Economy-wide Impact Assessment of Public Procurement for Innovation: A Computable General Equilibrium Approach

Shin, Ki Yoon[1], Yeongjun Yeo[1], Sungmoon Jung[2], Jeong-Dong Lee[1]

1 Technology Management, Economics and Policy Program, Seoul National University, Gwanak-gu, Seoul 08826, Republic of Korea; E-Mails: kiryoon92@snu.ac.kr (K.S.); yyj913@snu.ac.kr (Y. Y.) jeongdonglee@gmail.com (J.L.)

2 Busan Institute of Science and Technology Evaluation and Planning, Haeundae-gu, Busan 48058, Republic of Korea

---

Abstract

Recently, there is growing interest in demand-side innovation policy to guarantee enough demand for innovative suppliers. Public procurement for innovation (PPI) is one of the representative demand-side innovation policies, and has been evaluated as the most efficient policy tool for stimulating innovation. Many countries allocate a large proportion of government spending to public procurement, and most public demand in some technologies or industries, such as energy, environment, healthcare, and construction, is generated by public procurement. Despite the interest and effectiveness of public procurement for innovation, there is little work on policy impact assessment of public procurement for innovation from an economy-wide perspective. Most previous research has been limited to case studies and qualitative analysis. However, since public procurement for innovation has not only a direct demand effect but also indirect effects related to production, private demand, and innovation, it is worthwhile to analyze the policy impact of public procurement for innovation with an integrational approach. This study analyzes the various paths of policy impact of public procurement for innovation with a literature review and investigates the economy-wide effect of public procurement for innovation with knowledge-based computable general equilibrium (CGE). Knowledge-based CGE model includes R&D related account such as R&D capital and R&D investment in order to investigate the impact of innovation policies. In addition, This study uses further-modified knowledge-based CGE model with the account of public procurement and electric vehicle industry which is the new emerging industry. Moreover, in the equation structure, this study includes the equation of learning effect between cumulative production and unit cost for production. This study addresses the question whether economy-wide policy impact assessment is necessary before policy implementation, especially for innovation and industrial policy in certain sectors. The integrational framework suggested in this study could generate numerical and quantitative evidence for ex-ante policy impact evaluation, and it could be utilized for other innovation and industrial policy and policy mixing.

Keywords: Public Procurement for Innovation, Economy-wide Policy Impact, Computable General Equilibrium, Knowledge

---

1. Introduction

Due to the stagnation of economic growth in many countries, there is growing interest on the way to stimulate innovation which is key driving-force of economic revitalization. For many years, many countries have succeeded to become wealthier thanks to the government policy on technology and innovation, despite the differences on degree of intervention. The main scheme of technology and innovation policy for several decades was supply-side innovation policy such as R&D subsidy and tax grants which directly fosters the R&D to develop new innovative products and services. However, recently, some innovative ideas and technology cannot be finalized as final products due to lack of enough market demand in many countries. Therefore, many governments start to change their policy direction from supply-side innovation policy to demand-side innovation policy that has a goal of increasing market demand of innovation results.

Public procurement of innovation (PPI) is the representative tools among demand-side innovation policy to enhance public demand on innovative products and lead private demand on it. Public procurement is commonly used in many countries with the purpose of purchasing the goods for public institutions' uses. PPI broadens this goals of public procurement into stimulating innovation in private procurers.

Many studies pointed out the effectiveness of PPI in fostering innovation compared to other innovation policy tools. They stated that PPI can stimulate innovation from the early R&D stage to commercialization in private innovators, and enhance the market demand of innovative products with market creation, escalation, and consolidation. However, these effects are scattered in various literatures so the process which PPI leads R&D, innovation, market expansion, and ultimately, economic growth is not provided yet. On the contrary, it is significant and important to analyze the policy impact of PPI in economy-wide and integrational perspective since PPI influences on wide range of economy.

From this perspective, this study uses computable general equilibrium (CGE) modelling to capture economy-wide impact of PPI. CGE modelling help to examine the economy with respect to the interaction among various economic agents and the results from it in economic indicators. Specifically, knowledge-based CGE model which help to find R&D and innovation related policy impact is used for the analysis. From knowledge-based CGE model, economy-wide policy impact assessment of PPI can be done by checking the change of not only macro-economic indicators but also knowledge stocks, knowledge capital, and learning effects.

This study is organized as follows. Chapter 2 reviews previous literature of various innovation policy, policy trend and impact of PPI. The studies on knowledge-based CGE model also introduced in the Chapter 2. Chapter 3 states the methodology of knowledge-based CGE model with the construction of social accounting matrix (SAM) and the equation systems of CGE model. Chapter 4 reveals the result from the simulation based on the model with respect to economy-wide indicators and innovation-related variables. Finally, Chapter 5 concludes the study with economy and policy implication.

2. Literature Review

2.1. Two Categories of Innovation Policy Tools

Edler and Georghiou (2007) divided the innovation policy tools into two categories: supply-side innovation policy and demand-side innovation policy. Until now, supply-side innovation policy has been widely used in many countries in order to foster new technology and industry, and most utilized policy tools are R&D subsidy, R&D tax grants, and venture capital funds. On the other hand, many countries, especially some developed countries, felt the limitation of supply-side innovation policy since they have experienced long-run economic recession. Many experts point out that this limitation is due to the target of the supply-side innovation policy tools, which they only focuses on technology development, not on technology diffusion. For this reason, among the developed countries such as the United States, Japan, and some European countries, there is a growing interest on demand-side innovation policy that has the goal of both technology development and market penetration of the technology. It is because there are many cases which succeeded for developing the high-end technology but failed for commercialization due to the shortage of market demand.

Although there are many demand-side innovation policy tools such as regulation, standardization, and private demand subsidy, public procurement for innovation (PPI) is one of the representative demand-side innovation policy tools. Government utilizes PPI with a strategic goal of stimulating innovation with specifying innovative characteristics of the procured products. The procured products do not have to be the final products, but they can be services or even technologies, and government procures the products which do not exist yet but are about to emerge or develop in a short period (Edquist et al., 2000). McCrudden (2004) stated the status of PPI in European countries, where PPI is widely used as innovation strategy, utilizing it for environment-friendly materials and products to achieve both economic growth and mitigation of environmental destruction.

Many researches have done the comparison of the innovation impact between supply-side innovation policy and demand-side innovation policy (Mowery and Rosenberg, 1979; Geroski, 1990; Rothwell, 1994; Borras and Edquist, 2013). They commonly concluded that demand-side innovation policy has more direct and higher effect for fostering innovation than supply-side innovation policy. Especially, Edquist et al. (2015) stated that public procurement is the supreme method for fostering innovation compared to other innovation tools. Geroski (1990) also mentioned that public procurement has higher effect for stimulating innovation than R&D subsidy or R&D tax grants in the long-term perspective. Palmberg (2004) researched empirically, and concluded that public procurement led to successful commercialization with the investigating various communization-oriented innovation projects between 1984 to 1998.

As mentioned before, the strength of PPI for stimulating innovation is because PPI focuses on both technology development and market demand by specifying the demand for innovation results. Edler and Georghiou (2007) stated that private innovators can experience reduced market uncertainty which comes from unclear market demand in the early stage of commercialization. Therefore, the beneficiaries of PPI can earn profit from the innovation much more stable and it generates further innovation and interaction between private sector and suppliers (Aschhoff and Sofka, 2009)

2.2. Recent Status of Public Procurement for Innovation

Public procurement is widely used in many countries not only as a mean of stimulating innovation but also for general purpose of purchasing the products for the use of public sector. OECD (2015) stated that about 18% of each OECD member states' GDP is used for its public procurement spending, and energy, environment, construction, and public health sector are main target for it.

In Korea, Public Procurement Service (PPS) which manages public procurement both general and innovation-oriented has tried to utilize public procurement for fostering innovative SMEs. Especially, innovative products with environment-friendly features are encouraged to be purchased by public institution in priority (Choi, 2014). In addition, there has been a certification system for the innovative products in early-stage of commercialization by the government from 1993, and it is regulated for public institutions to have PPI contract from certified firms and products more than 20% of their total amount of public procurement (The Federation of Korean Industries, 2011)

East Asian countries including Korea, where government has done a great role in economic growth, also recognizes the importance of public demand in fostering and nurturing private sectors, especially domestic firms. For instance, both private and public Japanese firms with high-tech technology was benefited from the government regulation which the public institution should buy the products from them preferentially (Patrick, 1986). Sorte Junior (2016) pointed that public procurement has led to economic and industrial growth in Japan with a close tie between private or public suppliers and government institutions.

