum and coal products	3,568.4	**2,615.1**	43.4	**31.9**	755.6	157.5	**303.3**
S08	Chemicals, drugs and medicines	3,779.7	**1,154.5**	25.1	**7.3**	1,079.0	349.0	**785.1**
S09	Non-metallic mineral products	**933.4**	1,284.7	**37.9**	52.2	117.6	**246.5**	294.5
S10	Basic metal products	3,045.7	**2,232.0**	19.5	**16.3**	1,111.4	342.0	**571.0**
S11	Fabricated metal products	717.2	**611.4**	**16.9**	18.6	391.6	244.1	**296.0**
S12	General machinery and equipment	927.8	**739.4**	13.2	**13.0**	558.4	334.7	**412.2**
S13	Electronic and electrical equip.	6,776.4	**1,761.5**	32.7	**8.6**	1,548.5	350.7	**1,203.2**

S14	Precision instruments	287.8	**139.4**	23.0	**12.3**	89.2	27.6	**57.1**
S15	Transportation equipment	2,570.9	**1,729.9**	18.8	**14.3**	1,121.8	565.3	**720.2**
S16	Furniture and other manufactured prod.	**139.9**	476.9	**11.8**	36.3	75.8	**86.6**	133.2
S17	Electric, gas, steam and water supply	1,593.7	**940.3**	32.7	**19.5**	390.9	132.4	**226.6**
S18	Construction	7,403.8	**6,897.1**	48.4	**46.0**	766.7	2,044.6	**1,855.0**
S19	Wholesale and retail trade	**540.4**	2,941.8	**7.2**	31.7	694.0	**639.1**	1,014.3
S20	Accommodation and food services	3,197.4	**2,835.5**	54.7	**50.2**	543.3	61.8	**119.4**
S21	Transportation and warehousing	1,477.8	**451.9**	17.5	**6.8**	552.2	276.1	**513.9**
S22	Communications and broadcasting	1,644.7	**1,089.1**	36.8	**25.3**	352.0	143.6	**222.8**
S23	Finance and insurance	**1,033.9**	**1,149.7**	**11.7**	14.0	699.3	**543.2**	860.7
S24	Real estate and business services	4,244.3	**957.6**	21.5	**5.8**	1,426.1	824.1	**1,327.6**
S25	Public administration and defense	1,756.3	**410.3**	25.4	**6.2**	498.3	211.9	**417.5**
S26	Educational, health and social work	2,639.8	**1,888.4**	21.4	**16.9**	958.4	505.6	**703.7**
S27	Other services	1,812.5	**411.6**	18.3	**6.2**	700.6	376.8	**664.8**
	Industry Total	28,895.1	**9,418.9**	13.2	**6.0**	15,014.2	9,649.3	**15,009.1**

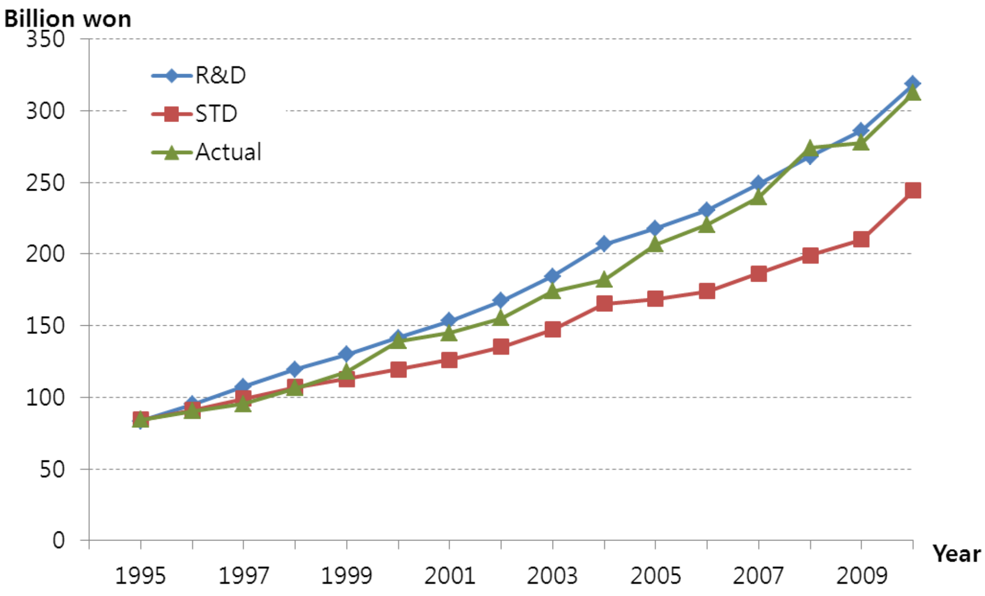
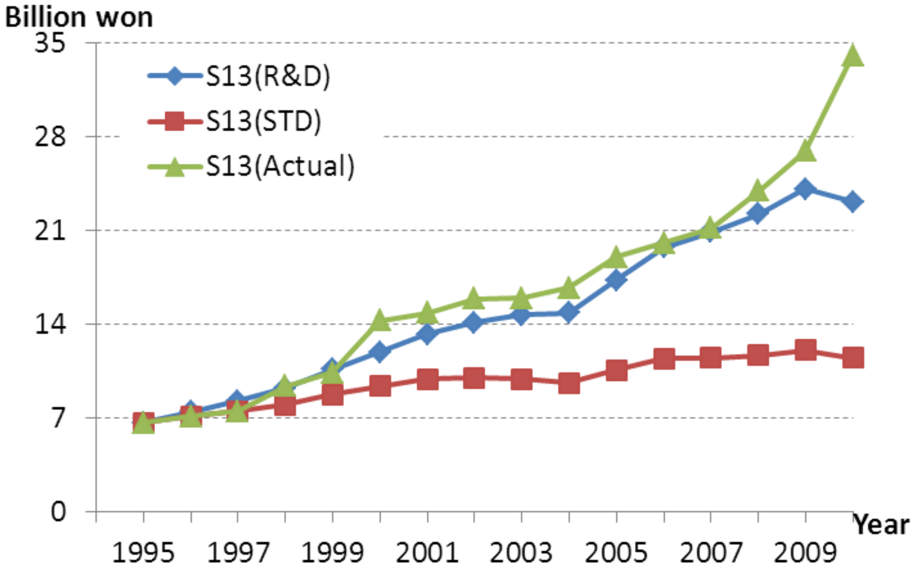
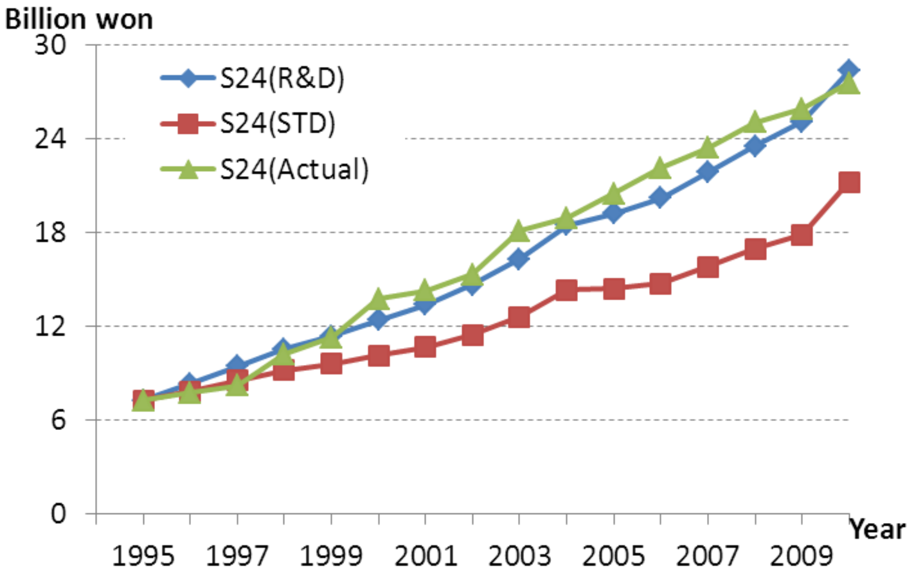


Figure 9. Estimations of whole-industry output from two models

To examine the results minutely, the industries in which the R&D-based model shows better performance are addressed first. Figure 10 depicts the top two sectors in scale among them: “Electronic and electrical equipment” (S13) and “Real estate and business services” (S24). The real output growth of the sectors are 9.5 percent and 11.9 percent in average annual increase, and the R&D-based model traces more similar growth trends than the standard model. Actually, these sectors are regarded to be knowledge-intensive sectors, hence knowledge input and TFP change in the R&D-based model are considered to be effective in describing their dynamics.

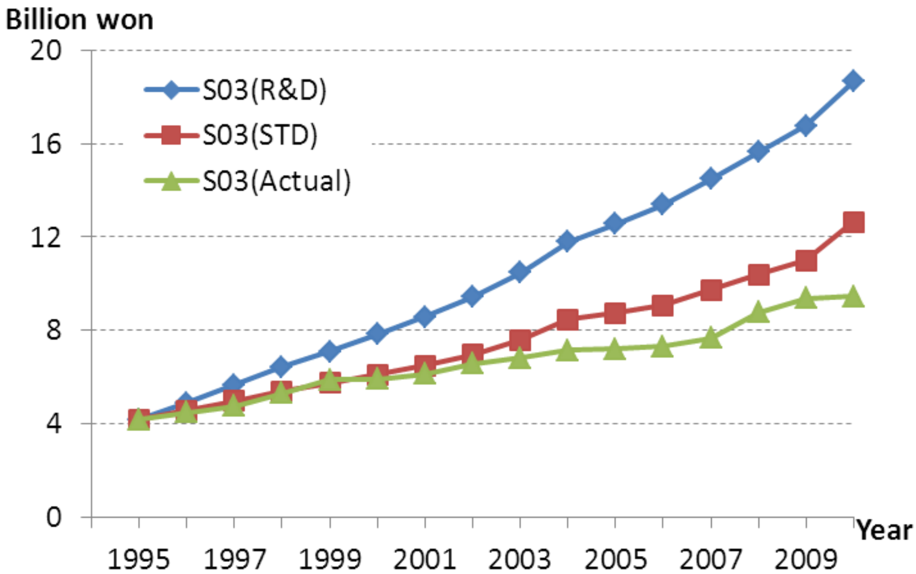


(a)

