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Study on Economy-wide Impact Assessment of Public Procurement for Innovation for New Emerging Industry: A Computable General Equilibrium Approach

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Abstract

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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. Therefore, 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).

This study chooses the electric vehicle (EV) industry to conduct empirical simulation and modified knowledge-based CGE model with respect to public procurement and learning effect. Thus, when there is a low R&D subsidy and a high sales incentive for EV with PPI, the policies achieve both EV market expansion and economic growth simultaneously. In other words, not all policy mixes achieve the policy goals of both GDP growth and EV industry expansion. This is because the policies have a reverse effect on other industries that are not targeted by the policies when the policy mix is different. Because there is little generation of private production of other industries and the government expenditure is used for PPI, the public and private R&D are not much higher than they would be if there were no policies. Finally, because of the increase in sales volume of EV, the EV industry experiences learning by doing and economies of scale,

which reduces the requirement for primary factors on the production process.

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, Innovation Policy, Policy Impact, Computable General Equilibrium

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Chapter 1. Introduction

1.1 Research Background

Recently, many countries worldwide have suffered from stagnation of economic growth. Both middle-income and high-income countries are trying to escape from the low growth by fostering new emerging industries. In fostering new industry, each country understands the significance of innovation, which is the driving force for economic growth. From this perspective, there is growing opinion that government should intervene in the industry and market sector more than before to create an innovative environment in the private sector (Mazzucato, 2013). However, to steer innovation policy in the right direction, it is necessary to identify the expected impact and results of the policy tools. To this end, with ever-increasing interest in innovation policy for each government, there is a need for a much deeper investigation and analysis of the economic impact of innovation policy.

From the Korean perspective, the Korean government is required to implement different innovation policy strategies different from the past decades. This is because the type of technology innovation for further growth of Korea is changing from catch-up innovation to creative innovation. This means that industries and firms should adjust their production and innovation routine from a fast-follower to a first-mover position (Lee, 2015). With the change of trends in industry, government policy must also change to secure and support the environment in which industries and firms can sell their creative goods or services. Therefore, although the Korean government has succeeded in implementing R&D policy to stimulate technology innovation for more than 30 years, this is the time for the government to become interested in not only technology development but also commercialization of innovation results.

This trend is not just confined to Korea; it is also prevalent in many middle and high-income countries. These countries have suffered from the decrease of the economic growth rate, and they are trying to find new ways to revitalize the economy. Thus, among various innovation policy tools, there is increasing interest in demand-side innovation policy, which has an impact on both technology development and market demand. This means that these countries have recognized the limitation of supply-side innovation policy, such as R&D subsidy and R&D tax grants, and the significance of creation and consolidation of the market for innovation results. With this change in innovation policy trends, some governments have started to utilize public procurement for stimulating innovation. Generally, public procurement is the purchase of a public institution for its own use. However, some countries have begun to use public procurement for purchasing innovative goods or even technologies, and this strategy is called public procurement for innovation (PPI). Public authorities utilize PPI for inducing and stimulating innovation in private sectors by specifying features of either technology or products and securing public demand for them in the market.

European countries are the leading nations in demand-side innovation policy. They have started to buy innovative goods and services with government expenditure, make regulations for the private sector to develop and purchase more innovative products, and provide subsidies for those purchasing the results of innovation. The U.S. and Japan are also implementing demand-side innovation policy in various industries, especially in energy, environment, and health care. The Korean government and decision-makers also understand the importance of demand for further innovation. However, few demand-side innovation policies have been implemented in Korea. This is because there is no quantitative or numerical evidence about the effectiveness of demand-side innovation policy.

Various studies and research projects have looked at the impact of PPI. Many of these have concluded that the effect of PPI on innovation and the economy is greater than that of any other innovation tool because it influences both technology and the market in both direct and indirect ways. Specifically, PPI has the direct effect of increasing demand for innovation results and has several indirect effects: creating a market, setting the standard, and changing private consumption habits.

However, most previous studies have been limited to qualitative description of various effects, and there are few empirical studies with specific cases and PPI projects. On the contrary, to construct and implement government policy in the real world, ex-ante policy impacts must be examined quantitatively, taking macro-economic influence into consideration. Therefore, a new framework that considers both technology and market must be constructed to investigate the policy impact of PPI from an economy-wide perspective.

1.2 Research Purpose and Methodology

Even though many countries have a growing interest in PPI, and despite its impact being described as the most effective among various innovation tools, there have been few approaches to analyze the policy impact of PPI from an economy-wide perspective. Most previous research has investigated the policy impact at either firm level or industry level, but the economy-wide impact could be different from either firm growth or industry growth. This is because there are various aspects of the policy impact of PPI among technology, industry, market, and macro-economic indicators, and the interaction between economic agents, including the production, household, government, and foreign sectors, should be considered in an economy-wide policy impact assessment.

Therefore, this study aims to examine the economy-wide impact of PPI from a combinational perspective. To conduct an economy-wide policy impact assessment, this study uses computable general equilibrium (CGE) modeling, which can determine both direct and indirect policy effects quantitatively with the economic linkage among economic indicators. In using CGE modeling, this study tries to find the impact of policy on knowledge capital and technology innovation, using a knowledge-based CGE model for the analysis. Knowledge-based CGE model explicitly defines the account of knowledge capital and knowledge factor as primary input. By conducting a quantitative analysis with a knowledge-based CGE model, the policy effect of PPI is investigated as the change of economy-wide indicators, such as GDP or industry production volume, and the change of innovation features such as knowledge stocks, R&D investment, and learning effect throughout the economy.

1.3 Outline of the Study

The study is organized as follows. Chapter 2 describes the theoretical background of the study. It summarizes the related previous research on various innovation and market policies for new emerging industry, especially focusing on public procurement for innovation and its economic effects. Chapter 3 explains the methodology used, which is the CGE approach. This chapter first presents the method used to construct a knowledge-based social accounting matrix and then describes the detailed methodology of the knowledge-based CGE model. Chapter 4 discusses the results of the simulation analysis on policy impact of public procurement for innovation from an economy-wide perspective using the knowledge-based CGE model. Finally, Chapter 5 concludes the study by summarizing the results and presenting policy implications. This chapter also describes the limitations of this study and presents a proposal for future study.

Chapter 2. Theoretical Background

2.1 Overview of Public Procurement for Innovation

Public procurement is the purchase of necessary resources by government or public institutions, and different from the private demand, the public concern should be considered on the procurement process (Sung, 2011). Recently, many countries try to utilize public procurement not only purchasing necessary products but also stimulating innovation in order to solve social and economic problem in their countries. Edquist et al. (2015) stated that public procurement is done for products and industries which have potential economic and social benefits when it is available in public but the market is not created yet due to the low technological competitiveness.

Regarding innovation policy, various innovation policy tools can be divided into supply-side innovation policy and demand-side innovation policy (Edler and Georghiou, 2007). Supply-side innovation policy mainly focuses on R&D and technology development and it includes some traditional R&D policy such as tax grants and subsidy. On the other hands, Demand-side innovation policy considers both technology innovation and its diffusion in the market. Public procurement for innovation is one of the demand-side innovation policy tools. Edler and Georghiou (2007) stated various innovation policy tools and Table 1 is summary of the categorization of them.