From 2006, China also initiated utilizing public procurement for stimulating innovation, especially in environmental sector. Chinese government regulates its government and public institution to buy environment-friendly products with certification from the government (Public Procurement Service, 2010).

Originally, the concept of PPI is widely used in European Union. EU declared Lead Market Initiative (LMI) for creating markets for innovation results with the enough public demand. Health sector is one of the representative sectors of LMI for fostering innovation and demand. STOPandGO project which stands for Sustainable Technologies for Older People – Get Organized started from April 2014, and EU has a goal to develop and diffuse technology for telehealth and telecare for the elderly. EU does not limit its scope in the public hospitals but try to gather the participation of many related industries to foster innovation and create the demand (Mori et al., 2016).

The United States has also been doing PPI in order to stimulate and create the market for innovation results. US PPI is mainly for ICT and defense-related sectors. Sung and Park (2013) gave the example of PPI in US, which public institution was encouraged to use new ICT technology such as cloud storage before the private diffusion and was given demand incentive for purchasing it in public administration process.

2.3. Policy Impact of PPI

Since PPI influences on the entire stages of product development from early R&D to commercialization, its policy impact also varies from the stages. In the early stage, PPI stimulates the innovation in the supplying firms. By PPI, private suppliers can be provided the information on desired or preferred properties on their products. This is because public institution usually makes a comment on their preference on procured products, and it is mainly related to the R&D and innovation activity of the suppliers. Private technology developers often experience technology uncertainty on their R&D because it does not forecast the capability of the developed technology. PPI can reduce this technology uncertainty, and private firms can increase their R&D investment to conduct innovation (Geroski, 1990). This increased volume of R&D investment fosters further development of the products (Edquist and Zabala-Iturriagagoitia, 2012; Hommen and Rolfstam, 2009).

In scale-up and demonstration stage, private firms can have testing ground their pilot projects through PPI. This experience help them to adapt and modify their technology and product through the public consumers' reactions, and it ultimately stimulates the creation of the market (Rothwell, 1994; Edquist, 1996). For example, several technology inventions in environment-friendly way such as low-electricity copy machine, energy-efficient TV and light bulbs were thanks to the public demand on them in the early stage of demonstration (Westling, 2000). Many researchers pointed out the difficulty which private innovators often face in scale-up and demonstration stage. This difficulty emerges from the market uncertainty that the suppliers cannot be guaranteed the demand for their products and are reluctant to invest more on commercialization efforts. PPI can reduce the market certainty and drive the suppliers to continue to develop their products into commercialization (Bauer et al., 2010). Empirically, the number of SMEs which participated in the Canadian PPI project, LightSavers, increased because the participants began to experience reduced market risk with guaranteed public demand (IISD, 2012).

In commercialization stage, PPI stimulate the diffusion of the innovation results. Market stages can be divided into three, creation, escalation, and consolidation, and PPI help to create and consolidate the market of new innovative products in private market. In the creation period, public institution continues to reduce technology and market uncertainty by purchasing the innovation results. As mentioned before, this effort of public sector help the private firms to increase the investment on further product development and diffusion effort (Edler and Georghiou, 2007). In addition, Bauer et al. (2010) investigated 31 cases of PPI on green products in Sweden and Denmark. They empirically concluded that the cases make private demand on green products increase and stated the reasons for it that public demand make private consumers think the procured products as certified one.

PPI also helps the escalation of the market for innovative products. Korkmaz et al. (2012) suggested that the large volume of public demand can reduce the unit production cost of the firms and it stimulates further expansion of production volume. Marron (2003) also stated that PPI helps the further investment on production facility and the private innovators can experience economies of scale and learning by doing effect to reduce required input. Moreover, procuring firms increase not only production facility but also R&D activity to develop their products' features and enhance their market share in the market. It is important to have larger R&D investment since accumulated knowledge from R&D can make spillover effect in the firms, industries, and entire economy (Adams, 1990; Terleckyj, 1980).

The market, however, can be monopolized through PPI because early PPI contract often has one or small number of the procuring firms. In market consolidation period, PPI can resolve this monopoly condition by adjusting the contract options and enhance competitive environment and consumer utility (Uyarra and Flanagan, 2010). Competitive market also generates further intra-industry or intra-market innovation and further specialization of the products (Brannlund et al., 2009). These innovation and specialization can reduce the prices of the products, and further increase the effectiveness and consumer utility. Empirically, European Commission (2012) analyzed that Italia experienced 27% reduced amount of cost to build approximately 5,000 public administration building which was conducted in PPI contracts with energy-saving technology.

2.4. Knowledge-based Computable General Equilibrium Model

Computable general equilibrium (CGE) model is economic model of equations systems which describes the general equilibrium in the economy (Choi., 2002). CGE model's equations contain several variables related to economic agents such as household, firms, government, and foreign sector and their interactions. Therefore, it is widely implemented in policy impact assessment of various fields (Hosoe et al., 2010). Since the importance of innovation policy in economy is growing recently, some studies started to adapt CGE model into innovation policy impact assessment. Specifically, there are some researches which tried to define the concept of R&D, knowledge, and innovation explicitly in equations systems of CGE model, often called knowledge-based CGE model.

First, Diao et al. (1999) constructed the CGE model with explicit definition of R&D production of new designs different from common final goods' production. R&D production is done by combination of labor, capital, and given knowledge stock. Labor, capital, and industry-specific knowledge are inputs to produce final goods. Industry-specific capital is linked with knowledge stocks' amount. They analyzed the impact of trade liberalization in Japanese economy with the base year of 1992, and concluded that the policy stimulates the knowledge spillover effect of foreign knowledge.

Bye et al. (2009) did the innovation policy impact assessment with CGE model, specifically by comparing R&D subsidy, capital subsidy, and investment subsidy on R&D production. They added the R&D production sector and differentiated-capital production sector with ordinary final good production sectors. They concluded that demand subsidy on R&D products cannot foster economic growth or social utility improvement since they had low elasticity of demand compared to that of other final goods.

Hong et al. (2014) tried to validate knowledge-based CGE model they constructed with Korean case. The model includes knowledge capital which explicitly redefined from physical capital. Knowledge capital is accumulated by knowledge capital investment from knowledge capital composite good. Knowledge capital good is generated by intermediate and R&D value added with combination of labor and capital in R&D activity. They concluded after the validation of the model that the model generally follows the real path of Korean economy in GDP, production, and R&D activity.

Hong and Lee (2016) also used knowledge-based CGE model to analyze different policy effect of R&D tax grants different from the size of the firm. The model recognized knowledge as production factor with labor and capital. In addition, they constructed the spillover effects of knowledge stock into equation systems. The knowledge stock is accumulated by the investment on R&D both from public and private sector. This study concluded that the R&D tax grants for SMEs is more effective to stimulate overall Korean GDP.

In sum, there have been some tries to construct knowledge-based CGE model to assess innovation policy and generated interesting results on macro-economic change. However, there was no adaptation of knowledge-based CGE model on PPI's policy impact assessment. This study tries to analyze the PPI with knowledge-based CGE model to capture both market or economy and technology or innovation impact of it.

3. Methodology

3.1. Construction of Knowledge-based Social Accounting Matrix

Social Accounting Matrix (SAM) describes the snapshot of economic systems in macro-economic perspective considering the interaction among the economic agents (Pyatt and Round, 1985). This study modifies the SAM of Republic of Korea to analyze the policy impact of PPI with market and innovation effects. Since modified SAM explicitly defines knowledge as production factor and capital, it is called knowledge-based SAM, which is introduced in Hong et al. (2014).

In Input-Output table of Korea, R&D expenditure is recorded as intermediate demand. Hong et al. (2014) regarded the amount of knowledge factor as the spending of each industry on the sectors of research institution and in-house R&D. Moreover, for transforming of R&D spending as knowledge capital, the expenditure of three sectors which are public research institution, non-profit research institution and in-house R&D was extracted. In addition, R&D investment was included in capital investment account, and its amount transformed into knowledge capital investment.