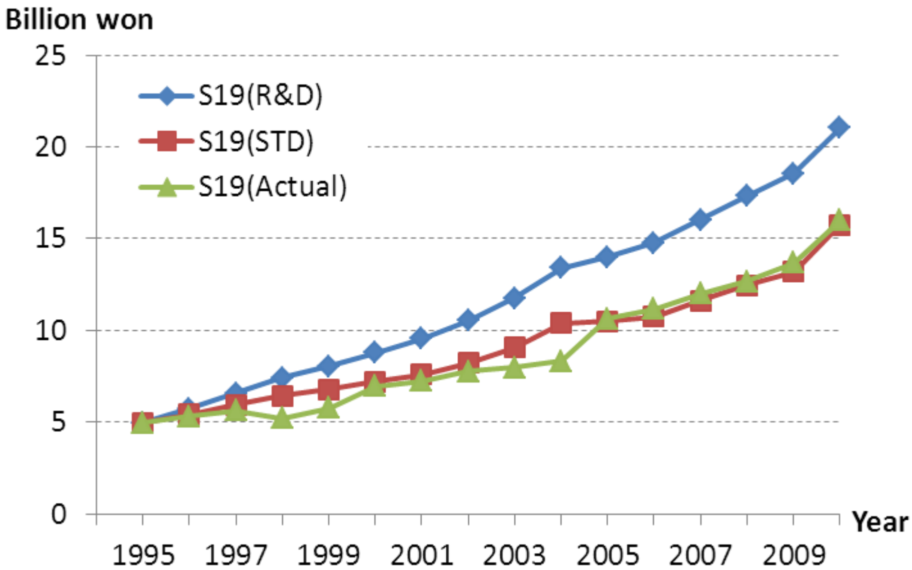


(b)

Figure 10. Sectors where knowledge-based model shows better estimation



(a)



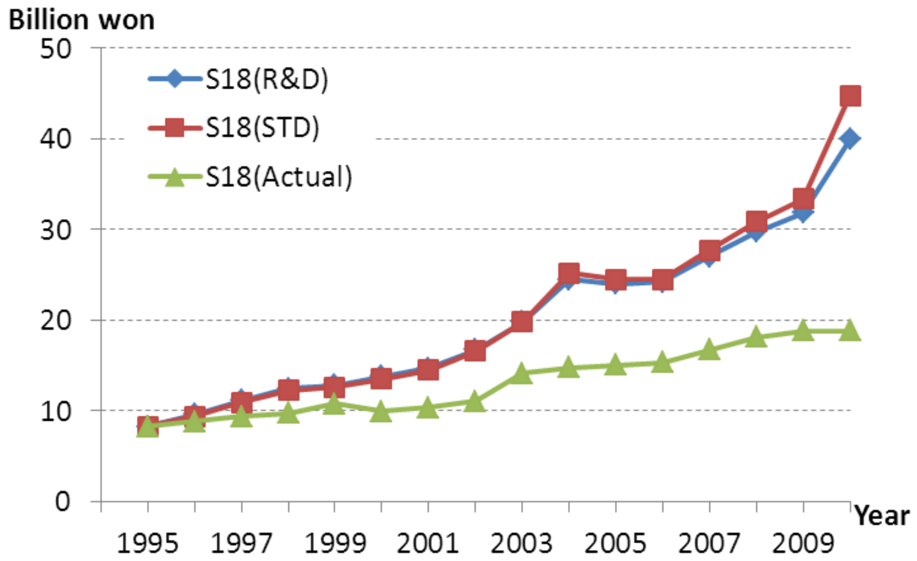
(b)

Figure 11. Sectors where standard model shows better estimation

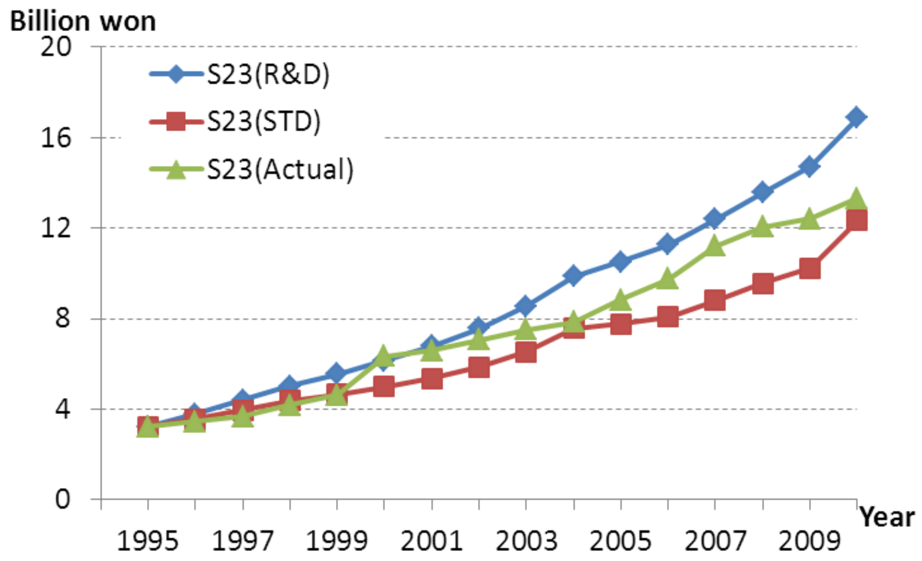
On the other hand, Figure 11 depicts the top two sectors in scale among those estimated better by the standard model. These are “Food, beverages and tobacco products” (S03) and “Wholesale and retail trade” (S19), whose real annual growth is 5.7 percent and 8.4 percent on average, respectively. In these sectors, the R&D-based model overestimates outputs, while the standard model is relatively better. That means that the effect of knowledge in the R&D-based model was too strong for these sectors. According to the design of TFP in Eq. (4.7), two elements may cause the misleading: knowledge stocks of government and other industries. For example, the benefit from government knowledge may be overvalued for these sectors by constant elasticity of $grdes$, or the elasticies from others ($rdes_i$) may be overestimated. Therefore, the R&D-based model needs to reexamine or adjust its parameters especially for those industries.

Two industries are ambiguous in terms of which model is preferable. These are “Construction” (S18) and “Finance and insurance” (S23), whose time-series data are displayed in Figure 12. The construction sector was the biggest sector in the base year of 1995, but its portion has decreased because of a low growth rate to become the sixth sector in scale in 2010. Despite the actual data, the two CGE models similarly overestimate growth in this sector. It can be supposed that the reason is the sector’s dominance over other industries in the base year, which is not influenced as much by the model structure. In the other case of finance and insurance, the R&D-based model overestimates the result while the standard model underestimates. This sector has experienced TFP growth, but this growth is not enough to be explained by the logic of

R&D setup, which is the conjectured reason for middle-level estimation between the two models.



(a)



(b)

Figure 12. Sectors where neither model shows good estimation

4.4 Sub-conclusion

The integration of R&D as an element in the CGE model has been tried during the past few years. While this is proper in light of the increasing proportions of knowledge-based industries, the validity of the R&D-based CGE model has not been tested. In this regard, this study tries to verify whether the R&D-based model has practical meaning, and evaluates the fit of the model with actual data. The advantage of R&D-based model is considered to overcome standard model in two aspects: typical two input factors (labor and capital) and fixed TFP coefficient. Therefore, the proposed R&D-based model regards knowledge stock as an additional primary input factor, and adopts knowledge spillover to have a positive effect on TFP. The estimation performance of the R&D-based model is compared to the standard model which omits these knowledge setups.

South Korean economic data in 1995 is selected to build the base-year SAM, and dynamic equations solve final output for industries until the year 2010. Because this validation process does not aim to forecast, factor endowments of labor and physical capital are exogenously given with actual data. The time-series data are calculated through a baseline scenario. Here, one may raise a question why there is no consideration of various exogenous shocks until 2010 in the real world. However, the main determinants of industrial growth are factor endowments which were already given with real data, so exogenous shocks in the real world were actually reflected in those data.

Giving additional shock has a risk of being arbitrary in its type and size though it may contribute to model fit.

The results show that the estimation performance of the R&D-based model is better in two-thirds out of 27 industries. Because the R&D-based model is better in those industries of high output share in GDP, its overall performance is satisfactory as appeared in Figure 9. Thus, it can be concluded that the two setups, knowledge stock and knowledge spillover, in the R&D-based model can be said to be valid. Nevertheless, if one needs to improve the model especially for some industries of lower estimation performance, setup of knowledge spillover may be the clue. For example, the elasticity parameter of knowledge stock can be revisited. Otherwise, the R&D-based model may adopt extra coefficients of absorptive capacity in the spillover function intending to adjust the size of spillover effect as Das and Powell (2001) did. This kind of treatment for industrial TFP changes is expected to improve the validity of the CGE model.

While the CGE model has advantages in theoretical integrity, its deductive logic, which does not need historical data, has been suspected of causing a gap with reality. Particularly, the limited number of input factors and the fixed value of the productivity coefficient are thought to be insufficient descriptions for modern production patterns in knowledge-based industries. This study found that long-term analysis with the standard CGE model leads to relatively big differences in real-industry growth. Therefore, using the CGE model for a long time horizon needs additional descriptions for productivity, and the R&D-based model can be a valid counterplan. International standards already adopt and recommend 2008 SNA for knowledge handling, so the R&D-based model is expected to be a more proper alternative.

Chapter 5. Impact of R&D policy by firm size

5.1 Background: Firm size and input-output analysis

I–O analysis is based on the matrix form of dataset, such as the I–O table or SAM, an extended version of the I–O table. Although the production part of the I–O table, in general, consists of industry sectors, it can be reorganized to meet a special purpose of analysis. If firm size needs to be incorporated as an additional consideration, there are two ways of modifying the table: reallocation of “production” accounts or adoption of firm in “institution” account.

The first attempt of I–O analysis according to firm size was suggested by Madsen and Jensen-Butler (2003). In their regional SAM of Denmark, they divided production and institution accounts into subsets of LE and SME. The SAM was categorized by firm size into six sectors and used for inter- and intra-regional analysis. In addition, Romero and Santos (2007) attempted to classify the I–O table by firm size. They reorganized the production account according to firm size, and used the table to propose new typology and analyze forward and backward linkage effects.

In the academic field, I–O analysis by firm size so far tends to be confined to regional studies. This is because the contribution of SMEs might be more significant in the regional scope of economy than in the national scope. Recently, however, practical needs have arisen for national economic analysis with respect to firm size. For example, the US

International Trade Commission (USITC) reported that the role of SMEs is important in international trade (USITC, 2010). The report conducted I–O analysis with the I–O table classified by LE and SME in the production account. It succeeded in calculating the SME suppliers' indirect contribution to value added, which was buried in LEs' exports.