Table 1. Supply-side and demand-side innovation policy tools

Categories	Tools	Contents
Supply-side policy	R&D subsidy	University/laboratory funding Strategic programs for industry Support for contract research
	R&D tax grants	Corporation tax reductions Reductions in employer's payroll tax Personal tax incentives for R&D workers
	Venture capital related policy	Public venture capital funds Subsidized private venture funds
	Information and networking	Advisory services Patent databases Science parks
Demand-side policy	Public procurement	R&D procurement Technology procurement Public procurement of innovative goods
	Regulation	Use of regulations and standards Technology platforms
	Support for private demand	Demand subsidies Tax incentives Awareness and training

2.1.1 Policy Trend of PPI

Different from ordinary public procurement, public procurement for innovation is strategic tool of public institution to stimulate innovation by specifying innovative factors in the procured products or services. Edquist and Hommen (2000) defines public procurement of technology as purchase of products, services, or systems which do not exist yet but are expected to develop in a short time. Recently, especially in European Union, public procurement for innovation is used for environment protection, sustainable growth, and enhancement of quality of life as the perspective of integration of economic growth and settlement of social problems (McCrudden, 2004).

Each country spends many portion of its government spending for public procurement. According to OECD (2015), each OECD country spends the amount of 18% of its GDP for public procurement on average. It also stated that public procurement expenditure is mainly on energy, environment, construction, and public health sector (OECD, 2015).

European Union implements Lead Market Initiative (LMI) in order to create the market for innovative products and services. Specifically, LMI has a purpose to stimulate the demand for innovation, especially in health, transportation, and environment sectors (Sung and Park, 2013). For example, EU starts STOPandGO project, which stands for Sustainable Technologies for Older People – Get Organized, on April 2014. It is the pilot project for development and diffusion of telehealth and telecare technology for elderly people. EU tries to determine the effectiveness of the project for not only hospitals and patients but also related industries (Mori et al., 2016).

United States also utilizes public procurement for creating the market for innovative products. It recognizes the significance of private sector for innovation and innovation policy trend changes toward the markets and firms. For instance, public institution in US was encouraged to use new and innovative technology in ICT sector such as cloud storage for the first time, and US government gave incentive to use new technology in public administration process (Sung and Park, 2013).

2.1.2 Effectiveness of PPI

With the categorization of innovation policy tools, there were many empirical researches on the comparison of innovation results between supply-side innovation policy and demand-side innovation policy (Mowery and Rosenberg, 1979; Borras and Edquist, 2013; Rothwell, 1994; Geroski, 1990).

According to many of previous researches, public procurement is evaluated as the most direct and effective policy tool for stimulating innovation among the other tools (Edquist et al., 2015). Rothwell and Zegveld (1981) and Geroski (1990) argued that public procurement stimulates innovation more than R&D subsidy and tax grants in the long run. Moreover, Palmberg (2004) investigated various commercialized innovation projects from 1984 to 1998 in the world and concluded that about 48% of successfully commercialized projects was thanks to the public procurement empirically.

The reason public procurement has greater effectiveness compared to supply-side innovation policy is that supply-side policy only focuses on technology development and does not consider the diffusion of that technology. On the other hand, through specifying demand, public procurement can eliminate information asymmetry by reducing market uncertainty which comes from low and unclear market demand in the early stage (Edler and Georghiou, 2007). In other words, public procurement makes suppliers have a chance to earn profit from innovation and it stimulates the market activity of interaction between suppliers and consumers (Aschhoff and Sofka, 2009).

In sum, as Choi et al. (2011) mentioned, public procurement regards consumers as important actors in innovation activity, so it can enlarge the depth and width of the innovation policy. With the limitation of supply-side innovation policy, expansion of government spending, and recognition of the effectiveness of public procurement, many countries are interested in public procurement nowadays.

2.1.3 Taxonomy of PPI

As public procurement has gotten high interest in innovation policy study, there were some studies on defining the taxonomy of public procurement or public procurement for innovation. First of all, Edquist (1996) integrated public technology procurement with technology or R&D policy, and he mentioned that public technology procurement (public procurement for technology) is demand-oriented innovation policy tools. In addition, he divided the public technology procurement with the purpose of policy. In the case that public authority tries to develop new technology by procurement process, he stated that it is technology development procurement. On the other hand, if the purpose of procurement policy is inducement of using existing technology, it is called technology diffusion procurement.

Edler et al. (2005) also categorized public procurement, especially focused on PPI. They divided PPI as three types, direct, cooperative, and catalytic PPI with the difference of end users. When the public institution buys a product or service for its own use, it is direct PPI. Public authority can include the specific features or technology to solve social problems into public procurement process but it is intrinsic. However, cooperative PPI is the case that the end users are both public institution and private consumers. In this case, public demand help launching the market and articulating private demand. Finally, catalytic PPI is the procurement of public institution to support private consumers to buy new or innovative products. In this case, although the procurement is done by public authority, the end users are private actors.

There was alternative approach to categorize PPI with the perspective that PPI influences not only technology innovation but also market demand. Uyarra and Flanagan (2010) classify four PPI type into market and technology features. First, experimental procurement is the procurement of product which the demand is dedicated in some groups and production technology is not yet standardized. Second, technology procurement is for the product with generic demand and specialized production technology. Third, when demand of the product is not generic but the production technology is already standardized, the procurement of that product is called adapted procurement. Finally, if the product has generic demand and standardized production technology, efficient procurement is used for that product.

In sum, there were some studies to try to make taxonomy of PPI, but the dimensions or types for categorization were not same for each study. However, it is important to set integrated taxonomy of PPI in order to analyze the policy impact of PPI in combinational and economy-wide perspective. This is because economy-wide impact of PPI could be evaluated differently according to the PPI types. Therefore, this study referred the previous approaches to set new and integrated taxonomy for PPI with the dimension of technology level and market level.

Because the most important aspect of PPI is that it influences both supply-side of technology development and demand-side of product and services market, it is worthwhile to set new categorization of the types of PPI with the stages of technology and market. For the market perspective, the stage and process of product development is addressed in product life cycle theory. Many researches employs and utilizes this concept differently, but generally product life cycle includes the stages of initiation, growth, consolidation, and decline (Cohen, 2010). Similarly, there is technology life cycle theory which defines the trends of technology development and innovation. Technology life cycle is also generally categorized in four stages, which are introduction, development, consolidation, and decline. Merino (1990) insisted that technology develops with S-curve which is similar with product life cycle. This study focuses on the market stage of initiation, escalation and consolidation. In addition, this study modifies the technology life cycle as demonstration, scale-up, commercialization, and standardization.

Type 1 PPI is for the technology in the stage that it is not developed yet or is in R&D stage. Pre-commercial procurement of technology can also be categorized into type 1 PPI. In this type, public authority can role as testing ground of new innovative technology or products. Because it is necessary to conduct R&D and achieve technology development in order to have the products as the results of innovation effort, public authority often implement R&D policy such as R&D subsidy and tax grants with type 1 PPI.

After the R&D stage, the firm starts to do demonstration and scale-up its technology into product. In this stage, public authority can implement type 2 PPI in order to create and escalate the private market for innovative products and services. In this stage, public authority often uses policies related to private demand such as sales incentive or demand subsidy with PPI.

It is possible that there is no or limited market for innovative products although the technology was already in standardization stage. This is often because the consumer class of those products is not generic. The products with specific demands or for social needs are often in this situation, and public authority can buy the products in order for firms to maintain their effort for innovation and production. This is type 3 PPI.

Type 4 PPI has a purpose of incremental innovation. After the technology developed and market escalated, public authority starts to stimulate competition among existing and potential producers in order to get quality enhancement and cost reduction. Figure 1 describes the different type of PPI into market demand and technology level.