Furthermore, since public institution spends the government budget for PPI, the amount of PPI is in government account in basic SAM. Due to the shortage of the data on PPI, this study extracted the total amount of public procurement from government spending. It is reasonable in the perspective that public procurement for new emerging industry is considered as PPI. Table 1 depicts the structure of SAM in this study.

Table 1. Structure of SAM

		Activity	Factor inputs			Institution			Investments			Tax	ROW		Total
		Intermediate	Labor	Capital	Knowledge	Household	Govern-ment	Public Procurement	Physical Capital	Knowledge capital			Export	Import	
										Private	Public				
Activity	Domestic Intermediates (28 industries)														
	Imported Intermediates (28 industries)														
Factor inputs	Labor														
	Capital														
	Knowledge														
Instituti-ons	Household														
	Government														
	Public Procurement						**TP**								
Investments	Physical Capital														
	Know. Capital – Private														
	Know. Capital – Public														
Tax															
ROW	Export														
	Import														
Total															

3.2. Construction of Knowledge-based CGE Model

Based on the knowledge-based SAM, this study uses knowledge-based CGE (KCGE) model, which is also introduced in Hong et al. (2014), to assess the policy impact of PPI. As mentioned in section 3.1., they defined knowledge as one of the production factor and capital which can be generated from private and public investment. This study includes the variable of PPI to assess the policy impact in endogenous manner. Figure 1 describes the equation structure of KCGE model.

For production, each firm generates output with the function of intermediate inputs and composited value-added which includes labor, capital, and knowledge as Eq. (1) and (2).

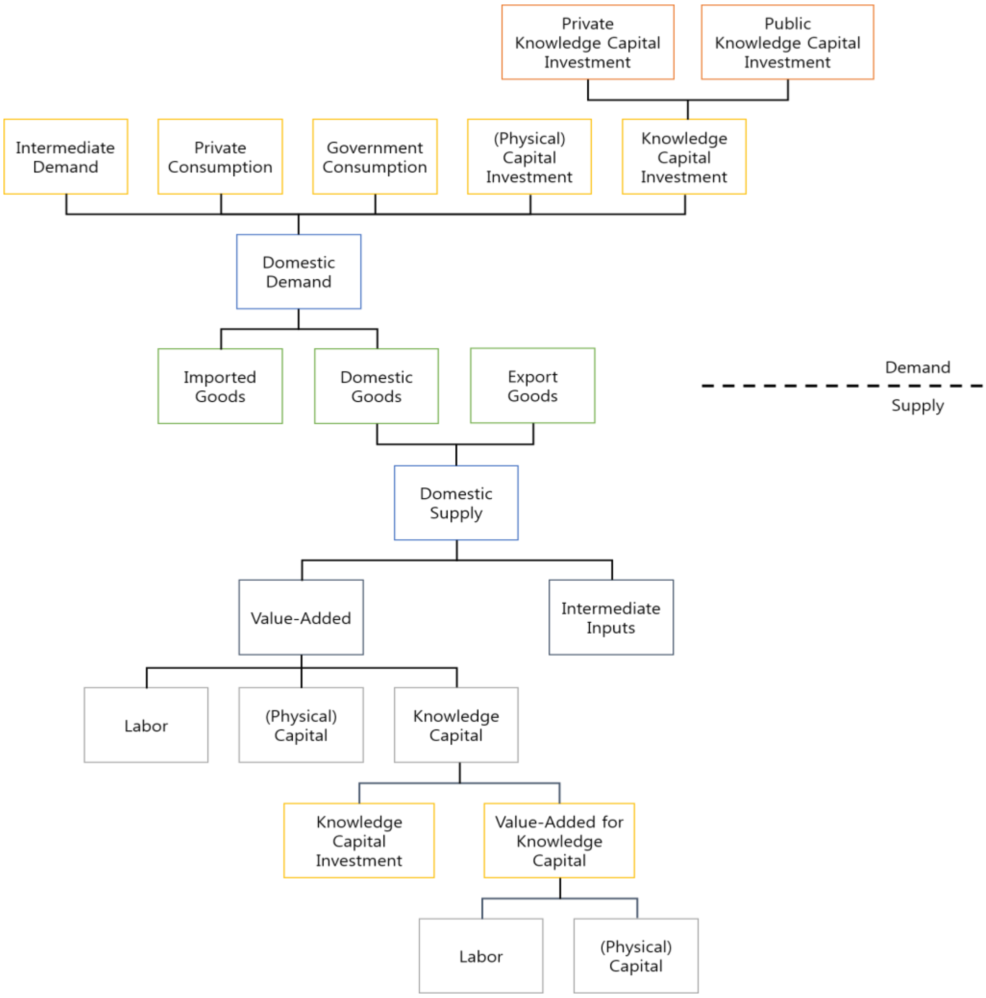

Figure 1. Equation structure of KCGE model

$$Z_j = \min\left[\frac{X_{1j}}{ax_{1j}^0}, \frac{X_{2j}}{ax_{2j}^0}, \dots, \frac{X_{nj}}{ax_{nj}^0}, \frac{VA_j}{ava_j^0}\right] \qquad (1)$$

$$VA_i = \theta_i^0 \cdot [\beta_{1i}^0 L_i^{-\rho} + \beta_{2i}^0 K_i^{-\rho} + (1 - \beta_{1i}^0 - \beta_{2i}^0) H_i^{-\rho}]^{-\frac{1}{\rho}} \qquad (2)$$

As indicated in Figure 1, labor and capital factors are also put into production of knowledge capital. The accumulation process of knowledge capital is similar with the production activities, which knowledge capital investment and value-added which includes labor and capital form it. Eq. (3) and (4) illustrates the function of knowledge capital accumulation.

$$RDZ_{rdt} = \min\left[\frac{XVRD_{rdt,1}}{axrd_{rdt,1}^0}, \frac{XVRD_{rdt,2}}{axrd_{rdt,2}^0}, \dots, \frac{XVRD_{rdt,n}}{axrd_{rdt,n}^0}, \frac{RVA_{rdt}}{avard_{rdt}^0}\right] \qquad (3)$$

$$RVA_{rdt} = \varphi_i^0 \cdot [\psi^0 RL_{rdt}^{-\rho} + (1 - \psi^0) RK_{rdt}^{-\rho}]^{-\frac{1}{\rho}} \qquad (4)$$

Because knowledge is defined as additional production factor, household also earn income from providing knowledge factor, the components of household income is three: labor income, capital income, and knowledge capital income. In addition, since labor and capital are used in both production activity and knowledge capital accumulation, household earn income from both activities. Household can spend its earning in consumption, saving, and tax.

Government income is from tax payments of private sector, which include income tax, tariff, and indirect tax. Government spends its income ordinary government expenditure, public procurement. The difference between government income and spending is defined as government saving.

In this paper, knowledge capital generates spillover effect on the production activities, and the amount of effect is proportion to the volume of intermediate transactions between industries in private sector (Terleckyj, 1980). Moreover, private production sector also uses public knowledge stock and the amount of spillover effect increases. Finally, knowledge spillover which from private and public knowledge stock positively related to the productivity of each sector in dynamic process. Eq. (5), (6), and (7) describes the knowledge spillover effect in production activity.

$$INTINDSP_j = \sum_{j,j \neq i} \lambda_{ji}^{0} \cdot H_j \tag{5}$$

$$SPCOEF_j = spc_j^0 \cdot INTINDSP_j^{rdedls_j} \cdot HG^{grdelas_j} \tag{6}$$

$$ava_j^1 = \frac{ava_j^0}{SPCOEF_j} \tag{7}$$

Investment has two categories: physical capital investment and knowledge capital investment. Total amount of investment is sum of these two parts. Saving is gathered from private sector, government, and household, and total amount of saving is same as that of investment, which is macro-closure.

For international trade, home country imposes tariff on the import products but do not subsidizes for export. Domestic demand is the sum of domestically consumed inter-country produced goods and imported goods. Domestic supply is the sum of domestic goods consumed inside the country and exported goods.