In addition, the Japanese Ministry of Small and Medium Enterprise Agency has published an I–O table based on firm size since 1984. In the case of the recent I–O table reported in 2012, 26 industries are subdivided into LEs and SMEs, and finally, 61 sectors are categorized (including 9 industries that are not divided). South Korea and Thailand have also been trying to design a prototype of the I–O table by firm size. The Korea Institute for Industrial Economics and Trade and the Office of Small and Medium Enterprises Promotion are leading the research in each nation, respectively (Lee et al. 2012; Lee et al. 2013).

The paper by Lee et al. (2013) is deeply associated with this study because it targeted the separation by firm size with Korean input-output table. They separated the industry transactions by SME and LE in 40 manufacturing industries, and conducted input-output analysis. Though the study stayed in calculating some coefficients from input-output data, it has important meaning in terms of industry level analysis on the transactions of SME and LE.

Particularly, the influence and sensitivity coefficient from input-output table has significant implication about the characteristics of SME and LE in Korean industry environment. Each coefficient means the forward and backward linkage effect, respectively. The estimated coefficients with derived input-output for 2010 are listed in Table 6. The bigger value between SME and LE are appeared in the shaded cells. Among the results in the table, the influence coefficient of SME tends to bigger in manufacturing, while LE is bigger in sensitivity coefficient. The implication of it is that SME is located in relatively independent status in industry. In other words, LE is more dependent in national level transactions. The fact is implicitly in line with the following analysis in this chapter.

Table 6. Influence and sensitivity coefficients by Lee et al. (2013)

Industry	Influence coefficient		Sensitivity coefficient	
	SME	LE	SME	LE
Manufacturing	1.252	1.148	1.368	2.061
Consumer goods	1.196	0.940	1.190	0.547
Basic material	1.271	0.988	1.768	2.962
Assembly & processing	1.266	1.297	0.976	1.403

Despite the actual policy needs above, the academic field has not highlighted inter-industry analysis by firm size. Moreover, an application of the CGE model concerning firm size has not yet been attempted. While the inter-industry analysis with a coefficient matrix from the I–O table is a partial equilibrium analysis that assumes linearity between input and output, the CGE model adopts a general equilibrium framework that assumes a non-linear relationship and feedback loop among economic variables. This feature enables us to investigate the spread effect to other economic agents as well as industrial sectors. In particular, the CGE model is useful in terms of quantitative measurement of policy effects by changing the value of exogenous policy variables.

5.2 CGE modeling for the tax incentive policy by firm size

Before constructing the CGE model, the SAM, the dataset of economic variables in the benchmark year of 2009, needs to be organized. This study aims to analyze R&D investment in SMEs, hence, it is desirable to separate R&D and firm type in the SAM accounts. Researchers can isolate these accounts through two steps because the conventional type of I–O table does not distinguish them.

In the first step, transactions in the R&D sector are isolated. The isolation of R&D transactions enables us to capture the role and interaction of knowledge in the economy correctly. Unlike previous research, which adopted a special assumption about R&D to split it from the existing I–O table (Sue Wing, 2003; Ghosh, 2007; Lecca, 2009), one can easily extract R&D account in the SAM because the South Korean I–O table already separates the R&D sector in a most-detailed classification level. The knowledge-based SAM comprised additional accounts of knowledge factor (*R*) and knowledge capital formation in private (*RH*) and public (*RG*). These additional accounts are appeared as green cell in Figure 13.

The detailed method to construct SAM is same with the description in Chapter 3. In short, R&D expenditure is regarded as a payment for input factor, and the demand by R&D sector is recognized as an investment for knowledge stock. Accordingly, the rows and columns of R&D sectors are displaced to new accounts. This chapter adopts basically the same method for the construction of knowledge-based SAM, but there is a few variations in terms of allocation.

In this analysis, the “depreciation in fixed capital” account in input-output table is not combined with “operating surplus” account, but maintain original values as independent terms (cell (8,1) in Figure 13). By doing this, only one balancing term (cell (7,6) in Figure 13) is necessary instead of three terms (cell (6,7), (7,8), and (8,13) in Figure 13) before. Moreover, there are no negative values in the balancing terms.

		Prod.		Factor			Inst.		Invest.			T.	ROW	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Production	Domestic goods (1)													
	Imported goods (2)													
Factor Input	Labor (3)													
	Capital (4)													
	Knowledge (5)													
Institution	Household (6)							X						
	Government (7)								X					
Investment	Physical capital (8)													X
	Knowledge capital — Private (9)													
	Knowledge capital — Public (10)													
Tax	(11)													
ROW	Exports (12)													
	Imports (13)													

Figure 13. Knowledge-based SAM

In the second step, the production accounts in the SAM after the first step are classified by firm size. At this point, the additional statistics are necessary for dividing the accounts by firm size. This study adopts the official statistical data of "Financial Statement Analysis," which are announced annually by the Bank of Korea. This data offers various indicators on financial statements and management evaluation according to LEs and SMEs in each industry. Therefore, the data enable us to obtain the ratio of SMEs on sales, value added, and R&D investment by industry. The contribution ratios of SME in imports and exports are obtained from tariff data by firm size from Korea Customs and

Trade Development Institute. Table 7 shows the classification of industry sectors identified in this study and the contribution ratio of SMEs on each index. Industry is classified into seven categories (from S01 to S07).

The rough classification of seven is caused by constraint on data, when different kinds of statistics are combined. That is, the classification in “Financial Statement Analysis” is different from that in input-output table, and data in some industries is not assorted by firm size. Furthermore, the tariff data are surveyed only for the manufacturing commodities, so that the data on import and export in service industry could not be collected. As a result, the separation by firm size was conducted targeting manufacturing sectors.

Therefore, five industries in manufacturing, except for agriculture, fisheries, mining industry (S01) and service (S07), are chosen for separation by firm size. Consequently, 12 sectors are identified for analysis.

Table 7. Share of SME by industry and economic indices

ID	Industry	Total sales (*A*)	Labor cost (*B*)	Operating surplus (*C*)	Depreci ation (*D*)	Corpor ate tax (*E*)	Develop ment cost (*F*)	Intermedi ate goods (*G*=*A*-*B*-*C*-*D*-*E*-*F*)	Export (H)	Import (I)
S01	Agriculture, fisheries, mining	-	-	-	-	-	-	-	-	-
S02	Food, textile, wood	64.9	64.9	51.5	55.4	47.7	71.2	66.1	68.1	70.3
S03	Petroleum, chemicals	31.0	50.9	28.8	31.3	29.0	40.3	29.5	19.5	36.4
S04	Metals, machinery	56.4	67.8	50.9	44.1	49.5	57.8	55.9	32.5	36.3
S05	Electrical, electronics	32.5	48.7	29.0	12.7	31.9	20.9	33.2	19.3	36.4
S06	Precision instruments, transport	31.5	34.3	19.4	31.4	15.4	28.4	32.1	10.4	51.1
S07	Service	-	-	-	-	-	-	-	-	-

* Sector S01 and S07 are not classified by firm size

Using the ratio in Table 7, the production accounts in the original SAM can be split by firm size. The details follow the estimation method proposed in USITC (2010). The final structure of the SAM is described in Figure 14. In order to split manufacturing industries in the production account by firm size, the contribution ratios of SME (columns (*A*)–(*G*) in Table 7) are multiplied by original partial matrices before separation (*Z*, *L*, *K*, *R*, *PK*, *T*).

For the splitting of "use industry" (column direction), Table 7 offers the ratio for production factors (columns (*B*), (*C*), and (*F*) in Table 7), depreciation rates (column (*D*)), and corporate tax (column (*E*)). The contribution ratio of SME in intermediate goods is calculated by subtracting all costs from total sales (column (*G*)). By this method, all columns in the intermediate goods section can be divided into LEs and SMEs. In case of intermediate goods, Lee et al. (2013) surveyed different dataset on material, fuel, and electric power cost and applied them discriminately according to industry. However, this study adopts simple method of USITC (2010) because the number of sectors in SAM is small.

For the splitting of "source industry" (row direction), an assumption on the source of intermediate goods is necessary. Because the SME share of sourcing is not directly computed, it is assumed that the supply of intermediate goods is proportional to the total output. Therefore, the ratio of total sales is used. Domestic demand can be calculated simply by subtracting intermediate supply from gross output. Import and export accounts are divided according to tariff data.

			Production		Factor	Inst.	Capital Formation	Tax	ROW
			LE	SME					
			1 … N	1 … N	L K R	H G	PK **RH** **RG**	T	E M
Production	**LE**	1 … N	(1-(*A*))• (1-(*G*))Z	(1-(*A*))(*G*)Z					
	SME	1 … N	(*A*)(1-(*G*))Z	(*A*)(*G*)Z					
Factor Input		L K **R**		(*B*)L (*C*)K (*F*)R					
Institution		H G							
Capital formation		PK RH RG		(*D*)PK					
Tax		T		(*E*)T					
ROW		E M							

Figure 14. Knowledge-based SAM differentiating SMEs and LEs

The equation system is basically same with the description in Chapter 3. That is, the two properties with regard to knowledge are reflected to the system. Each sector adopts its own knowledge stock as one of primary factor input, while knowledge stocks of other sectors enhance its TFP by spillover effect. The other sectors here consist of other private sectors and one public sector. This design enables the endogenous explanation for knowledge stocks in production process.

Household maximize its utility by consumption within budget constraint. The consumption targets consumption goods of XP, not redefining final consumption commodity in Chapter 4. Therefore, the equilibrium point is solved in every period by maximizing utility function of Eq. (3.54).

This chapter aims to analyze the impact of tax incentive on R&D, so policy variable needs to be chosen. In Chapter 3, τ_{rdt}^{RD} is separately introduced in Eq. (3.13). It is a term of tax ratio in the production of R&D investment. Tax incentive only benefit private sectors, hence the policy shock is implemented by changing the values of τ_{PRV}^{RD}. It means a decrease in the price of R&D investment goods, which results in the increase in the quantity of R&D investment.