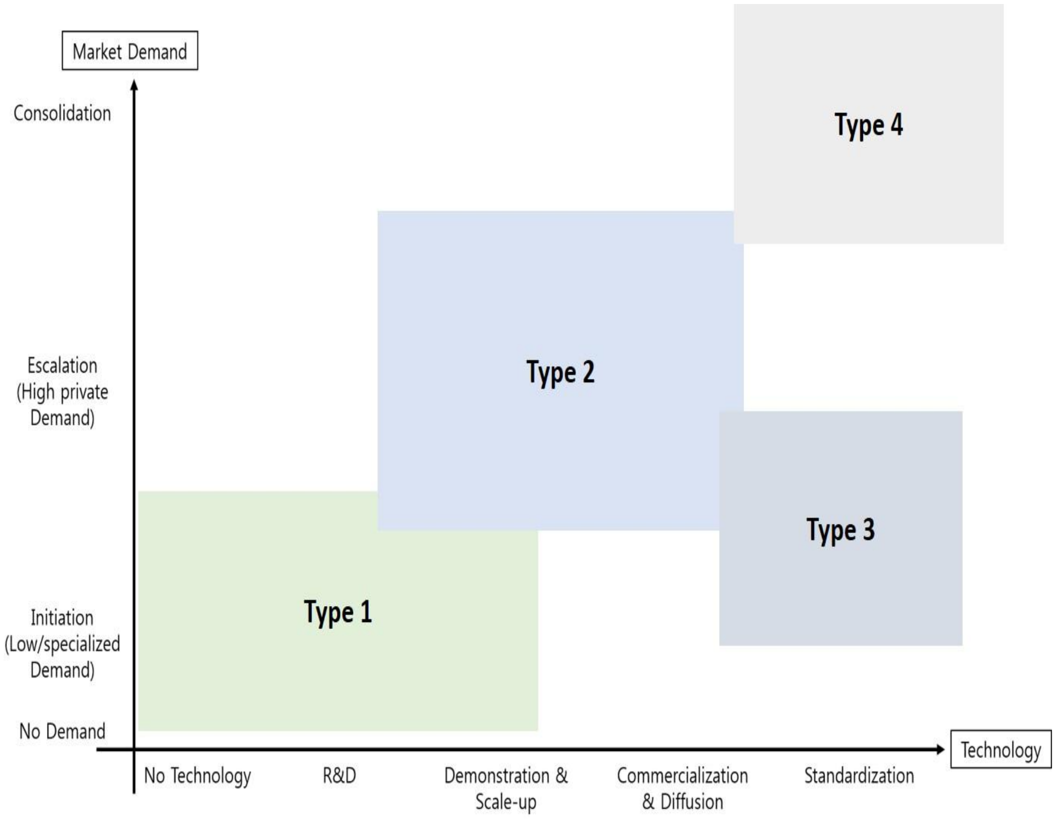

Figure 1. New integrated taxonomy of PPI

2.2 Economic Effects of PPI

For the effectiveness of PPI, there were a number of researches which examined the economic impact of PPI. Many of them are qualitative analysis or case studies, and they reveal various direct and indirect economic effects related to market and innovation. However, there are not framework to integrate various effects of PPI in economy-wide perspective. Therefore, this study tries to summarize the economic impacts of PPI and link them in order to analyze economy-wide or macroeconomic impact of PPI.

2.2.1 Market effects

2.2.1.1 Creation of the market with leading consumer role

PPI influences on market itself with increase of public demand. Edquist et al. (2015) suggested that economic impact of PPI can be linked with the stage of market growth, which is initiation, escalation, and consolidation of market. First of all, by large volume of public demand, public authority reduces or even eliminates market and technology uncertainty which the innovative firms often face. Technology developers face market and technology uncertainty when they are not confident with enough market demand for their products or services, and it leads them to hesitate about aggressive investment for both R&D and production facility. In this case, public sector can specify the volume of demand and stimulate R&D investment of private innovators for commercialization (Edler and Georghiou, 2007). Moreover, Bauer et al. (2010) analyzed 31 cases of public procurement projects of green products in Denmark and Sweden, and concluded that private demand for green product expanded thanks to public procurement. They insisted that the reason for increasing private demand is that public procurement for those products made private actors regard the publicly procured products as guaranteed ones. Thanks to PPI, the procured firms can experience larger demand of both public and private and lower market uncertainties. In addition, Rothwell (1994) addressed that private firms can utilize the public demand by PPI as testing ground of their products and it helps them to enter or create new market for their products. Edquist (1996) also argued that suppliers can get information about the technology or features what consumers require for the products and modify them after PPI, and, thus, commercialization could finalize earlier. Furthermore, Van Calster (2002) and Marron (2003) stressed that PPI let potential suppliers enter easier and earlier by creating the market with public demand. In sum, public sector roles leading consumer of innovative products and services by PPI, and it creates the market and helps the technology developers to participate in that market.

2.2.1.2 Inducing private demand and escalation of the market

After market creation, PPI is utilized for expansion of private demand and escalation of the market. This is because public sector uses PPI not only for its own use but also giving the signal for using innovative products or services to private sector (OECD, 2000). Payne et al. (2013) focused on PPI for green products, and they concluded that various PPI projects in United States, EU, and Japan make private actors' consumption habit become greener. In addition, PPI in market escalation stage is often purchase of large volume of innovative products and services by public authority, and it leads the developers and suppliers to reduce unit cost with sales expansion (Korkmaz et al., 2012). In conclusion, PPI can change the consumption habit of private actors more into innovative ways and make the innovative firms reduce unit cost and increase the sales.

2.2.1.3 Stimulating competition and consolidation of the market

From R&D stage to market escalation stage, PPI often generate monopoly or monopolistic competition market of procured product unintentionally due to the standardization of product features. However, in order to enhance the utility of private consumers, it is needed to eliminate monopoly market and achieve competitive environment. Public authority can utilize PPI with procurement contract options to stimulate competition and reduce market power of small number of suppliers (Uyarra and Flanagan, 2009). Brannlund et al. (2009) suggested that market competition was stimulated by PPI and there were benefits from the competition such as intra-industry innovation and specialization compared to the case that public sector produces by itself. Moreover, European Commission (2012) empirically analyzed the case of procurement of energy-saving technology for construction of public administration building in Italy, and concluded that there was approximately 27% of cost reduction effect compared to the previous year among 5,000 public administration building. In other words, public sector can stimulate new entry of potential suppliers even in escalated market by PPI, it makes the market become more competitive environment.

In conclusion, PPI creates the market for innovative products and services by public demand, and it stimulates the commercialization interest of suppliers. In addition, by large volume of public demand, the private demand for innovative products and services also stimulates and producers experience cost reduction and sales increase. Finally, PPI can enhance the market competition and increase consumer utility. Figure 2 illustrates the market effects of PPI which summarized in this part.