Next, for production again, productivity is enhanced not only by knowledge spillover effect but also accumulation of production volume, which is learning by doing. Productivity enhancement from learning by doing is shown as a form of unit cost reduction and it makes private consumers be more likely to consume the products with lower price (Krzyzanowski et al., 2008). This study constructs the model of learning by doing for only one industry which is targeted sector of PPI. It is not surprising since PPI increases the sales volume of the sector and ultimately generates larger production and learning by doing effect. Productivity changes in dynamic process similar with the process of knowledge spillover. Eq. (8), (9), and (10) depicts the process of learning by doing effect.

$$lpc_i = \frac{1}{((STG_{it} \cdot gelas_i) \cdot (STP_{it} \cdot pelas_i))} \tag{8}$$

$$lr_i = \frac{lpc_i}{((STG_{it} \cdot gelas_i) \cdot (STP_{it} \cdot pelas_i))} \tag{9}$$

$$ava_i^2 = \frac{ava_i^0}{lr_i} \quad (10)$$

Finally, for dynamics, labor, capital, and knowledge stock are naturally accumulated by time. Labor stock is influenced by population growth, and capital stock is affected by depreciation and additional investment. Knowledge capital also has depreciation and additional knowledge investment and these changes the volume of knowledge capital stock.

4. Simulation Analysis

4.1. Policy Scenario

This study conducts economy-wide policy impact assessment of PPI for new emerging industry. However, governments do not solely implement PPI to stimulate specific sector and products, but utilize various other innovation policy tools. Therefore, this study considers the possibility of policy mix of innovation policy, which includes PPI, demand subsidy, and R&D tax grants.

For new emerging industry, electric vehicle (EV) industry was chosen for simulation analysis. Although EV industry does not have much production volume yet, many countries have interest in foster EV development and diffusion due to its environment and economic impact. Environmentally, replacement of conventional vehicle (CV) into EV can reduce the amount of CO2 emission, and mitigate greenhouse effect and global warming. Moreover, since automobile sector has many forward and backward linkage sector in its production such as metal products, electronic products, and distribution and retail service, the change of vehicle industry leads transformation of production structure in other industry, and ultimately triggers macro-economic change.

The policy scenarios are constructed in three policy tools: PPI, demand subsidy, and R&D tax grants. PPI policy shock is implemented in exogenous change of EV PPI share in total government expenditure. Demand subsidy and R&D tax grants are given in change of indirect tax and production sector of EV industry respectively. Table 2 illustrates the policy scenarios in this study.

Table 2. Policy scenarios

Scenario	Public procurement for innovation	R&D tax grants	Sales Incentives
Base Scenario (BAU)	No Policy Shock		
Scenario 1	50% increase until 2030	Same scale as the amount of sales incentive of 70% reduction	25% reduction until 2030
Scenario 2	50% increase until 2030	Same scale as the amount of sales incentive of 25% reduction	70% reduction until 2030
Scenario 3	100% increase until 2030	Same scale as the amount of sales incentive of 70% reduction	25% reduction until 2030
Scenario 4	100% increase until 2030	Same scale as the amount of sales incentive of 25% reduction	70% reduction until 2030

4.2. Simulation Results

First, for macro-economic indicator, Gross Domestic Production (GDP) is investigated. As figure 2 depicts, in scenario 2 and 4 which has low R&D tax grants and high demand subsidy, GDP increases compared with base scenario with no policy shock. On the other hand, when government implements high R&D tax grants and low demand subsidy on EV industry, there are negative impacts on GDP through scenario 1 and 3. For PPI, it is positive to increase the volume but the direction changes when there is too much spending on EV PPI rather than other government expenditure.

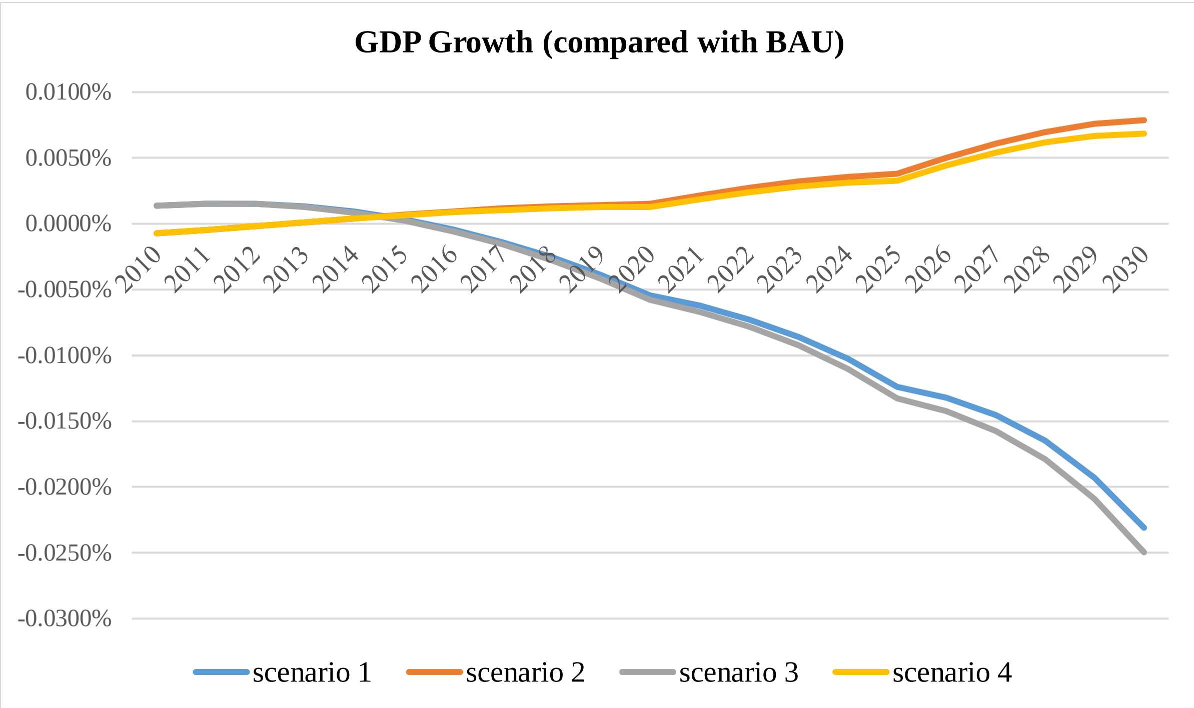

Figure 2. Change of GDP growth in each scenario

The shift of GDP growth rate results from the change of production activities. Since EV industry is beneficiary in various innovation policy tools, the production volume of EV industry increases compared with BAU. The findings suggest that EV industry achieve higher industry growth when there is larger volume of EV PPI. Figure 3 illustrates the production volume change of EV industry.

Next, the growth of EV industry influences on other industry either in positive or negative way. CV industry is expected to be harm from EV industry's expansion, and figure 4 proves it. The decreasing volume of CV industry production tends to follow the growth rate of EV industry. The sectors which its production is used for EV sector as intermediate input are also affected by EV industry's growth. We first supposed that electric products manufacturing can benefit from the expansion of EV sector, but figure 5 shows that its production volume is negatively influenced by EV growth rate. It is not unbelievable since electric products are not solely used in EV manufacturing and other industry's change also has an influence on their production activity.