The additional modification in equation system is the logic of knowledge stock accumulation. Until this chapter, the perpetual inventory method (PIM) is adopted in both physical and knowledge stock accumulation. In this chapter, however, an efficiency term is added to the R&D investment of private sector. It is related to the investment efficiency according to firm size.

$$H_{i,t+} = (1 - rdep) \cdot H_{i\,t} + IR_{i\,t} \cdot (H_{i\,t})^{\gamma} \qquad \text{Eq. (5.1)}$$

As described in Eq. (5.1), the accumulation logic of R&D stock follows the conventional PIM but makes a partial modification to reflect the characteristics by firm size. A firm with a low level of knowledge stock has the same amount of stock increase with R&D investment, while a firm with a high level of stock has a lower increase, even in proportional investment. That is, the increase of knowledge stock is affected by the existing stock already accumulated. This is in line with empirical findings that larger firms are less efficient in R&D investment, as discussed in Subsection 2.2.2. Eq. (5.1) shows that the existing stock of knowledge affects the efficiency of new investment. However, the accumulation of physical stock follows the conventional form of PIM.

In this process, it is necessary to decide the value of elasticity (γ) which defines the level of efficiency. The elasticity, together with knowledge stock *H*, determines the actual contribution of investment *INVRD* to knowledge stock. Table 8 lists the level of efficiency according to *H* and γ.

In our dataset, sectoral knowledge stock *H* has its value between 7 and 4,176 (unit: 10 billion won). Accordingly, for example, elasticity of -0.05 means that about 60 ~ 90% of investment actually accumulated to knowledge stock. Meanwhile, elasticities of -0.1 and -0.01 assumes too big and too small decline respectively, which is far from practical recognition on investment efficiency. The sensitivity of simulation result is not high from the variation of γ between 0.04 and 0.06, so this study adopts the value as -0.05.

Table 8. Efficiency according to the values of γ

H	γ		
	-0.1	-0.05	-0.01
1	1	1	1
10	0.794	0.891	0.977
100	0.631	0.794	0.955
1,000	0.501	0.708	0.933
10,000	0.398	0.631	0.912

5.3 Simulation results

This study analyzes the effects of R&D tax credits according to firm size. In the case of South Korea in 2010, R&D investment in the private sector added to 27.7 billion US dollars while R&D tax credits were 1.64 billion US dollars, giving an average tax credit rate of 5.6% for both LEs and SMEs. Policy scenarios are set to offer an additional 1%p in tax credits to manufacturing LEs and SMEs over 5 years from 2010. Besides, R&D investment of manufacturing LEs was 2.64 times more than that of SMEs in the benchmark year, so the volume of 1%p tax credits for LEs is larger than that of SMEs. Therefore, one more scenario is considered: giving tax credits of 2.64%p to SMEs. This is to make SMEs' tax reduction amount the same as that of LEs at 1% p. The three scenarios are summarized in Table 9.

Table 9. Scenario definition

Beneficiary in manufacturing sectors	Additional reduction of tax rate for R&D expenditure		
	Pro-SME (1%p)	Pro-LE (1%p)	Pro-SME (2.64%p)
LE	-	1%p	-
SME	1%p	-	2.64%p

Figure 1 depicts the trends of gross domestic product (GDP) and consumer utility in terms of the relative percentage change to the baseline scenario. Figure 1(a) shows that at national level, additional tax credits to LEs (scenario 2) is more effective than those to SMEs (scenario 1). However, this is because manufacturing LEs invest more in R&D than SMEs in the benchmark year. If the same volume of tax credits for LEs in Scenario 2 is reduced for SMEs (scenario 3), the relative change of growth increases to 0.69% in the short term (5^{th} year of the policy), which is more than double 0.31% in scenario 2.

Consumer utility shows similar growth to GDP, as shown in Figure 1(b). Because the utility is defined as a function of household consumption, the increase in utility represents the increase in consumption and subsequent increase in the quality of life. According to Figure 15 (a) and (b), the relative utility growth is about half of production growth, which means that the R&D tax incentive policy have more influence on production side than consumer side.

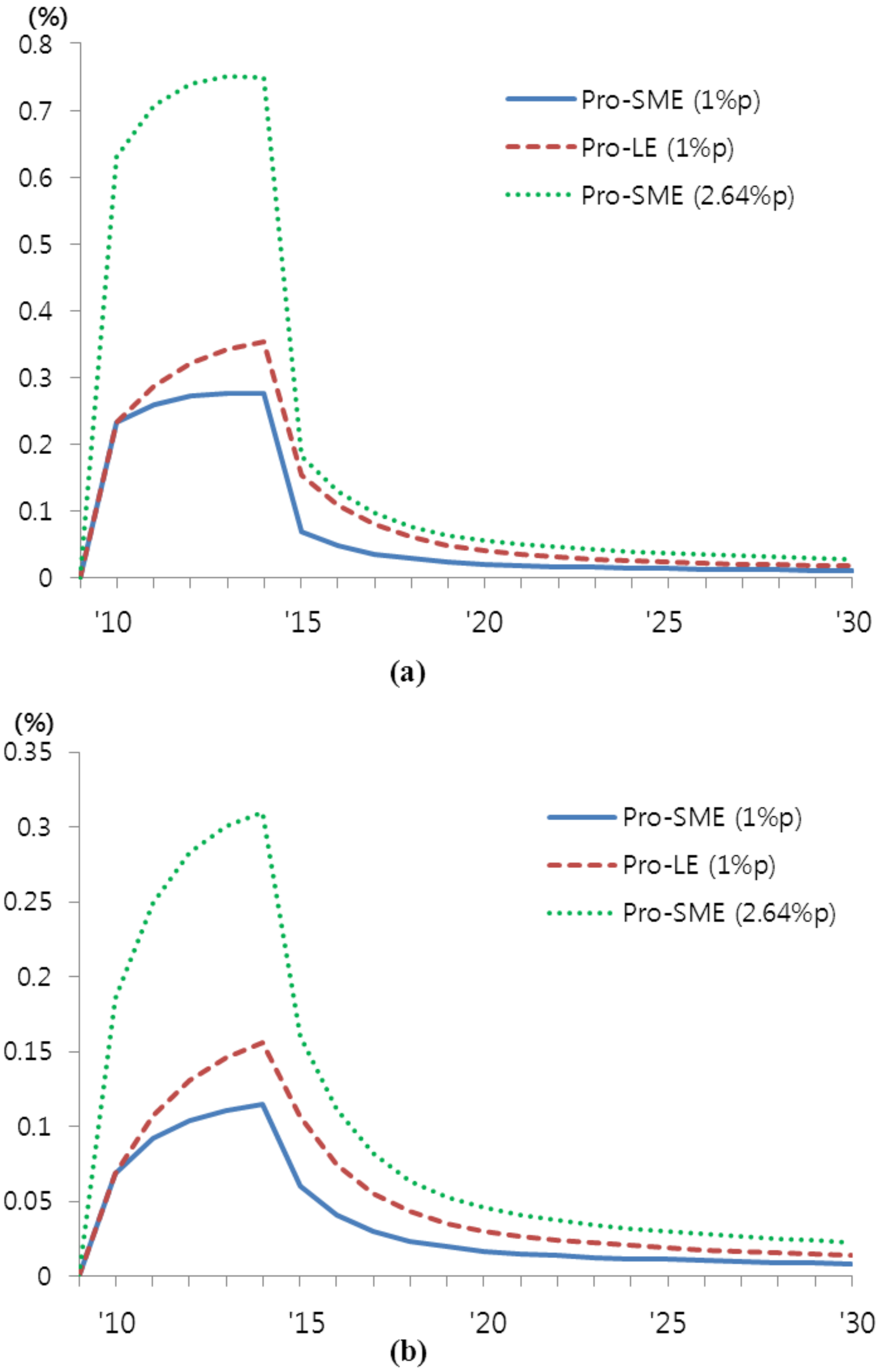


Figure 15. Deviation from baseline in (a) GDP and (b) consumer utility

This result comes mainly from the change in knowledge stock. Additional tax credits lower the price of R&D investment, and then, the quantity of R&D investment increases. This causes an increase of knowledge stock which has two influence paths to production process. In the first path, the enhancement of each sector's own knowledge stock directly affects the production capacity of the sector. In the second of path, the knowledge stocks of other sectors indirectly enhance target sector's TFP by spillover effect. These two channels eventually induce the increase in each sector's production. Thus, gross output increases compared to the baseline scenario. This process of influence is briefly described in Figure 16.

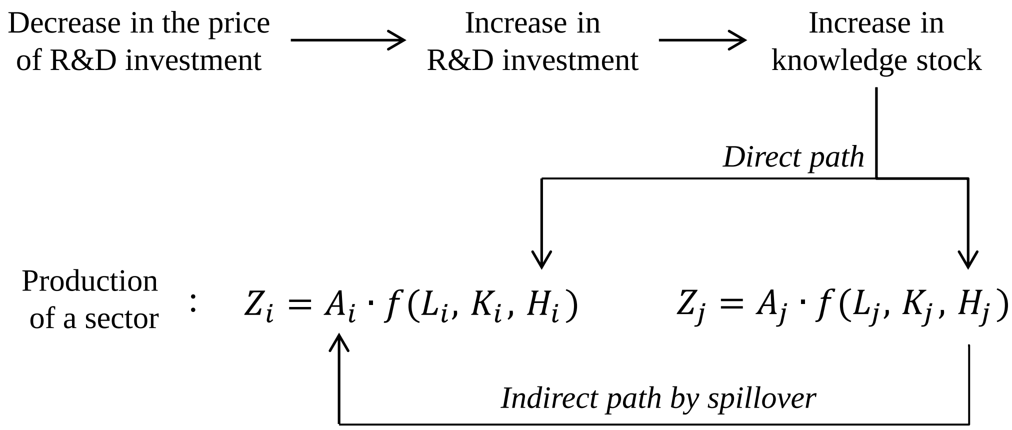


Figure 16. Paths of R&D tax incentive

The change in private R&D investment according those channels can be found in Figure 17. In the two scenarios of 1%p incentive, the increases of private R&D investment are similar. That is, policy target induces little distinction in overall R&D investment. However, the ways of investment flow to sectors are different by two scenarios.