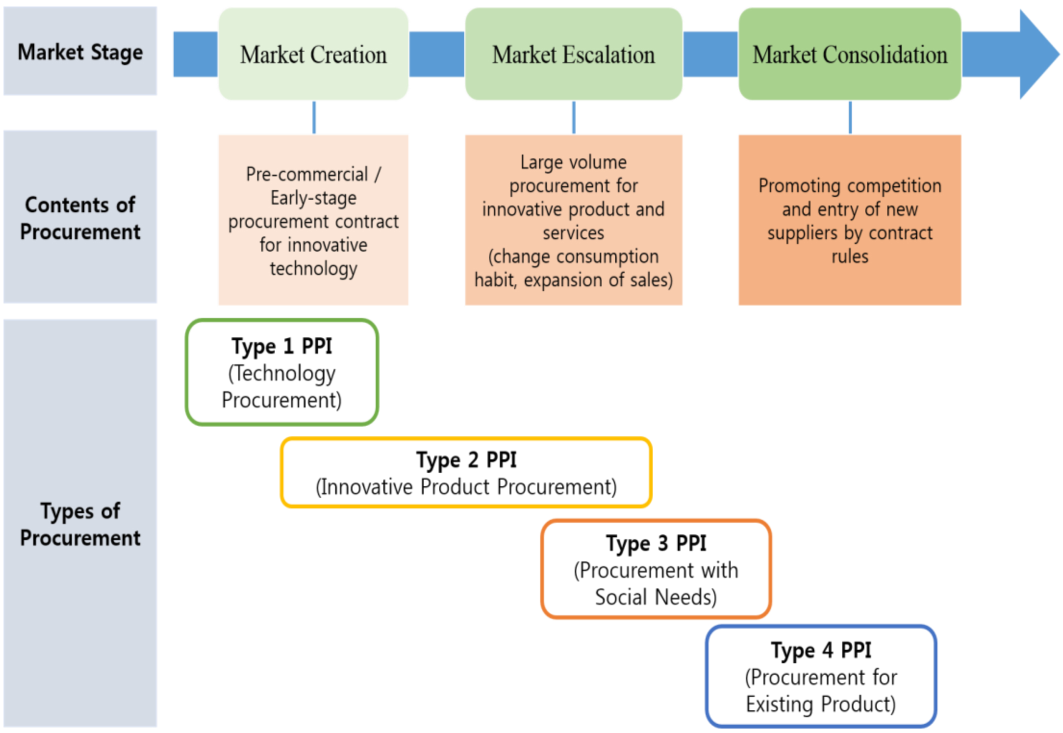

Figure 2. Market effects of PPI

2.2.2 Innovation effects

2.2.2.1 Stimulating innovation investment and testing ground

As innovation policy tool, PPI affects not only market demand but also innovation or technology development. When public authority starts to purchase innovative technology in the early stage of R&D, private technology developers is guaranteed enough demand for their products at the time of commercialization of the product. Specifically, public sector gives the information on technology features to technology developers, and it reduces the technology uncertainty from R&D stage to commercialization stage, and finally, it motivates private innovators to invest more on R&D and innovation (Geroski, 1990). The investment on R&D is increased thanks to the public demand in the early stage of production, and it leads the development of new product (Edquist and Zabala-Iturriagagoitia, 2012; Hommen and Rolfstam, 2009). While supply-side innovation policy such as R&D subsidy only focuses on the early stage of product development which is technology development and expansion of technology capability, PPI influences on whole stage of production and increases production capacity of private sectors (Heo, 2011). In other words, PPI influences on not only technology development but also technology diffusion.

In addition, since PPI is used for the testing ground of innovation results for the suppliers, they can easily adapt and enhance the technological performance through the information on consumers' requirement gathered from public demand. Westling (2000) investigated various cases of technology invention and stressed that many of them such as low-electricity copy machine, energy-efficient light bulbs, and energy-efficiency TV successfully survived in the private market thanks to public demand in the early stage of the inventions.

In sum, PPI motivates the innovation interest of private sectors and help the private firms to invest more on R&D by reducing technology uncertainty and giving the testing ground for their products, and as a result, the radical innovation which is the development of new product is achieved.

2.2.2.2 Reducing market uncertainty

By purchasing large volume of innovative products and services, the private suppliers can benefit from economies of scale. Most of the innovative products and services experiences "Death Valley" in the stage of scale-up and commercialization. Death Valley means the innovative firm faces market uncertainty about demand in scale-up and commercialization period, and it makes the firm to reduce additional R&D or product development investment, and finally the firm fails to commercialize its results in the market. The main reason of Death Valley is unclear and insufficient early market demand. However, public authority specifies and guarantees large volume of demand as PPI contract, and the firm can experience less market uncertainty on demand. Bauer et al.

(2010) argued that PPI reduces the market risk from demonstration to scale-up stage of the products which have faced stagnation of product development effort. IISD (2012) investigated the public procurement project, LightSavers, in Canada, and it found that a large number of small and medium enterprises participated in the project thanks to the reduced market risk. In other words, PPI reduces market risk by specifying the demand, and it leads the private suppliers to invest more for commercialization of their products.

2.2.2.3 Learning effect and incremental innovation

In addition, PPI accelerate technology and product diffusion in the private sector by increasing the sales volume of the private suppliers. Marron (2003) insisted that suppliers which participate in PPI project increase investment on production facilities in order to enhance production capacity, and this leads to economies of scale and learning by doing effect. PPI expand the sales volume of suppliers in various paths. It means that they can earn more money from the innovative products by increasing production facility. To this end, due to economies of scale and learning by doing effect, the unit production cost for the innovative products goes down and the quality of that products enhanced, so the market expands more and more. Moreover, thanks to the cost reduction, the private consumers faces lower prices, and this leads enhancement of social welfare. Suppliers in entire economy can also implement additional innovation effort with increased sales, which is inter-industry and intra-industry spillover effects of innovation (Adams, 1990;

Terleckyj, 1980). In conclusion, PPI stimulate the demand for innovative products, and the suppliers experience economies of scale and learning by doing. As a result, the incremental innovation which is cost reduction and quality enhancement is made by the private suppliers, and there is improvement of social welfare and additional innovation due to spillover.

The innovation effect of PPI can be summarized as follows. PPI helps the private technology developers to invest on R&D during whole stages of product development. In early R&D stage, PPI reduces the technology uncertainty by specifying demand and providing testing ground of the potential innovation results. From demonstration to scale-up stage, the private suppliers can benefit from lowered market risk thanks to PPI. After scale-up stage, the private firms experience economies of scale and learning by doing effect with large volume of public demand, and it accelerate the commercialization. Finally, during the commercialization stage, PPI draws incremental innovation of the firm and additional innovation effort in the whole industry or economy. Figure 3 depicts the flow of innovation effect of PPI summarized in this part.

2.2.3 Impact paths of PPI

From the review of previous literatures, it is confirmed that PPI has various direct and indirect effects related to market and innovation. However, it is also found that various effects are not considered in economy-wide perspective and scattered without common framework for policy impact evaluation. Moreover, the most of analyses were done with qualitative analysis or case studies. There were some studies which tried to investigate the impact of PPI on market demand or innovation quantitatively, but they are also limited on partial equilibrium perspective which did not consider the relationship between economic actors and industries.