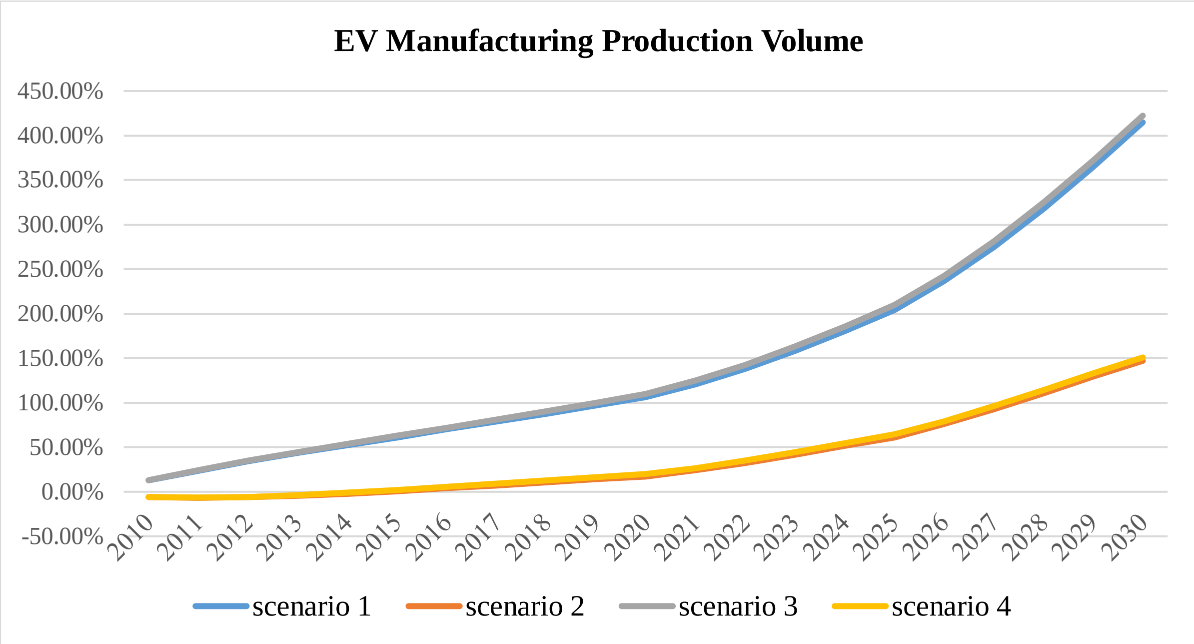

Figure 3. Change of EV manufacturing production volume in each scenario

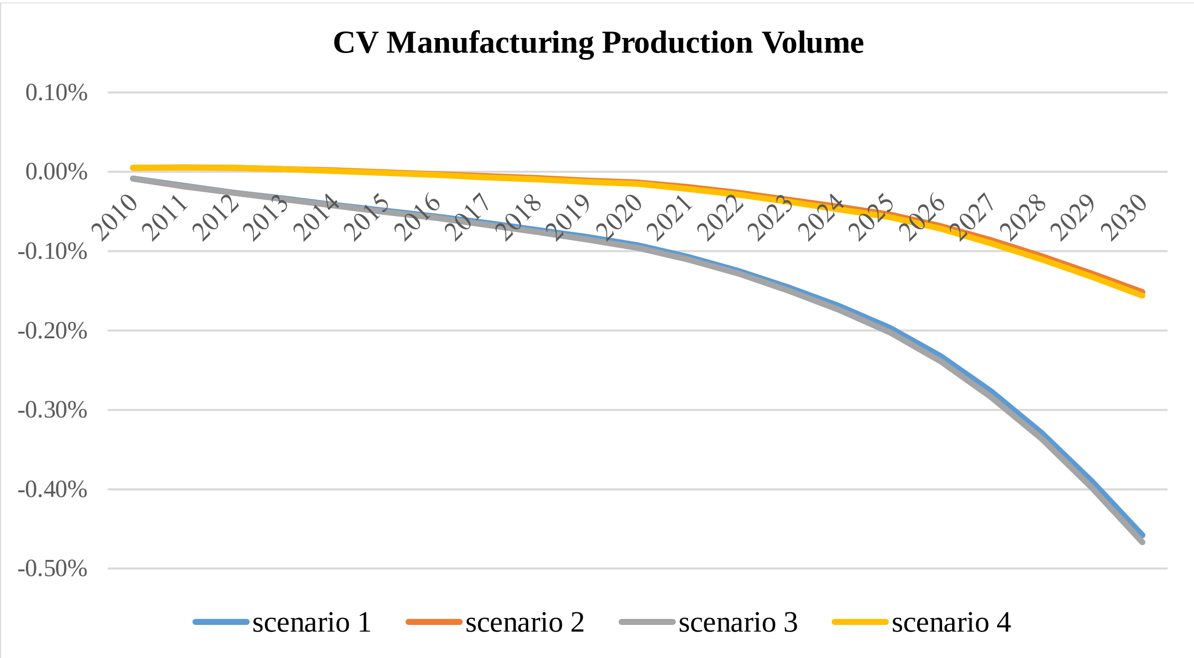

Figure 4. Change of CV manufacturing production volume in each scenario

On the other hand, there is a sector which shows the growth of production volume with EV industry expansion, which is basic metal products manufacturing. Figure 6 shows that the production volume of metal products increases in all scenarios. The growth rate is higher in scenario 1 and 3 which EV industry expands more than in scenario 2 and 4. It implies that basic metal products sector grows in proportion to the expansion of EV industry.

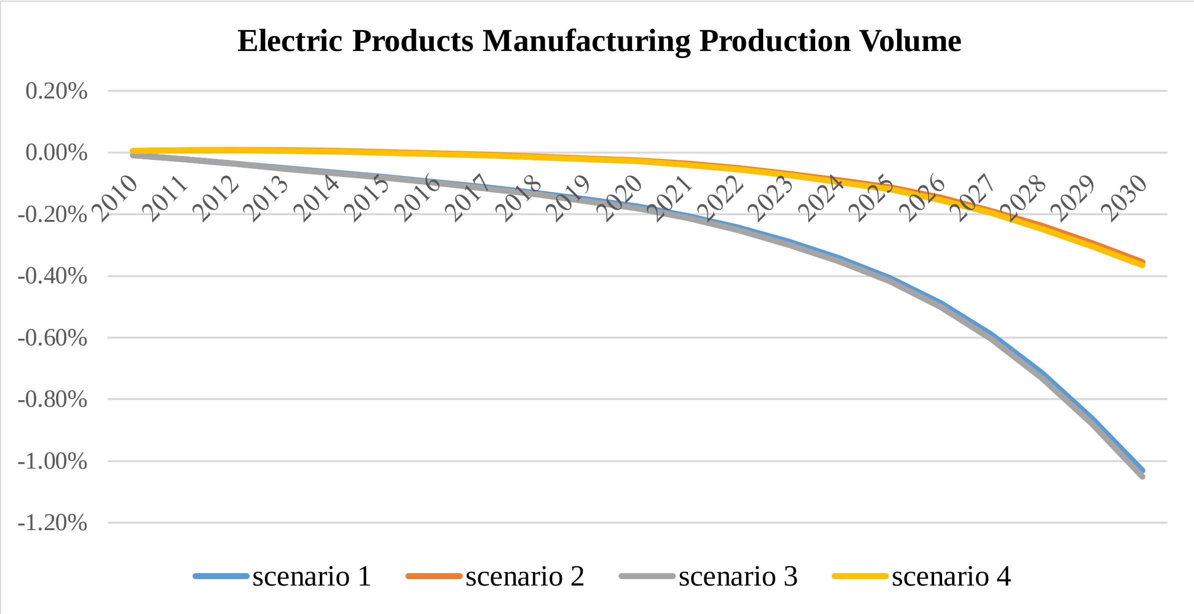

Figure 5. Change of electric products manufacturing production volume in each scenario