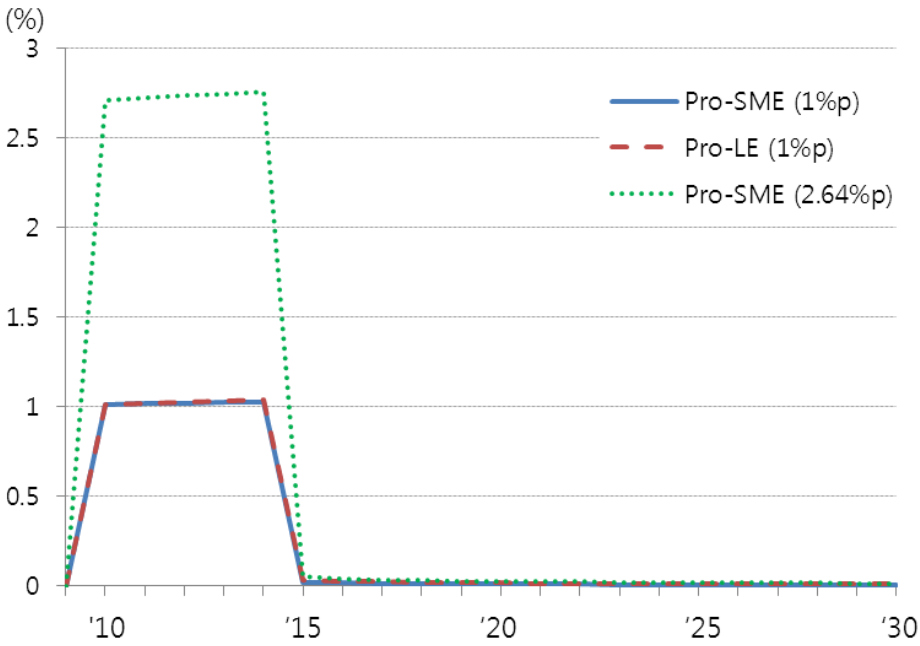


Figure 17. Increase of R&D investment (*RDZ*) in private sector

Table 10 shows the sectoral increase in R&D investment. Each values in table means the growth rate compared to BAU, and are calculated with estimates in 2014, the last year of policy shock. The first scenario means a benefit to SME, which causes the increase of R&D investment in SME sectors (S02S, S03S, S04S, S05S, S06S). In contrast, the second scenario of tax incentive to LE cause the increase in LE sectors (S02L, S03L, S04L, S05L, S06L). The amounts of increase have variance because the private investment goods are designed to be allocated to each sector according to Tobin's Q principle. These increases of R&D investment result in the enhancement of knowledge stock of each sector, which is a direct path in Figure 16.

Table 10. Increase in R&D investment by sector

	Pro-SME (1%p)	Pro-LE (1%p)	Pro-SME (2.64%p)
S02L	0.020	1.207	0.053
S02S	1.200	0.016	3.218
S03L	-0.035	1.081	-0.094
S03S	1.131	-0.042	3.028
S04L	-0.048	1.052	-0.130
S04S	1.154	-0.068	3.091
S05L	0.002	1.436	0.001
S05S	1.182	0.170	3.164
S06L	-0.039	1.055	-0.104
S06S	1.151	-0.044	3.084

The indirect path for the increase of output is caused by spillover effect. The positive spillover effect to TFP is designed as a function of other sectors' knowledge stocks, thus the degree of spillover effect is a key link between knowledge stock and gross output. Though the spillover coefficients endogenously grow over time, the relative size among sectors maintains across all periods.

Table 11 lists the average of spillover coefficients during the period of policy shock (from 2010 to 2014). When comparing the values LE and SME, LE has bigger value in S03 (petroleum, chemicals), S05 (electrical, electronics), and S06 (Precision instruments, transport) industry, while SME has slightly bigger value in S02 (food, textile, wood) and S04 (metal, machinery) industry. Reminding the definition of spillover coefficient in Eq. (3.46), sectors with high level of spillover coefficient means that they are more dependent on the spillover from other sectors' knowledge stock. In other words, in S03, S05, and S06 industry, LEs are bigger recipients of knowledge spillover than SMEs.

Table 11. Average of spillover coefficients

Firm size	Sectors in manufacturing				
	S02	S03	S04	S05	S06
LE	1.0617	1.0580	1.0578	1.0593	1.0594
SME	1.0619	1.0572	1.0579	1.0561	1.0581

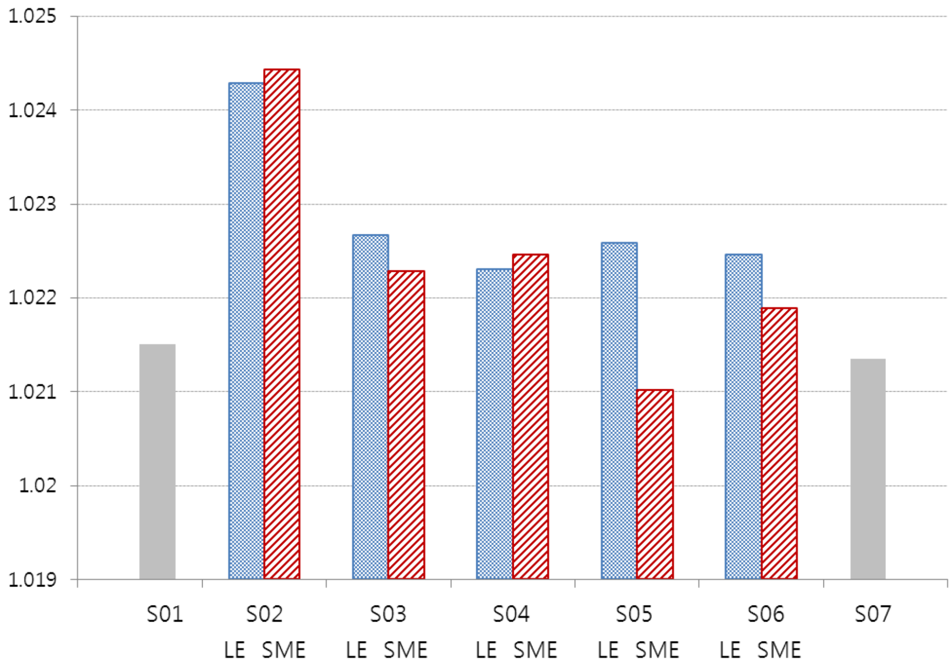


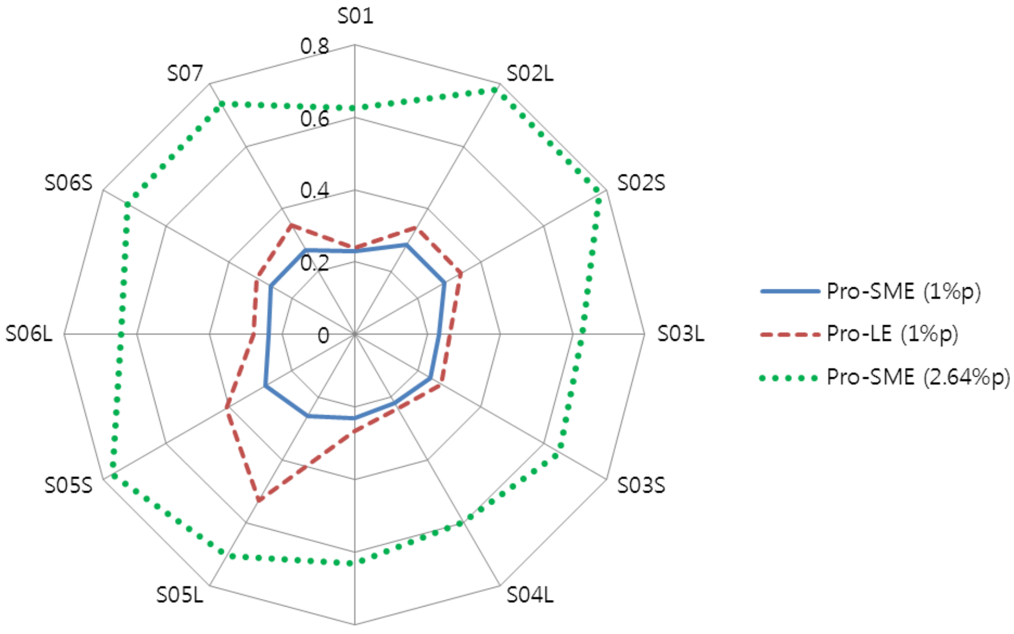
Figure 18. TFP benefit from other sectors in 2010 (BAU)

The effect of knowledge spillover can be more detailedly discussed by industry. Figure 18 illustrates the spillover coefficients in 2010. The coefficient may also be interpreted as a degree of benefit in TFP from other sectors' knowledge. In terms of absolute size, the S02 industry is found to have remarkably bigger value than others. It means that the productivity of food, textile, and wood industry get much benefit from technical progress of other industry. For example, the technology improvement in machinery industry may strongly pull the growth of food, textile, and wood industry.

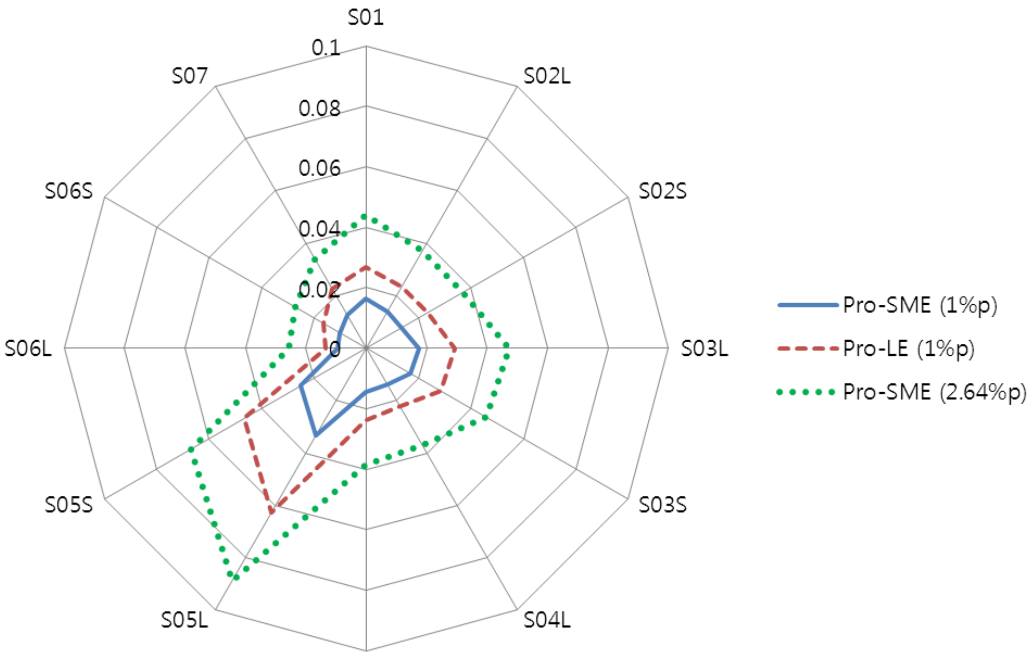
In terms of firm size, the SMEs in S05 and S06 industry have the smallest 2 among all sectors. This means that the SMEs are relatively independent from other sectors' knowledge. It means that their growth depends more on their own R&D efforts than other sectors. However, the LEs in S05 and S06 industry are appeared to have as high dependence as other sectors except S02.