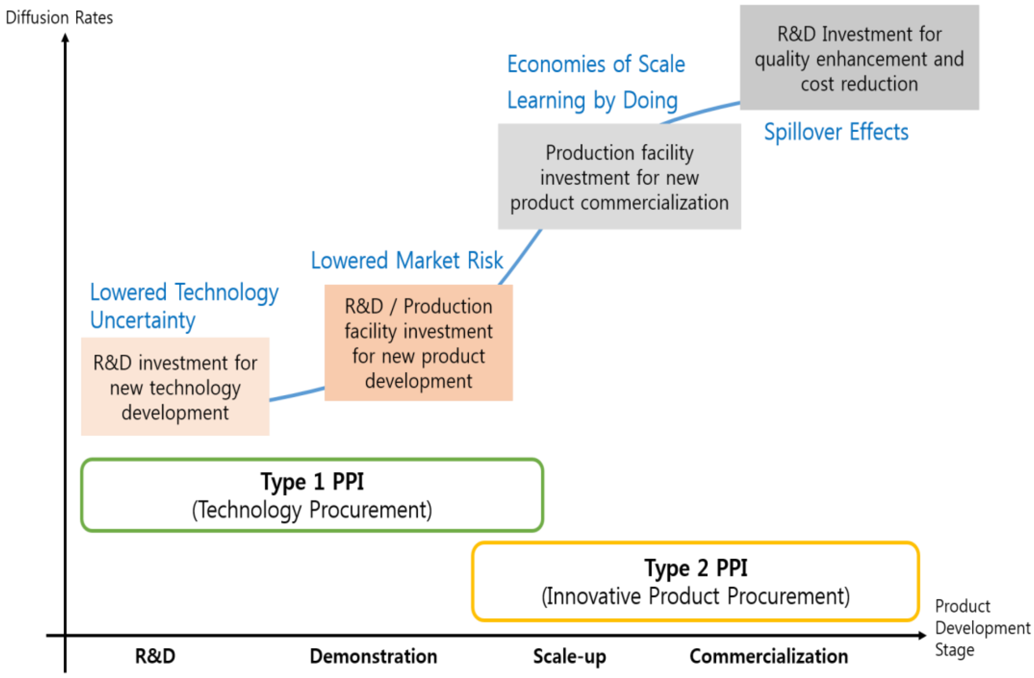

Figure 3. Innovation effects of PPI

It is important and worthwhile to investigate PPI's impact in economy-wide perspective because PPI has not only direct effect of public demand expansion but also several indirect effects such as economies of scale, spillover effects, and change of private demand habit. The indirect effects are analyzed deeply only when it is considered the impact paths which draws the origin, waypoints, and the destination of policy impact because various macro-economic and technology indicators are linked in the effect. General equilibrium analysis which this study tries to conduct as quantitative manner requires the description of policy impact beforehand since general equilibrium perspective includes the relationship between the economic actors and industries. Since the indirect effects of PPI influences mainly on the interaction between economic agents such as the firms, household, and government, general equilibrium approach helps to conduct PPI policy impact assessment in new integrated framework.

Moreover, each government try to raise their spending on PPI nowadays. There were some studies which tried to investigate the impact of government spending change into general equilibrium approach such as Athanassiou et al. (2002) and Yang et al. (2015), but they are limited into the military spending. Therefore, since government spends numerous budget on PPI and it has various impacts with different paths, it is necessary to study policy impact assessment for PPI with economy-wide perspective.

The impact paths of PPI can be drawn as a form of causal loop. From the literature review in Section 2.2, this study depicts the causal loop of policy impact of PPI as Figure 4. It describes the various economic and technological indicators and their relationship, with the policy shock of PPI and final destination of policy as GDP which is the representative macro-economic indicator. By Figure 4, it is clearly checked that there are direct and indirect economic impacts of PPI and their path for macro-economic variables.

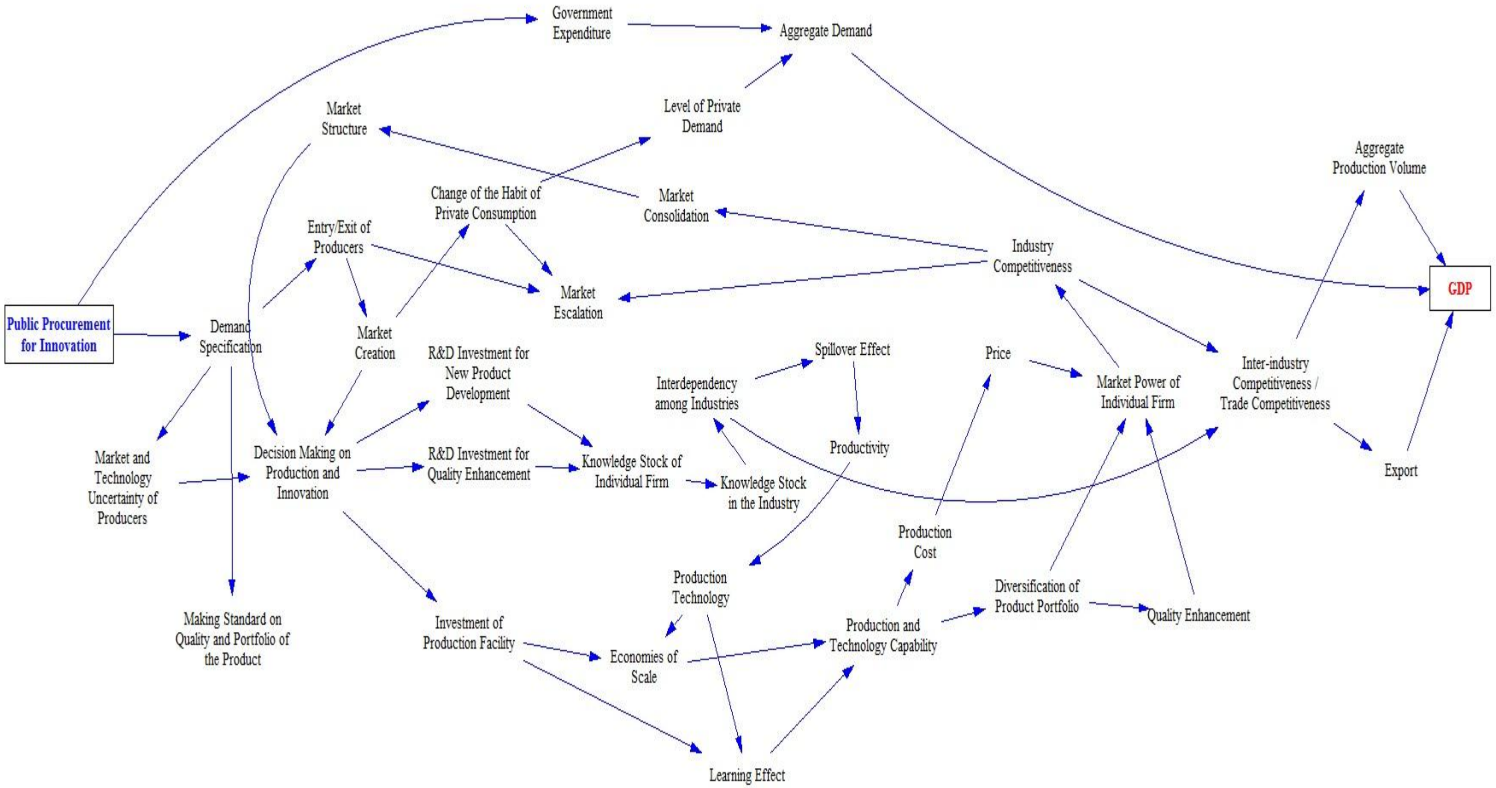

Figure 4. Causal loop of policy impacts of PPI

2.3 Review of the Innovation Policies for New Emerging Industry

Each government implement various policies for fostering new emerging industry in order to stimulate or revitalize economic growth. After Solow (1956), the economic growth theories regard technological development as a key driving force of economic growth, followed by Romer (1986), Lucas (1988), and other great scholars. Although Solow treated technological development as exogenous factor in his model, Romer and Lucas thought that human capital with accumulated knowledge roles importantly in technological development. Technological development makes chance of developing new products or services, and the industry is emerging when the technology is commercialized successfully. Therefore, new emerging industry of the country reflects its circumstances of technological development, or innovation.

It is also known that there is a relationship between technological change and economic situation. Schumpeter (1939) and Kondratiev (1925) addressed that economic cycle turns from boom to recession or vice versa because of innovation such as industrial revolution and diffusion of production mechanism of Ford. In sum, it is widely known that innovation is the most important factor for economic growth or cycle among many scholars and policy makers.

Moreover, many countries suffer from economic stagnation recently. Developed countries try to revitalize the manufacturing industry in their territory. For several decades, many firms and factories in developed countries has moved their facilities to the developing countries in order to reduce the production cost, which is called offshoring. However, the governments of developed countries request them to return for revitalizing the manufacturing industry and capability in those countries, which is called reshoring. In order to stimulate reshoring, each government implement various innovation policy to help the private producers to conduct innovation and business well (Livesey, 2012). On the other hand, many developing countries are also worried about the decrease of the economic growth rate. Kharas and Kohli (2011) pointed the concept of middle-income trap, which developing countries lose global competitiveness in their growth engines industry and experience lower economic growth than before. In order to escape from middle-income trap, the governments in developing countries also try to find emerging industry for new driving force of economic growth, and implement various policies to foster it. Both for developed and developing countries, it is growing interest in the innovation policy to find new growth engines industry for each country.