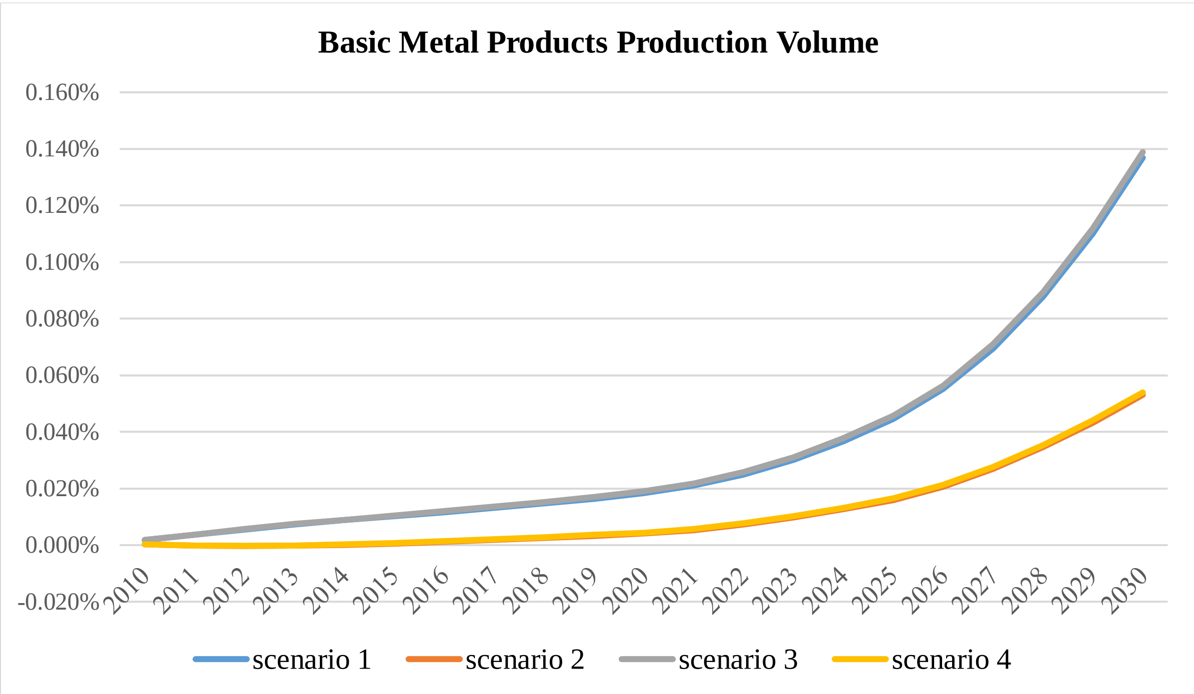

Figure 6. Change of basic metal products manufacturing production volume in each scenario

Among service sectors, transportation and retail service is one of the most influenced sectors. As similar with the case of electric products manufacturing sector, production volume of transportation and retail service is also negatively affected by the growth of EV industry. Because transportation and retail service mainly uses conventional vehicle, its production volume is influenced by the change of CV industry's production volume.

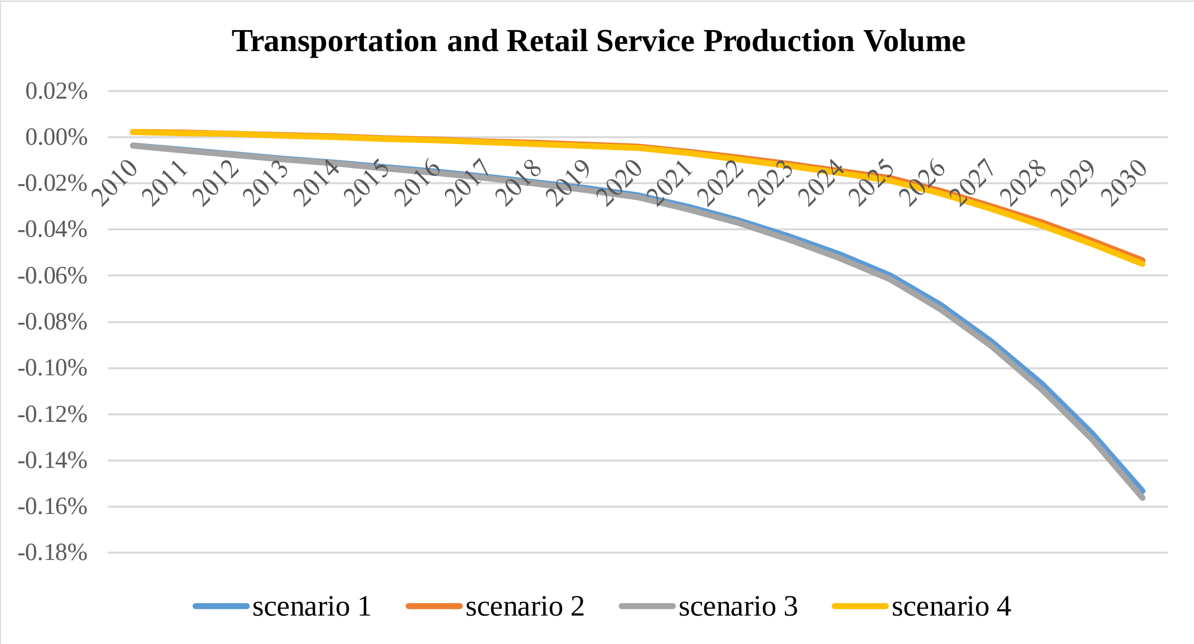

Figure 7. Change of transportation and retail service production volume in each scenario

Next, since the goal of innovation policy tools such as PPI, demand subsidy, and R&D tax grants is inducement of R&D activities in private sector, it is worthwhile to investigate R&D stock in EV sector and entire economy which results from R&D investment. Figure 8 describes that EV industry's R&D stock increases in all scenarios. Specifically, the accumulation is faster in scenario 1 and 3 which EV industry's production growth is higher than in the other scenarios. It implies that increase of production volume leads the sales expansion and it generates additional fund for R&D investment.

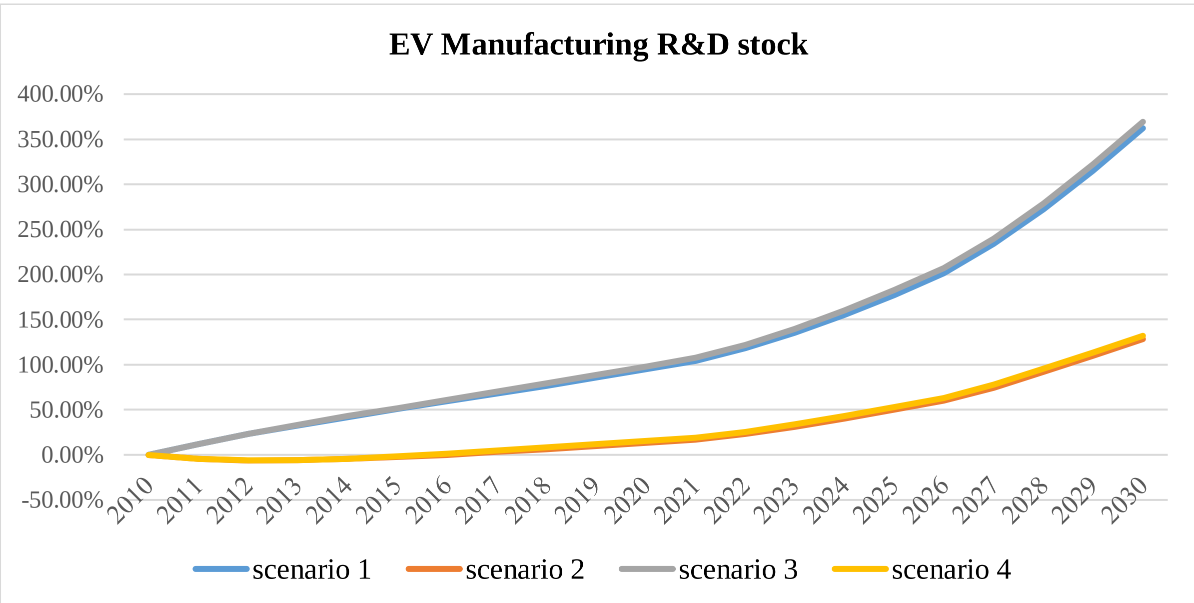

Figure 8. Change of EV manufacturing R&D stock in each scenario

On the other hand, total R&D investment does not follow the trend of EV R&D stock. Since other industries such as CV manufacturing, electronic products manufacturing, and transportation and retail service is negatively affected by policy shocks toward EV, their R&D investment might decrease compared with base scenario. Moreover, PPI uses public expenditure, so it is possible for government to have less budget for other public R&D spending. Therefore, as Figure 9 illustrates, total R&D investment decreases in all scenarios.