Although the knowledge of LE has more spillover power than that of SME in case of S02 and S04 industry, the differences of values between LE and SME are relatively small in those industries. Therefore, in the perspective of whole manufacturing industry, the overall spillover value of LE is larger than that of SME. In other words, SME exert more influence in productivity spillover than LE. Therefore, the investment promotion of SMEs, at least in the case of R&D investment, produces not only output growth of SMEs but also series growth of LEs. In practical context, one can imagine that the knowledge flow from LEs to SMEs is more awkward than the flow in the opposite direction.

In addition, it is possible to investigate sectoral growth in each scenario. Figure 19 shows the deviation of sectoral output from the baseline. Because of the variation of the values over time, the short-term result in 2014 (5 years after the start of the policy) and the long-term result in 2024 (10 years after the policy termination) are selected. When comparing the results in Figure 19(a), pro-SME policy induces relatively even growth across all sectors, while pro-LE policy benefits S05 sectors (electronics and electrics), especially S05L (LE in electronics and electrics), more than others. This trend becomes noticeable in the long run, and thus, all scenarios converge to the similar result, as can be seen in Figure 19(b). The reason is supposed to be that the S05 sector is a knowledge-intensive industry, so that knowledge stock additionally accumulated in the sector has a better output-growth effect than that in other sectors has.



(a)



(b)

Figure 19. Growth rate of sectorral output in (a) 2014 and (b) 2024

5.4 Sub-conclusion

This study used a knowledge-based CGE model to analyze the effects of tax credits on R&D investment according to firm size. The SAM was constituted to have the accounts of knowledge factor and knowledge investment, and differentiated LE and SME sectors in the production account. Moreover, the accumulation of knowledge stock was set to incorporate the empirical result that SMEs are more efficient in R&D investment.

The simulation results showed that support for LEs is better for economic growth in the case of applying the same percentage discount of tax rate, while support for SMEs is better in the case of deducting the same volume of tax. These results are attributed to changes and spillover of knowledge stock. In the South Korean manufacturing industry, LEs appear to be more dependent on knowledge spillover than SMEs, so that additional investment in SMEs boosts total output, also inducing growth of LEs. This implies that prioritizing SMEs for the tax benefit is more efficient in terms of national gross output, when policymakers need to allocate a fixed amount of fiscal benefit by firm size. The results, however, cannot be generalized because the relationship between LEs and SMEs depends strongly on national characteristics.

This study is the first attempt to discuss the economic effect of SMEs from the perspective of general equilibrium. Previous studies on R&D in SMEs have been based on microeconomic or partial equilibrium analysis; hence, the influence of SMEs by other economic variables—such as consumption, industry sector, and exports—inevitably rests on an assumption of *ceteris paribus*. The CGE model of this study specifies the relationship among macroeconomic variables and simulates the impact of SME policy to estimate the change of the variables numerically. Because macroeconomic analysis is rare especially in R&D issues for SMEs, this study is expected to initiate a new category of discussion.

Another contribution of this study is found in the reflection of national characteristics on the roles and effects of SMEs. SMEs have different status depending on affiliated country and industry. For example, SMEs may comprise an axis of strong forward-linkage effects if they have a major portion of intermediate goods in an industry. Moreover, each country has a different industrial structure, so that the impact of SMEs must be different by country. The characteristics of industry structure appear in the national I–O table, and therefore the analysis based on the I–O table can estimate more exact effects of SME policy, which has not been generalized across countries.

This study aimed to analyze R&D promotion policies by firm size through a CGE model but the simulation results have some limitations. First, the production functions have a Cobb–Douglas form, so the substitution elasticity of knowledge can be criticized to be unrealistic. Second, the elasticity parameter in R&D investment (γ in Eq. (5.1)) was set arbitrarily, so it needs to be estimated from empirical data. Lastly, this model assumed full employment and did not consider the unemployment rate. Because SMEs cover more than 70% of total employees, SME-related policy should be considered with the variables of unemployment or social welfare, but this version of the model is not sufficient to deal with them. Future research needs to consider these points.

Chapter 6. Conclusion

6.1 Summary of main findings

This paper has attempted to analyze the effects of policies that aim to improve the innovative capability of SMEs. For the first procedure, the design process to adopt knowledge into CGE model is described. In addition, the knowledge-based CGE model is validated to test the feasibility of the simulation model. Finally, this paper estimates the economic effects of tax incentive for R&D activity. The main findings can be briefly stated as follows.

Chapter 3 introduces the process of adopting the knowledge factor in the CGE model. The CGE model consists of SAM and an equation system. In SAM, R&D expenditure is regarded as a production factor and listed as a separate account. Knowledge stock formation is also identified by private and public types and placed as new accounts. In the equation system, two general characteristics of knowledge are implemented; knowledge is used as a primary input factor for the production process, and knowledge has spillover effects contributing to the improvement of other producers' productivity. With these considerations on knowledge, the CGE model can be applicable to simulations related to innovation policies.

Chapter 4 conducts a validation process for the proposed CGE model. To evaluate the validity of the knowledge-based CGE model, its simulation result is compared with the result from the standard CGE model. To be specific, the industry production outputs are estimated from the base year of 1995 to 2010, and these values are compared with real data. Simulation results show that the knowledge-based model estimates better than the standard model in two-thirds of 27 sectors. The sectors with better fitness occupy larger proportions in GDP, so that the overall performance can be said to be higher in the knowledge-based model. Most of the previous literature on the knowledge-based CGE model focused on either the method of incorporating or the policy impact on knowledge, and they did not attempt to see the compatibility or suitability of their model with real world. The validation process of this paper, however, shows that the introduction of knowledge contributes to the plausibility of the CGE model. The result of Chapter 4 guarantees not only the reality of the analysis in the next chapter, but also the meaningfulness of future research on the knowledge-based model.

Chapter 5 analyzes the effect of tax incentive on R&D activity as the policy target is changed by firm size. In order to find the macroeconomic effects of policy by firm size, the production accounts in the input-output table are divided by LE and SME. In addition, the term representing the efficiency of the R&D investments was included in the knowledge stocks accumulation equation. Simulation results show that higher economic growth is derived when LE is supported under the same tax rate change and when SME is supported under the same tax amount change. The results can be understood to be derived from two channels of knowledge in the model: one is direct benefit to the sector’s own knowledge stock, and the other is indirect benefit by spillover from other sectors’ knowledge. The second channel needs to be the point of focus. In manufacturing sectors overall, SME exerts a stronger spillover effect in knowledge than LE. Therefore, the improvement of innovative capability in SME causes sequential effects to the productivity of LE. The discussion in this chapter is significant because the analysis on the effect of R&D by firm size is raised from a firm-level approach to an industry and national level approach. Specifically, among recent attempts to adopt the input-output table in the issues of firm size, Chapter 5 presents a possibility to enlarge the inter-industry analysis to the framework of general equilibrium.

6.2 Policy implication

The final goal of policy is to benefit the public, even when the policy targets a specific firm group, hence policy-maker need to have a macroeconomic perspective when designing policy by firm size. However, the macroeconomic impacts of policy incentives that discriminate based on firm size are difficult to determine. Just as inter-industrial relationships in a certain nation are complex, the interrelation between SMEs and LEs is not simple due to the distinctive business status for each enterprise. According to the interrelation, the policy incentive for either size group may have different impacts on the national economy.

Specifically regarding the issue of knowledge stock, the increase of knowledge stock of SMEs turns out to be more effective for the national economy than that of LEs, as already discussed in Chapter 5. In other words, when the same amount of tax incentive is available, the SME-biased support would cause a greater positive effect on the whole economy. Therefore, the innovation policy for promoting innovation capacity of SMEs is socially acceptable in order to achieve not only higher productivity of the entire industry, but also greater welfare for consumers.

When examining the result from the perspective of firm, it is a reminder of the necessity of symbiosis between LEs and SMEs. The discussion in Chapter 5 emphasized the positive path from SMEs to LEs: the enhancement of SMEs' productivity not only benefits SMEs themselves, but also transfers to LEs through the spillover effect. However, the same effect in the opposite direction is also found, with the only difference being its smaller quantity. Therefore, it is clear that the overall economy can also profit if the knowledge transfer from LEs to SMEs becomes greater. Because LEs and SMEs are closely related through supply and demand of their output, the progress of any side results in the consequent progress of the other side.

In Korean industry environment so far, inter-enterprise relationship and cooperation have been usually led by large firms, and they tend to unilaterally absorb the innovative achievement of SMEs, such as know-how and newly developed technology. In other words, SMEs gain relatively smaller benefits in knowledge and know-how when collaborating with LEs. This can be linked to the contractor-subcontractor conflict between LEs and SMEs, one of the hot controversial social issues in Korea. From the perspective of the policy-maker, policies such as supporting joint R&D projects between LEs and SMEs can be considered in order to induce the positive externality of productivity spillover and the accompanying growth of both LEs and SMEs.

Bibliography

Acemoglu, D., Johnson, S., & Robinson, J. A. (2000). The colonial origins of comparative development: An empirical investigation. *The American Economic Review,* 91(5), 1369–1401.

Acs, Z. J., & Audretsch, D. B. (1988). Innovation in large and small firms: an empirical analysis. *The American Economic Review*, 78(4), 678–690.

Acs, Z. J., & Audretsch, D. B. (1991). R&D, firm size and innovative activity. In Z. J. Acs & D. B. Audretsch (Eds.), *Innovation and technological change: An international comparison* (pp. 39-59). New York: Harvester Wheatsheaf.

Acs, Z. J., & Audretsch, D. B. (2003). Innovation and technological change. In Z. J. Acs & D. B. Audretsch (Eds.), *Handbook of entrepreneurship research: An interdisciplinary survey and introduction* (pp. 55-79). Boston, MA: Kluwer.

Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, 60(2), 323-351.

Aghion, P. (2011). Industrial policy, entrepreneurship and growth. In D. B. Audretsch, O. Falck, & S. Heblich (Eds.). *Handbook of research on innovation and entrepreneurship* (pp. 45-54). Cheltenham, UK: Edward Elgar Publishing.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In R. Nelson (Ed.), *The rate and direction of inventive activity: Economic and social factors* (pp. 609-626). Princeton, NJ: Princeton University Press.