In conclusion, each government try to stimulate the innovation in order to have economic growth and implement several policies for innovation nowadays. From this perspective, Edler et al. (2016) defines innovation policy as “public intervention to support the generation and diffusion of innovation” (p. 3). From the section 2.1, this study categorizes the innovation policy as supply-side policy and demand-side policy. This section summarizes some innovation policy tools which are commonly used for developing new emerging industry in each country.

2.3.1 Supply-side policy

2.3.1.1 R&D subsidy

R&D subsidy usually categorized as direct supply-side policy, which means that it let the firm conduct innovation by giving grants or subsidizing loans. This policy is based on the assumption that innovation will be made by the R&D conducted within firms, and it leads to the production of new innovative products or services (Cunningham et al., 2016). The economic rationale behind this assumption is that public authority notions that private R&D level is below than socially sufficient level because of externalities when there is no public intervention. The production of innovative products or services leads the emergence of new industry. Therefore, with this assumption, R&D subsidy is widely used for the governments to stimulate new emerging industry by making the private firm invest on innovation.

There are a number of studies which try to reveal the relationship between public R&D subsidy and private R&D spending. Bassanini and Ernst (2002) mentioned there was no change of private R&D observed from analyzing 18 OECD countries which gave public R&D subsidy from 1993 to 1997. On the other hand, Coccia (2012) revealed that there is positively significant relationship between public R&D expenditure and private R&D investment in Italy and many of other OECD countries. While these studies used the data of country-level, Zhu et al., (2006) analyzed with industry-level R&D data in

Shanghai, China, and concluded that R&D investment was increased by government R&D subsidy for the beneficiary industries. There are many studies with micro-level or firm-level data to analyze the policy impact of R&D subsidy. Czarnitzki and Bento (2013) used Community Innovation Survey (CIS) data and found that the firm granted R&D subsidy spend 3.75 percent more on R&D spending than the firm without subsidy. However, Guerzoni and Raiteri (2015) analyzed the policy mix of R&D subsidy, tax grants, and public procurement, and concluded that R&D subsidy cannot generate the R&D spending increase of the firm without public procurement.

However, by considering different characteristics of the firms, the direction of the effectiveness of R&D subsidy on the private R&D spending could be changed. Lach (2002) insisted that R&D subsidy increases R&D spending for small-sized firms, but decreases it for large-sized firms. Paunov (2012) mentioned that the direction could be different from the age of the firm, and Görg and Strobl (2007) argued that it is matter for the direction whether the firm is domestic or multinational.

In sum, there are mixed-evidences on the effectiveness of R&D subsidy. According to the characteristics and circumstances of the targeted firms, the influence of R&D subsidy on the innovation effort of them might be different. Therefore, the findings from previous studies told us that the direction of the relationship between R&D subsidy and the volume of R&D investment of the granted firm could be different from various factors. Especially in economy-wide perspective, the characteristics of the beneficiary industry and the policy mix with other innovation policy tools can generate conflicted conclusion with other previous studies. Moreover, it is also needed to realize the fact that the increased R&D effort is meaningful only when it makes the emergence of new products or services in the market. which is pointed as one of the main limitations of R&D subsidy policy to fostering new products and industries.

2.3.1.2 R&D tax grants

Different from direct R&D subsidy, R&D tax grants reduce the tax burden of the firm and lower the R&D cost indirectly. OECD statistics (OECD, 2013) gave us the information about the amount of R&D tax incentives and stated that it is similar with the amount of direct R&D subsidy. The reason why governments implement R&D tax grants is that the firms with R&D tax grants feel reduced tax burden for R&D activity, increase their R&D investment, and it leads the increase of innovation activity (Larédo et al., 2016). Many countries lower the tax for the firms in newly established market in order to help them to survive. With R&D tax grants, these firms can save money for tax and invest it for R&D activities, and, thus, the new industry fosters and escalates.

As many countries implement R&D tax grants policy, there are many previous works on the effectiveness of R&D tax incentives for private R&D investment expansion. Guceri (2015) estimated the increased amount of R&D investment for the firms with R&D tax grants and concluded that the amount of R&D investment in the beneficiary firms was 18% higher than that in the other firms. Klassen et al. (2004) used OLS estimation for the data from manufacturing and service firms in Canada and US and argued that there is additional R&D investment thanks to R&D tax grants as amount of $1.3 in Canada and $3.0 in US. In addition, there are some studies on R&D price elasticities to estimate the sensitivity of the firms for reduced R&D tax burdens (McKenzie and Sershun, 2010; Mulkay and Mairesse, 2013; Westmore, 2013).

Although there are some methodological limitations on the previous studies such as causality problem, high adjustment costs from other activities to R&D, and the choice of control group, the conclusions are similar that reduced R&D tax burdens thanks to R&D tax grants help the firms to increase investment for R&D. Raised private R&D expenditures generates intra-industry or inter-industry knowledge spillovers.

However, similar with R&D subsidy or other supply-side innovation policy, it is important to understand that increase of private R&D investment is not a final goal of the government for implementing R&D tax grants policy. Government utilize it in order to foster new emerging industry with innovative goods or services, and thus, the targeted firms of R&D tax grants should materialize the innovation effort in goods or services. Therefore, for the policy impact assessment of R&D tax grants, R&D subsidy, and other supply-side policy, it is needed to analyze the innovation outcome and market impact of the firms which government helps to become innovative.

In conclusion, R&D tax grants and R&D subsidy are the representative supply-side innovation policy tools. Although there are mixed results for effectiveness of them, it is validated that they influence on technology development and innovation of the firm.

Several middle-income countries including Korea succeed to have economic growth by stimulating innovation with these two policy for decades. However, it is also validated that the supply-side innovation policy tools cannot generate the market demand of innovation results and it is one of the reasons that innovative firms cannot survive in scale-up and commercialization stage. As mentioned in section 1.1, the innovation trend of the industry in Korea changes from catch-up to creative innovation. In order to demonstrate the creativity, a number of trial for technology and product development is required. However, by only supply-side innovation policy, the granted firms or industries cannot withstand the trial and failure in demonstration, scale-up, and commercialization stage. Therefore, in order to support the private innovators to endure trial and failure process and make innovation results be commercialized, government strategy should be changed from supply-oriented to balanced consideration of supply and demand.

2.3.2 Demand-side policy

2.3.2.1 Public procurement for innovation

Although many countries have implemented both R&D subsidy and R&D tax grants in order to foster innovation and new emerging industry, they felt the limitations of those policy and the necessity of switching the policy scheme. It is because supply-side innovation policy tools only consider the early stage of technology development or R&D

of the firms, and the governments realize that the increased innovation effort of private sector does not always lead to commercialization of innovative goods or services. As a result, some countries and international institutions, especially OECD, started to have interest in demand-side innovation policy which consider both technology development and commercialization of innovation outcomes. From this perspective, public procurement which is purchase of goods or services for public use has recently been utilized for stimulating innovation in private sector, which called public procurement for innovation (PPI).

PPI is relatively new concept for innovation policy research despite the long history of usage of public procurement itself. Among EU region, several policy report started to mention the importance of public demand in innovation with public procurement from mid-2000s (Edler et al., 2005; Wilkinson et al., 2005; Aho et al., 2006, European Commission, 2007). OECD also initiated the project on demand-side innovation policy in 2008 and has reviewed the circumstances of demand-side innovation policy including PPI in OECD economies periodically (Uyarra, 2016).