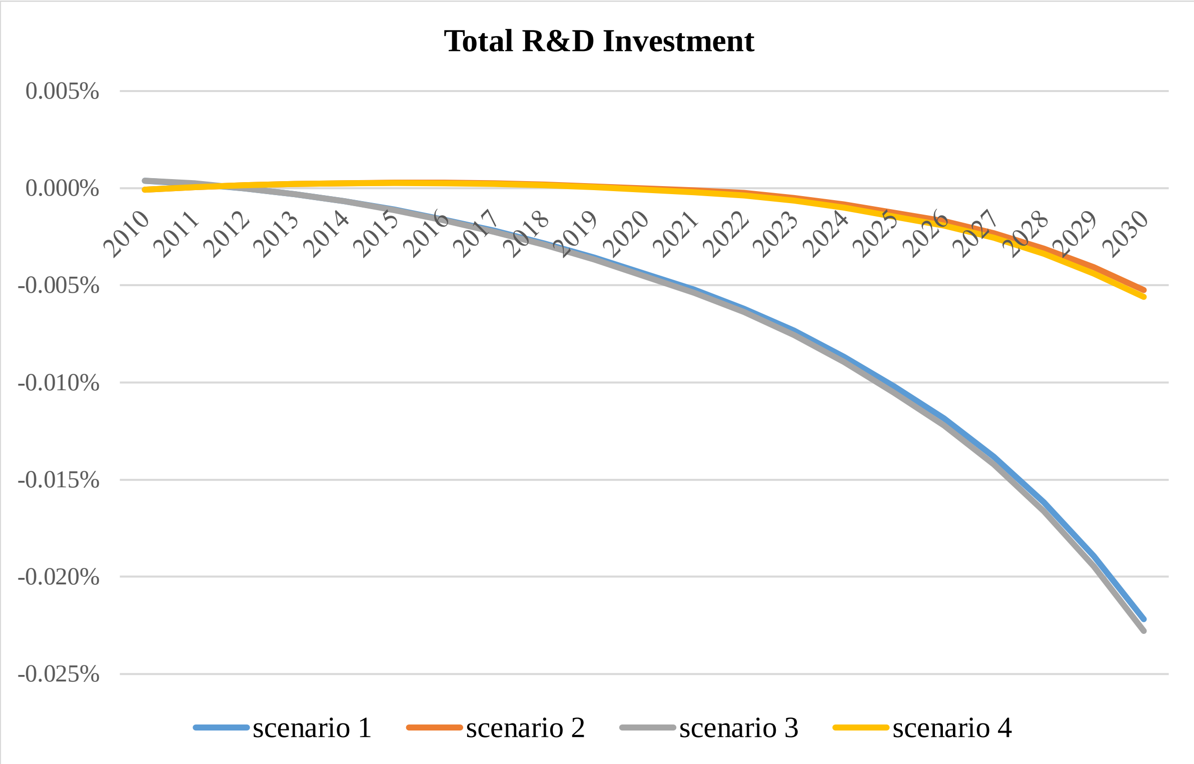

Figure 9. Change of total R&D investment in each scenario

Finally, this study constructs the KCGE model with learning by doing effect. Learning by doing effect realizes in decrease of unit cost of production. Decrease of unit cost of production is same as that of factor requirement coefficient because the firm can reduce the production factor to make same volume of products when unit cost decreases. Figure 10 shows the change of factor requirement coefficient in EV manufacturing sector and suggests there is learning by doing effect as EV industry expands. In other words, it is said that EV industry continues to achieve productivity improvement from innovation policy for EV development and diffusion.

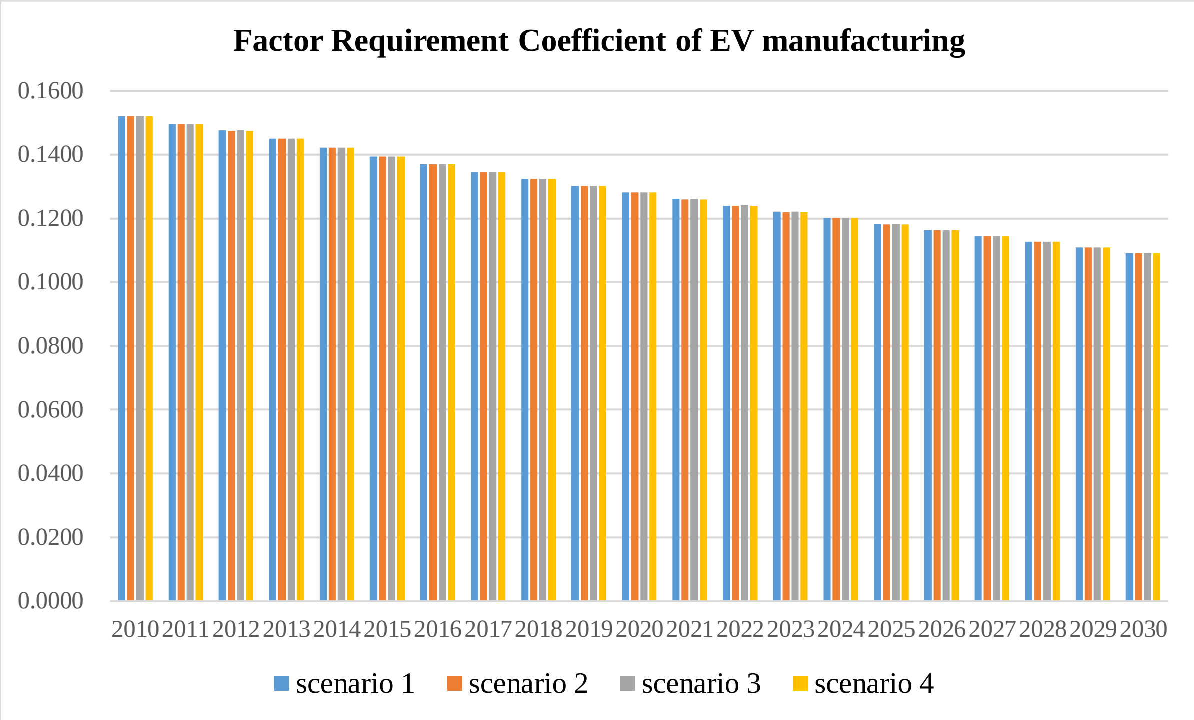

Figure 10. Factor requirement coefficient of EV manufacturing in each scenario

5. Discussion

This study modified KCGE model and analyzed impact assessment of innovation policy for EV diffusion including PPI, demand subsidy, and R&D tax grants. The findings suggested that GDP could either decrease or increase although EV industry expanded thanks to the policy implementation. It was because all industries are interrelated and the change of EV industry influences on other industry's output. For instance, CV industry, electric products manufacturing industry, and transportation and retail service were negatively influenced by EV industry's expansion. On the other hand, basic metal industry's output was simulated as growing when government implements innovation policy to stimulate EV industry. Thus, with integration of each sector's change of output, the direction of GDP change could be different.

Specifically, GDP was higher in scenario 2 and 4 comparing with base scenario. GDP expansion might be from increase of EV industry's output despite the decrease of other industry's production volume. On the other hand, in scenario 1 and 3, the reason for GDP decreasing could result from sudden rise of EV industry's production because it derived negative impact on other industry's production activity. In other words, policy mix with high R&D tax grants and low demand subsidy made larger expansion of EV industry but led negative impact on GDP. However, that with higher importance in demand-side innovation policy than supply-side innovation policy generated both expansion of total output and EV industry's output.

For R&D, investment on innovation activity in EV industry increased followed by production volume expansion. However, total R&D stock from public and private investment decreased in all scenarios. It might be from the decrease of available funds for additional R&D spending both in public and private sectors. In private sector, many industry experienced output reduction from government policy, and it led decreasing profit. Therefore, private firms could have less available amount for R&D investment comparing with base scenario. In public sector, government spends lots of its revenue on PPI expenditure and revenue even decreases from giving R&D tax grants and demand subsidy. Thus, the proportion of public R&D investment cannot but decrease since it is difficult to increase government revenue in a short period. Because of reduced R&D stock in entire economy, it is possible to predict that R&D spillover effect could be reduced except for EV industry.

6. Conclusion

This study aimed to analyze the policy impact of PPI from an economy-wide perspective. This study used a literature review to summarize and conceptualize the various impacts of PPI. The study found that most of the literature is limited to either case analysis or qualitative description of the impact of PPI policy. From this perspective, this study utilized the knowledge-based CGE model to investigate PPI policy impact in a quantitative manner for the case of EV.

The finding suggests that the innovation policy for the EV sector does not always generate economic growth and EV industry expansion simultaneously. For the scenarios that achieved desirable results, the production volume of the EV industry in the early stage is found to be even lower than it is in the case of no policy. However, after some years, the expansion of the EV market and economic growth are achieved simultaneously. In the early stages, EV makers concentrate on technology development, and PPI helps them to survive in the market, despite low demand. Subsequently, private consumers start to buy EV with a high sales incentive, and PPI stimulates private demand more.