Baldwin, W., & Scott, J. (1987). *Market structure and technological change*. Chichester: Harwood.

Becker, G. S. (1964). *Human capital: a theoretical analysis with special reference to education*. New York: Columbia University Press.

Beckman, J., Hertel, T., & Tyner, W. (2011). Validating energy-oriented CGE models. *Energy Economics*, *33*(5), 799-806.

Bor, Y. J., Chuang, Y. C., Lai, W. W., & Yang, C. M. (2010). A dynamic general equilibrium model for public R&D investment in Taiwan. *Economic Modelling*, *27*(1), 171-183.

Bound, J., Cummins, C., Griliches, Z., Hall, B. H., & Jaffe, A. B. (1984). Who does R&D and who patents? In Z. Griliches (Ed.), *R&D patents and productivity* (pp. 21-54). Chicago: University of Chicago Press.

Burniaux, J. M., & Truong, T. P. (2002). *GTAP-E: an energy-environmental version of the GTAP model* (GTAP Technical Papers 16). Center for Global Trade Analysis, Purdue University.

Bye, B., Fæhn, T., & Heggedal, T. R. (2009). Welfare and growth impacts of innovation policies in a small, open economy; an applied general equilibrium analysis. *Economic Modelling*, *26*(5), 1075-1088.

Bye, B., Fæhn, T., Heggedal, T. R., Jacobsen, K., & Strøm, B. (2008). *An innovation and climate policy model with factor-biased technological change: a small, open economy approach* (Report no. 2008/22). Statistics Norway.

Chandler A. D. (1990). *Scale and scope: the dynamics of industrial capitalism*. Cambridge, MA: Harvard University Press.

Chang, H. J. (2002). *Kicking away the ladder: Development strategy in historical perspective*. London: Anthem Press.

Chung, Y. S. (2006). A study on the gap in productivity and earnings between large and small-medium enterprises: An analysis of the report on Mining and Manufacturing Survey. *The Korean Small Business Review*, 28(4), 135-161. (in Korean)

Cohen, W. M. (1995). Empirical studies of innovative activity. In P. Stoneman (Ed.), *Handbook of the economics of innovation and technological change*. Boston: Blackwell.

Cohen, W. M. (2010). Fifty years of empirical studies of innovative activity and performance. In B. H. Hall, & N. Rosenberg (Eds.), *Handbook of the economics of innovation Vol. 1* (pp. l29-213). UK: Elsevier.

Cohen, W. M., & Klepper, S. (1996). A reprise of size and R&D. *The Economic Journal*, 106(437), 925-951.

Cohen, W. M., Levin, R. C., & Mowery, D. C. (1987). Firm size and R&D intensity: A re-examination. *The Journal of Industrial Economics*, 35(4), 543-565

Comanor, W. S. (1967). Market structure, product differentiation, and industrial research. *The Quarterly Journal of Economics*, 81(4), 639–657.

Cook, L. H. (1980). *Validation of a Johansen-Type Multi-Sectoral Model: Norway, 1949–*

1961 (Doctoral dissertation), Department of Economics, Monash University, Australia.

Das, D. D., & Powell, A. A. (2001). Absorption capacity, structural similarity and embodied technology spillovers in a 'Macro' model: An implementation within a computable general equilibrium framework. *The Korean Journal of Policy Studies*, 16(1), 111-132.

Dennis, W. (1999). Research mimicking policy: Entrepreneurship/small business policy in the United States. In D. L. Sexton & H. Landstrom (Eds.), *Handbook of entrepreneurship* (pp. 64-82). Oxford, UK: Blackwells.

Diao, X., Roe, T., & Yeldan, E. (1999). Strategic policies and growth: an applied model of R&D-driven endogenous growth. *Journal of Development Economics*, 60(2), 343–380.

Diao, X., Elbasha, E. H., Roe, T. L., & Yeldan, A. E. (1996). *A dynamic CGE model: An application of R&D-based endogenous growth model theory* (EDC working paper 96-1). Economic Development Center, University of Minnesota.

Dixon, P. B., Harrower, J. D., & Vincent, D. P. (1978), *Validation of the SNAPSHOT model* (Preliminary Working Paper SP-12), IMPACT Project, Melbourne.

Dixon, P. B., & Rimmer, M. T. (2010). Validating a detailed, dynamic CGE model of the USA, *The Economic Record*, 86(s1), 22-34.

Dixon, P. B., & Rimmer, M. T. (2013). Validation in computable general equilibrium modeling. In P. B. Dixon & D. Jorgenson (Eds.), *Handbook of computable* *general equilibrium modeling* (pp.1271-1330). Waltham, MA: North-Holland.

Evenson, R. E., Kortum, S., & Putman, J. (1988). *Estimating Patents by Industry Using the Yale-Canada Patent Concordance* (mimeo). New Haven: Yale University.

Galbraith, J. K. (1956). *American capitalism* (rev. ed.). Cambridge, MA: Riverside Press.

Galbraith, J. K. (1967). *The new industrial State*. Princeton NJ: Princeton University Press.

Gellman Research Associates (1982). The relationship between industrial concentration, firm size, and technological innovation. Washington, D.C.: US Small Business Administration, Office of Advocacy.

Ghosh, M. (2007). R&D policies and endogenous growth: A dynamic general equilibrium analysis of the case for Canada. *Review of Development Economics*, 11(1), 187–203.

Goulder, L. H., & Schneider S. H. (1999). Induced technological change and the attractiveness of CO2 abatement policies. *Resource and Energy Economics*, 21(3), 211-253.

Grabowski, H. G. (1968). The determinants of industrial research and development: A study of the chemical, drug, and petroleum industries. *The Journal of Political Economy*, 76(2), 292-306.

Graves, S. B., & Langowitz, N. (1993). Innovation productivity and returns to scale in the pharmaceutical industry. *Strategic Management Journal*, 14(8), 593–605.

Griliches, Z. (1973). Research expenditures and growth accounting. In: B. R. Williams

(Ed.), *Science and Technology in Economic Growth* (pp. 59-83). New York: John Wiley & Sons.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics*, 10(1), 92-116.

Griliches, Z. (1980). Returns to Research and Development Expenditures in the Private Sector. In J. W. Kendrick & B. N. Vaccara (Eds.), Chicago: University of Chicago Press.

Griliches, Z. (1988). Productivity puzzles and R&D: Another nonexplanation. *Journal of Economic Perspectives*, 2(4), 9-21.

Guellec, D., & Van Pottelsberghe de la Potterie, B. (2003). The impact of public R&D expenditure on business R&D. *Economics of innovation and new technology*, 12(3), 225-243.

Hall, B., & Van Reenen, J. (2000). How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy, 29*(4), 449-469.

Hamberg, D. (1964). Size of firm, oligopoly, and research: The evidence. *Canadian Journal of Economics and Political Science*, 30(1), 62-75.

Henderson, R., & Cockburn, I. (1997). Firm size and research productivity in drug discovery. In S. Jacobzone (Ed.), *La santé: trajectoires d'avenir*. Paris: INSEE.

Hertel, T. W. (Ed.). (1997). *Global trade analysis: Modeling and applications*. Cambridge, MA: Cambridge University Press. Updated information available at http://www.gtap.org.

Holtz-Eakin, O. (2000). Public policy toward entrepreneurship, *Small Business Economics*, 15(4), 283-291.

Hong, C., Yang, H., Hwang, W. S., & Lee J. D. (2014). Validation of an R&D-based computable general equilibrium Model. *Economic Modelling*, 42, 454–463.

Horowitz, I. (1962). Firm size and research activity. *Southern Economic Journal*, 28(3), 298-301.

Howe, J. D., & McFetridge, D. G. (1976). The determinants of R&D expenditures. *Canadian Journal of Economics*, 9(1), 57–71.

Johansen, L. (1960). *A multi-sectoral study of economic growth*. Amsterdam: North-Holland Publishing Company.

Jung, H. S., & Thorbecke, E. (2003). The impact of public education expenditure on human capital, growth, and poverty in Tanzania and Zambia: A general equilibrium approach. *Journal of Policy Modeling*, 25(8), 701-725.

Kamien, M. I., & Schwartz, N. L. (1982). Market structure and innovation. Cambridge, MA: Cambridge University Press.

Kehoe, T. J., Polo, C., & Sancho, F. (1995). An evaluation of the performance of an applied general equilibrium model of the Spanish economy. *Economic Theory*, 6(1), 115-141.

Kehoe, T. J. (2005). An evaluation of the performance of applied general equilibrium models on the impact of NAFTA, In T. J. Kehoe, T. N. Srinivasan, & J. Whalley (Eds.), *Frontiers in Applied General Equilibrium Modeling* (pp. 341-377).

Cambridge, UK: Cambridge University Press.

Kim, W. K. (2013). *Analysis on the effect of R&D investment by firm size* (Issue paper 2013-305). Seoul: Korea Institute for Industrial Economics & Trade (in Korean).

Kim, K. H. (2014). Characteristics and implications from the SME policies in Korea and Germany, Presented at Korea-Germany Joint Conference by The Korea Chamber of Commerce & Industry, Seoul, Korea.

Kleinknecht, A. (1987). Measuring R&D in small firms: How much are we missing? *The Journal of Industrial Economics*, 36(2), 253–256.

Klepper, S. (1996). Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review*, 86(3), 562-583.

Křístková, Z. (2012). Impact of R&D investment on economic growth of the Czech Republic: A recursively dynamic CGE approach. *Prague Economic Papers*, 4, 412–433.

Křístková, Z. (2013). Analysis of private R&D effects in a CGE model with capital varieties: The case of the Czech Republic. *Czech Journal of Economics and Finance*, 63(3), 262-287.

Krueger, A. O., & Tuncer, B. (1982). An empirical test of the infant industry argument. *The American Economic Review*, 72(5), 1142-1152.

Krueger, A. O. (1990). Government failures in economic development. *Journal of Economic Perspectives*, 4(3), 9–23.

Lall, S. (1992). Technological capabilities and industrialization, *World Development*, 20(2), 165–186.

Landes, D. S. (1970). *The unbound Prometheus: technological change and industrial development in western Europe from 1750 to the resent*. Cambridge, MA: Cambridge University Press.

Lecca, P. (2009). *Three essays on regional economic modelling* (Doctoral dissertation). Department of Economics, University of Cagliari, Italy.