The technology and market impact of PPI was already mentioned in section 2.2. Because the history of academic studies on policy impact assessment of PPI is not long as that of supply-side innovation policies, there is few study which the assessment does not limited in its target or methodology (Uyarra, 2016). Uyarra (2016) insisted that different framework with the analysis of supply-side innovation policy should be implemented for the evaluation of PPI. Since PPI has many paths of direct and indirect effects and large causal scope from technology R&D to market consolidation, as summed in section 2.2, it is needed to understand them integrated perspective with the consideration of entire economy.

2.3.2.2 Sales incentive (subsidy and tax)

Sales incentive with subsidy or tax foster the private demand by lowering willingness to pay of private consumers. Government utilize sales incentive in order to escalate the market for targeted products or services regardless of its innovativeness. However, similar with public procurement, some countries started to use sales incentive for the innovative products to create and expand the market of them since there is growing interest in demand for innovation. As one of the innovation policy tools, in order to achieve economic growth and social goal, sales incentive is utilized to foster new emerging industry by stimulating private demand (Edler, 2016).

Because the importance of demand has only recently been recognized for innovation policy decision-making process, there is few studies on the innovation impact of sales incentive policy or even demand-side innovation policy. Klaassen et al., (2005) analyzed the innovation impact of R&D subsidies and demand-side measures and concluded that R&D subsidy drives innovation of quality enhancement or new product development more and demand-side measures drives innovation with cost-reduction more. Diamond (2009) studied the impact of tax incentives for hybrid electric vehicle (PEV) in US on the diffusion of PEV. He found the PEV has diffused a lot during the analysis period, but it is thanks to the rise of oil price, not the tax incentives policy itself. Wengel et al. (1995) investigated the case of demand subsidy for computer-integrated manufacturing (CIM) and computer-aided design (CAD) system in Germany. They are recognized as innovation of production technology process, and German government subsidize them not for technologies themselves but for buyers of technologies. Finally, they insisted that the speed of the diffusion of those technology was faster in the firms which participated in the government's subsidy project than the firms which did not.

Because sales incentive is recognized as innovation policy tools only recently, the innovation impact path of sales incentive policy to innovation of suppliers is not investigated yet. However, with the consideration of demand for innovation, it is important to analyze the policy impact of sales incentive in terms of innovation policy in order to catch the market effects of innovation policy.

In conclusion, there is growing interest in demand-side innovation policy, and some countries, especially European countries, started to implement it in real world. Demand-side innovation policy tools influence the private innovators from R&D stage to market consolidation stage. However, although PPI which is the representative tools of demand-side innovation policy is recognized as the most effective to stimulate innovation, the governments does not utilize PPI or demand-side innovation policy vigorously in real policy making and implementation. This is because only qualitative analysis describes the effectiveness of the policy tools and there is no numerical and macro-economic evidence which influences on decision-making process. As a result, it is worthwhile to evaluate economy-wide effects of innovation policies with consideration of the demand-side innovation policy tools.

2.4 Overview of the Electric Vehicle Industry

Recently, there is unusual climate change around the world, and the greenhouse gases from the vehicle is pointed as one of the main reasons for it. Therefore, many countries try to introduce clean or environment-friendly vehicle which has low emission or even no emission of CO2. Among various kinds of new vehicle, electric vehicle (EV) gets interest from many countries and industries since it generates no CO2 emission during driving. In addition, the development of EV is also related to the change of sources of electricity generation from fossil fuels to renewable energy. In addition to the environmental effect, EV also has significant economic potential to become new driving force of the economic growth. It is because the vehicle industry has numerous forward and backward industries such as electric product manufacturing, transportation and distribution services. Therefore, the development of EV industry generates large production inducement effect to other industries. EV market expands every year and many countries try to develop highly efficient EV and diffuse EVs in public. For these reasons, each country tries to foster EV industry by various policy means. This part summarizes the current status and policy trend of EV industry, especially public procurement policy.

2.4.1 Market and technology trend of EV industry

The market of electric vehicle is growing fast. According to IEA (2016), the number of whole electric cars in the world reaches at 1.26 million, which is more than twice of the number in 2014. In country level, Norway is the most EV-diffused country, which the proportion of EV to total vehicle reaches 23%. US and China is the largest EV market in the world, more than 70,000 EV was newly registered in US, and about 147,000 EV was newly adapted in China during one year of 2015. As total stocks of EV, US has the most number of EVs, and China, Japan, and Netherlands follow. In Korea, there are about 4,000 EVs on the road, but more than half of them, 2,540, was deployed in 2015. The market share of EV is 0.2% in Korea (IEA, 2016).

For the market penetration of EV, one of the most important factor is charging infrastructure. Therefore, the market trends of EV can be also understood by the degree of deployment of the charging infrastructure in public. IEA (2016) suggested the total EVSE (electric vehicle supply equipment) stock per million inhabitants, and Norway has 15,143 EVSE stocks per million people. There are some countries which exceed 1,000 stocks per million people such as Netherlands, Denmark, Sweden, US, and Japan. China has only 265 EVSE stocks yet, and only 113 EVSE stocks per million people is located in Korea (IEA, 2016). Table 2 summarizes the market share of EV in 2015 and total EVSE stock per million inhabitants for some countries.

Table 2. Market trend of EV for some countries

Country	Market Share of EV	Total EVSE Stock per million inhabitants
Korea	0.20%	113
United States	0.70%	1340
Canada	0.40%	612
Germany	0.70%	664
France	1.20%	970
Netherlands	9.70%	6280
United Kingdom	1.00%	933
Norway	23.30%	15143
Sweden	2.40%	1674
India	0.10%	5
Japan	0.60%	1171
China	1.00%	265

There are many EV makers in the world, and they devote to develop EV with higher specifications. For EV, the key technology factors to determine the specifications of entire car are driving range and battery storage. Tuttle and Baldick (2015) addressed that key factor affecting EV prices is the cost of batteries, and there is much effort to develop cheap and effective battery for EV in the world. The storage and weight of battery affects the driving range of EV. All EV makers try to extend the driving range with full charge for their cars due to the shortage of EVSE yet. In addition, battery storage determines not only the driving range but also the highest speed or capacity of engine in EV.

This study searched the driving range and battery storage for several car makers. The data is from the official webpage of each car maker. According to the data, Tesla, which is US company, has the EV model with highest specifications in the world, Tesla Model S. Tesla Model S has the driving range of 315 miles, and 100 kWh of battery storage. BYD e6, from BYD in China, has the second longest driving range of 186 miles and also the second largest battery storage of 61.4 kWh. The other EVs are in similar technological specifications, with from 70 to 100 miles for driving range and 19 to 30 kWh for battery storage. Table 3 is the summary of the driving range and battery storage from several EV makers.

Regarding these market and technology trend of EV industry, this study compares the current status of EV for each country with respect to market factor and technology factor. For market factor, the value of market shares of EV in 2015 and that of total EVSE stocks per million inhabitants is generalized on the interval [0, 1], and sum the generalized value with no weight. For technology factor, this study regards the EV technology status of certain country as technology specifications of the representative EV maker of that country. The value is also the sum of two generalized values on the interval [0, 1], which are the driving range and battery storage. Figure 5 depicts the diagram of current status of

EV market and industry.