Generally, this study implies that the implementation of innovation policy that targets certain industries, with the aim of stimulating them, should be carefully analyzed because it could have negative effects from an economy-wide perspective. Although PPI and other innovation policies are attracting growing interest for stimulating innovation and revitalizing the economy, they do not always generate desirable outcomes, because of the complexity of the interactions between economic actors and industries. This result also implicates the significance of the characteristics of each nation, such as economic status, R&D trends, and production environment, for policy decision-making. Therefore, it is necessary and worthwhile to analyze economy-wide policy impact before policy decision and implementations.

This study also has methodological implications; in that it develops a new integrational perspective for policy impact assessment through combination between qualitative description and quantitative simulation. There are limitations for each methodology: these are the absence of numerical evidence and validation of equation structure, respectively. However, this study developed the causal loop of PPI policy impact through the review of qualitative descriptions, and implemented it for the equation structure of the CGE model. This new perspective for policy impact assessment enables ex-ante policy evaluation before innovation policy decision-making. Since this perspective provides quantitative and numerical results based on the validated impact paths, the data acquired can become effective evidence for policy implementation, not only for PPI but also for other innovation policy tools.

Reference

Adams, J. D. (1990). Fundamental stocks of knowledge and productivity growth. *Journal of Political Economy*, *98*(4), 673-702.

Aschhoff, B., & Sofka, W. (2009). Innovation on demand – can public procurement drive market success of innovations? *Research Policy*, *38*(8), 1235-1247.

Bauer, B., Christensen, J., & Christensen, K. (2010). *Benefits of green public procurement*. Copenhagen: Nordic Council of Ministers.

Borras, S., & Edquist, C. (2013). The choice of innovation policy instruments. *Technological Forecasting and Social Change*, *80*(8), 1513-1522.

Brannlund, R., Lundberg, S., & Marklund, P. O. (2009). *Assessment of green public procurement as a policy tool: cost-efficiency and competition considerations* (Umeå Economic Studies No. 775). Umeå: Umeå 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 Modeling*, *26*(5), 1075-1088.

Choi, H. (2002). Study on computable general equilibrium (CGE) model. *Yonsei Economy Study*, *9*(2), 177-217. (In Korean)

Choi, J. H. (2014). *Plan for Public Procurement for Innovation for the Products from Innovative SMEs* (STEPI Insight No.143). Sejong: Science and Technology Policy Institute (STEPI). (In Korean)

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

Edler, J., & Georghiou, L. (2007). Public procurement and innovation – resurrecting the demand side. *Research Policy*, *36*(7), 949-963.

Edquist, C. (1996). Government technology procurement as an instrument of technology policy. In Teubal, M., Foray, D., Justman, M., & Zuscovitch, E. (Eds.), *Technological infrastructure policy* (pp. 141-170). Dordrecht: Springer Netherlands.

Edquist, C., Hommen, L., & Tsipouri, L. (Eds.). (2000). *Public technology procurement and innovation*. Boston, MA: Kluwer Academic Publishers.

Edquist, C., Vonortas, N. S., Zabala-Iturriagagoitia, J. M., & Edler, J. (Eds.). (2015). *Public procurement for innovation*. Cheltenham: Edward Elgar Publishing.

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2012). Public procurement for innovation as mission-oriented innovation policy. *Research Policy*, *41*(10), 1757-1769.

European Commission. (2012). *Buying green: a handbook on green public procurement*, Brussels: European Commission.

Geroski, P. A. (1990). Procurement policy as a tool of industrial policy. *International Review of Applied Economics*, *4*(2), 182-198.

Heo, C. S. (2011). *Comparison of public procurement for innovation of major countries* (FKI Issue

Paper 2011-185). Seoul: The Federation of Korean Industries (FKI). (In Korean)

Hommen, L., & Rolfstam, M. (2009). Public procurement and innovation: towards a taxonomy. *Journal of Public Procurement*, *9*(1), 17-56.

Hong, C., & Lee, J. D. (2016). Macroeconomic effects of R&D tax credits on small and medium enterprises. *Economic Systems Research*, *28*(4), 467-481.

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

Hosoe, N., Gasawa, K., & Hashimoto, H. (2010). *Textbook of computable general equilibrium modeling: programming and simulations*. Basingstoke: Palgrave Macmillan.

IISD. (2012). *Procurement, innovation and green growth: the story continues…*.Winnipeg, MB: International Institute for Sustainable Development (IISD).

Korkmaz, K. A., Syal, M., Harichandran, R. S., & Korkmaz, S. (2012). *Implementation of sustainable and green design and construction practices for bridges* (RC-1586). East Lansing, MI: Michigan State University.

Krzyzanowksi, D. A., Kypreos, S., Gutzwiller, L., & Barreto, L. (2008). Supporting hydrogen based transportation: case studies with Global MARKAL Model. *Computational Management Science*, 5(3), 207-231.

Marron, D. (2003). Greener public purchasing as an environmental policy instrument. *OECD Journal on Budgeting*, *3*(4), 72-105.

McCrudden, C. (2004). Using public procurement to achieve social outcomes. *Natural Resources Forum*. *28*, 257-267.

Mori, A. R., Albano, V., Contenti, M., & Mercurio, G. (2016). IPICT-an explanatory scheme about the innovation phenomena towards integrated care enhanced by digital technologies. *Journal of the International Society for Telemedicine and eHealth*, *4*, e3(1-11).

Mowery, D., & Rosenberg, N. (1979). The influence of market demand upon innovation: a critical review of some recent empirical studies. *Research Policy*, *8*(2), 102-153.

OECD. (2000). *Greener public purchasing: issues and practical solutions*, Paris: OECD.

OECD. (2015). *Government at a Glance 2015*, Paris: OECD.

Palmberg, C. (2004). The sources of innovations–Looking beyond technological opportunities. *Economics of innovation and new technology*, *13*(2), 183-197.

Patrick, H. (1986). *Japanese High Technology Industrial Policy in Comparative Context* (Working Paper No.1). New York, NY: Center on Japanese Economy and Business, Graduate School of Business, Columbia University.

Payne, C., Weber, A., & Semple, A. (2013). *Energy efficient public procurement: best practice in program delivery*. Berkeley, CA: Lawrence Berkeley National Laboratory.

Public Procurement Service. (2010). *Study on the method for developing public procurement and supporting small and medium-sized firms through compared to Chinese public procurement policy*. (Project Report of Public Procurement Service). Daejeon: Public Procurement Service. (In Korean)

Pyatt, G., & Round, J. I. (Eds.) (1985). *Social accounting matrices: a basis for planning*. Washington

DC: The World Bank.

Rothwell, R. (1994). Toward the fifth-generation innovation process. *International Marketing Review*, *11*(1), 7-31.

Sorte Junior, W. F. (2016). Nurturing Domestic Firms through Public Procurement: A Comparison between Brazil and Japan. *Public Policy and Administration*, *31*(1), 29-50.

Sung, J. E., & Park, I. Y. (2013). *Analysis on change of innovation policy of some countries to overcome low economic growth* (STEPI Issues & Policy 2013-68). Sejong: STEPI. (In Korean)

Terleckyj, N. (1980). Direct and indirect effects of industrial research and development on the productivity growth of industries. In Kendrick, J. W., & Vaccara, B. N. (Eds.), *New developments in productivity measurement* (pp. 357-386). Chicago, IL: University of Chicago Press.

The Federation of Korean Industries. (2011). *Comparison of public procurement for innovation among major countries* (FIP-2011-0004, Company R&D Strategy Report 5). Seoul: The Federation of Korean Industries (FKI). (In Korean)

Uyarra, E., & Flanagan, K. (2010). Understanding the innovation impacts of public procurement. *European Planning Studies*, *18*(1), 123-143.

Van Calster, G. (2002). Green procurement and the WTO - shades of grey. *Review of European Community & International Environmental Law*, *18*(1), 298-305.

Westling, H. (2000). *Final management report – Annex Ⅲ co-operative procurement of innovative technologies for demand-side management* (EI 6:2000), Paris: IEA.