Lee, J. M. (2012). A study on the expansion of IO bable with separate account for SMEs in Korea. KIET Research Report 2012-172, Korea Institute for Industrial Economics & Trade (in Korean).

Lee, J. M. (2013). *A Study on the Structure of SME's Input Output Table in Korea* (KIET Research Report 2013-674). Seoul: Korea Institute for Industrial Economics & Trade (in Korean).

Legge, J. M. (2000). The economics of industrial innovation. *Review of Political Economy*, 12(2), 249–256.

Lemelin, A., & Decaluwé, B. (2007). *Issues in recursive dynamic CGE modeling: investment by destination, savings, and public debt. A survey*. (Working paper). Urbanisation, Culture et Société, INRS.

Levicki, C. (1984). *Small Business Theory and Policy*. Beckenham, UK: Croom Helm Ltd.

Link, A. N. (1981). *Research and Development Activity in US Manufacturing*. New York: Proger.

Link, A. N., & Bozeman, B. (1991). Innovative behavior in small-sized firms. *Small Business Economics*, 3(3), 179–184.

Link, A. N., Seaks, T. G., & Woodbery, S. R. (1988). Firm size and R&D spending: Testing for functional form. *Southern Economic Journal*, 54(4), 1027–1032.

Madsen, B., & Jensen-Butler, C. (2003) Accounting and modelling SMEs in the regional economy. In B. Fingleton, A. Eraydin, & R. Paci (Eds.), *Regional economic growth, SMEs, and the wider Europe* (pp. 129-148). Aldershot, UK: Ashgate Publishing.

Mansfield, E. (1964). Industrial research and development expenditures: Determinants, prospects, and relation to size of firm and inventive output. *The Journal of Political Economy*, 72(4), 319-340.

NABO (2012). *Intensive Report on National Budget Plan 2013 (III)* (Analysis on National Budget Plan, Series 9). Seoul: National Assembly Budget Office. (in Korean)

NABO (2013). *Report on National Budget Plan 2014 by Division (I)* (Analysis on National Budget Plan, Series 6). National Assembly Budget Office. (in Korean)

OECD (2004). *OECD productivity database: calculation of multi-factor productivity growth*, Organization for Economic Co-operation and Development. Retrieved from http://www.oecd.org/std/productivity-stats/29880777.pdf

OECD (2009). *Competition policy, industrial policy and national champions, Global forum on Competition* (DAF/COMP/GF(2009) 9). Directorate for Financial and

Enterprise Affairs Competition Committee, Organization for Economic Co-operation and Development.

Ortega-Argilés, R., Vivarelli, M., & Voigt, P. (2009). R&D in SMEs: a paradox?. *Small Business Economics*, 33(1), 3-11.

Pack, H., & Saggi, K. (2007). The case for industrial policy: A critical survey. *World Bank Research Observer*, 21(2), 267–297.

Pavitt, K., Robson, M., & Townsend, J. (1987). The size distribution of innovating firms in the UK: 1945–1983. *Journal of Industrial Economics*, 35(3), 297–316.

Romer P. M. (1990). Endogenous Technological Change. *The Journal of Political Economy*, 98(5), S71-S102.

Romero, I., & Santos, F. J. (2007). Firm size and regional linkages: A typology of manufacturing establishments in southern Spain. *Regional Studies*, 41(5), 571–584.

Rothaermel, F. T. (2001). Complementary assets, strategic alliances, and the incumbent's advantage: An empirical study of industry and firm effects in the biopharmaceutical industry. *Research Policy*, 30(8), 1235-1251.

Rothwell, R., & Dodgson, M. (1994). Innovation and size of firm. In M. Dodgson & R. Rothwell (Eds.) *The handbook of industrial innovation* (pp. 310-324), Cheltenham, UK: Edward Elgar.

Scherer, F. M. (1965). Firm size, market structure, opportunity, and the output of patented inventions. *The American Economic Review*, 55(5), 1097-1125.

Scherer, F. M., & Ross, D. (1990). *Industrial market structure and economic performance*. Boston: Houghton Mifflin.

Scherer, F. M. (1986). *Innovation and growth: Schumpeterian perspectives*. Cambridge, MA: MIT Press.

Schumpeter, J. A. (1912). *Theorie der wirtschaftlichen entwicklung*. Leipzig: Duncker & Humblot.

Schumpeter, J. A. (1942). *Capitalism, socialism and democracy*. New York: George Allen & Unwin.

Soete, L. L. (1979). Firm size and inventive activity: The evidence reconsidered. *European Economic Review*, 12(4), 319-340.

Storey, D. J. (2003). Entrepreneurship, small and medium sized enterprises and public policies. In Z. J. Acs & D. B. Audretsch (Eds.), *Handbook of entrepreneurship research*. Boston, Dordrecht and London: Kluwer.

Sue Wing, I. (2001). *Induced technical change in computable general equilibrium models for climate-change policy analysis* (Doctoral dissertation). Engineering Systems Division, Massachusetts Institute of Technology.

Sue Wing, I. (2003). *Induced technical change and the cost of climate policy* (Joint Program on the Science and Policy of Global Change Report no. 102). Cambridge, MA: Massachusetts Institute of Technology.

Taylor, L., Bacha, E. L., Cardoso, E. A. & Lysy, F. J. (1980). *Models of growth and distribution for Brazil*. New York: Oxford University Press for the World Bank.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, 15(6), 285-305.

Terleckyj, N. (1974). *Effects of R&D on the productivity growth of industries: An exploratory study* (Report No. 140). Washington, D.C.: National Planning Association.

Torres-Fuchslocher, C. (2010). Understanding the development of technology-intensive suppliers in resource-based developing economies. *Research Policy,* 39(2), 268–277.

USITC (2010). *Small and medium-sized enterprises: characteristics and performance* (Investigation No. 332-510). USITC Publication.

Valenzuela, E., Hertel, T. W., Keeney, R., & Reimer, J. J. (2007). Assessing global computable general equilibrium model validity using agricultural price volatility. *American Journal of Agricultural Economics*, *89*(2), 383-397.

Meijl, H. V. (1997). Measuring the impact of direct and indirect R&D on the productivity growth of industries: Using the Yale technology concordance, *Economic Systems Research*, 9(2), 205-211.

Verbič, M., Majcen, B., & Cok, M. (2009). *Education and Economic Growth in Slovenia: A Dynamic General Equilibrium Approach with Endogenous Growth*. Munich: University Library of Munich.

Visser, S. (2007). *R&D in Worldscan* (CPB Memorandum No. 189). CPB Netherlands Bureau for Economic Policy Analysis.

Worley, J. S. (1961). Industrial research and the new competition. *The Journal of Political Economy*, 69(2), 183-186.

Yang, H., Jung, S.M., & Lee, J. D. (2012). A study on the knowledge-based social accounting matrix. *Productivity Review*, 26(3), 257-285. (in Korean)

Zürn, M., Küster, R., Ellersdorfer, I., & Fahl, U. (2007). R&D investment and knowledge input in a technology oriented CGE model. Presented at EcoMod Conference on Energy and Environmental Modelling, Moscow.

Abstract (Korean)

중소기업은 우리나라의 경제에서 중요한 축을 담당하고 있는 주체이다. 따라서 중소기업의 혁신역량을 제고시키기 위한 정책적 노력이 지속되어왔다. 그러나 이러한 혁신역량 지원정책이 국가경제의 전반적인 성장에 충분한 효과를 발휘하는지, 그리고 그 정도는 어느 정도인지에 대한 논의는 비교적 활발하지 못하였다. 이는 기업 대상 정책의 효과를 산업과 경제 전반에서 측정할 수 있는 분석틀이 제안되지 않았기 때문인 것으로 판단된다.

본 논문은 혁신역량의 증대정책이 기업규모별로 주어졌을 때 해당 정책이 거시 경제에 미치는 영향을 정량적으로 파악할 수 있는 분석법을 제시하고자 하는 동기에서 출발하였다. 연산일반균형은 생산부문을 담당하는 산업간 거래관계와 함께 소비부문의 주체인 가계 및 정부, 그리고 투자와 무역 부분까지 포괄한 거시경제현상을 설명하는 도구이기 때문에, 혁신역량에 대한 요소를 부가한다면 연구 목적을 달성할 수 있는 적절한 방안이 될 것으로 생각하였다.

정책의 효과를 분석하기에 앞서, 혁신역량을 지식으로 대리하여 반영한 지식기반 연산일반균형 모형을 구성하고 그 현실적합성을 검증하였다. 제안된 모형에서 지식은 생산을 위한 주요 요소로 쓰이며, 다른 주체가 보유한 지식으로부터 파급효과를 가진다는 점을 반영하였다. 과거 데이터를 이용하여 비교한 결과 이러한 가정이 반영된 모형이 그렇지 않은 모형보다 현실 데이터를 더 잘 추정한다는 결과를 얻을 수 있었다.

이에 기반하여 기업규모별 혁신역량 증대정책의 효과를 구성한 모형을 통해 분석하였다. 기업규모별 분석을 위해, 기초 데이터가 되는 사회계정행렬의 생산부문을 대기업과 중소기업으로 구분하고, 연구개발 투자효율에 대한 항을 모형에 추가하였다. 해당 모형을 이용하여 연구개발 활동에 대한 세율을 감소시켜 주는 정책을 분석의 대상으로 하였다. 분석 결과, 동일한 세금변화율을 적용할 경우에는 대기업에 적용하는 것이, 그리고 동일한 양의 세액을 공제하는 경우에는 중소기업에 적용하는 것이 더 큰 경제성장을 이끌어냄을 알 수 있었다.

특히 두 번째 결과는 정부의 정책예산에 제약이 있을 시, 중소기업에 대한 정책을 우선하는 것이 더 효과적이라는 함의를 지닌다. 이러한 결과가 도출된 것은 중소기업의 지식스톡 증가와 이를 통해 야기되는 타 섹터로의 지식 스필오버 효과가, 대기업의 경우에 비해 더 큰 연쇄효과를 가져오기 때문인 것으로 파악되었다. 결국 본 연구를 통해 중소기업에 대한 혁신역량 지원정책은 생산과 소비의 증대로 이어져 경제 전체에 긍정적인 효과를 가져온다는 점을 확인하고 그 결과를 정량적으로 도출할 수 있었다.

주요어 : 중소기업, 혁신역량, 스필오버 효과, 연구개발 세제혜택, 지식기반 연산일반균형
학 번 : 2010-30274