Table 3. Technology trend of EV for some EV makers

EV model	Country of EV maker	Driving range (miles)	Battery storage (kWh)
Kia Soul EV	Korea	93	27
Tesla Model S	United States	315	100
Mercedes B-class Electric Drive	Germany	85	28
Bolloré Bluecar	France	160	30
Vauxhall Ampera (Chevrolet Volt)	United Kingdom	38	17.1
Think City	Norway	100	23
Volvo C30 electric	Sweden	90	24
Mahindra e20	India	75	19
Nissan LEAF	Japan	100	30
BYD e6	China	186	61.4

According to the Figure 5, the four groups of current market and technology status of EV is founded. First of all, most of the countries are located in similar status, which is low technology factor and low market factor. China has some advanced technology compared to others, but the market is not escalated. United States is the most advanced country for EV technology, but the market penetration of EV is not yet fulfilled. Finally, Norway has the most escalated market for EV but the technology factor of EV maker of Norway is not matured. From Figure 5, it is implied that each country has different status of EV market and technology, so it should implement different strategies and policies in order to diffuse EV effectively by each country.

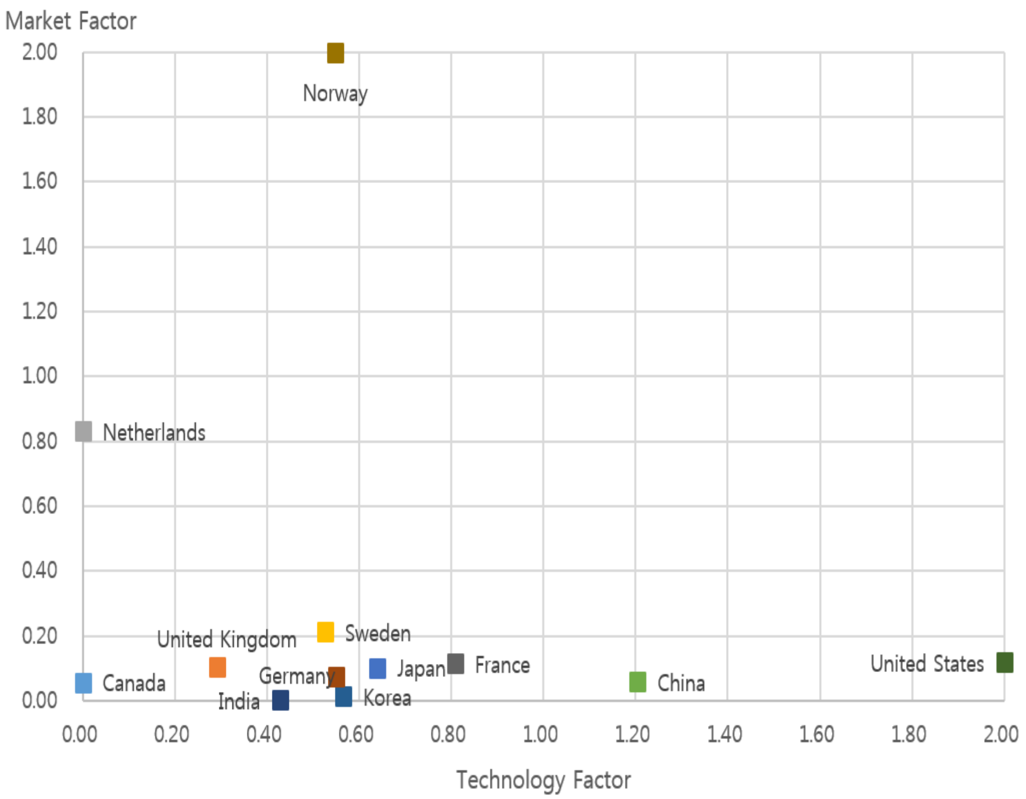

Figure 5. Current status of EV market and technology

2.4.2 Policy trend of EV

Some countries tried to develop EV with higher specifications through some vehicle makers, and implemented the policy for diffusion of EV. However, despite the effort of the governments and firms, the technology and market environment of EV is not mature yet. Therefore, for EV industry, they have to implement doing both innovation policy to develop EV and market diffusion policy to make private actors have EV simultaneously.

The countries which try to foster EV industry has two purposes for their policy. One is environmental factor that EV can reduces the air pollution. The other is economic factor that EV industry can become new driving force of economic growth. Vehicle industry has various linkages among other industries, and it means that the small change of vehicle industry can affect a large volume of change of other industries, so the economy-wide indicators must be influenced.

European Union set the policy objective of sustainable growth from 2010, and implement various policies for EV from technology development to market escalation in order to take the initiative in global EV industry and market. For example, EU has a plan to subsidize 5 billion euro for EV infrastructure and renewable energy development, and Germany especially invested 500 million euro for EV technology development until 2011 (Kang, 2015). For the sales incentives, Germany and France have subsidy for purchasing EV at least 4,000 euros (Mock and Yang, 2014). Moreover, as one part of Lead Market Initiative (LMI), each EU country purchases EV for its own uses. For example, Germany addressed the plan to purchase 20% of new public vehicle as EV.

US has a policy initiative of reshoring, which make the production facility return in US territory. With this policy trend, US supports the top EV makers, Tesla and Nissan, for them to invest their production facility in the US (Leurent and Windisch, 2011). US also implements public procurement for EV, it has a plan to replace 40,000 vehicles for public activity into electric vehicle (Kang, 2015). In addition, US federal government and state government gives the subsidy for the purchasing EV to individual buyers up to 7,500 US dollar (Kang, 2015).

Japan also implement both EV R&D policy and demand policy. Japan had a plan to subsidize on EV and electricity storage technology about 10 billion Japanese yen in 2013 (Kim et al., 2013). For public procurement, Japan try to replace the vehicle in post office into electric vehicle, and the number is about 20,000 (Kang, 2015). Japan also set 8 pilot cities to construct EV infrastructure with the cooperation among local government, EV makers, electricity company, and local companies (Ando, 2014).

China started to develop EV later than the other countries, but their top EV maker, BYD, became one of the top EV sellers in the world. China made a plan to support EV development and diffusion as amount of 100 billion Chinese yuan from 2011 for 10 years (Kang, 2015). China started public procurement of EV from 2005, and set the regulation for public institution to purchase more than 30% of newly procured vehicle as electric vehicle from 2014 to 2016 (Son and Shin, 2016; Zhou et al., 2015). For sales incentives, China gives differently from the types of EV which are pure EV or hybrid EV (Son and

Shin, 2016).

Korea also try to diffuse EV and implement several policies. The main policy for EV market expansion in Korea is demand subsidy. Korea gives the private consumers the largest amount of sales incentive in the world, which is 12 million Korean won at most. In addition, Korean government cuts the tax on vehicle the amount of 3.1 million Korean won for whom buys EV. Public institutions in Korea also regulated to purchase EV, and 310 number of vehicles are planning to procured in 2016. For EV development, Korean government gives R&D subsidy or conducts direct R&D to develop medium size EV, and the amount of subsidy is 100 billion Korean won at most. In regional perspective, Jeju province declared to become EV-only zone by 2030 and try to construct the infrastructure for EV-friendly way and replace all conventional vehicle into EV (Lee, 2014).

Most of the countries which try to develop and diffuse EV implement both innovation policy and market policy. Among them, public procurement is one of the key policies for each country because it can be utilized as both innovation policy and market policy. Since EV industry and market is in early stage, public procurement of EV can be regarded as type 1 or type 2 PPI. For the countries which try to develop their own EV model, their procurement can be seen as type 1. On the other hand, there are some countries which try to diffuse EV with continuous effort to have higher technological specifications through their own EV maker. Public procurement of EV in those countries can be categorized as type 2. Leurent and Windisch (2015) evaluated PPI as the effective policy which can stimulate both economies of scale in supply-side and price reduction in demand-side policy simultaneously. Therefore, it is important to consider the policy impact of PPI as well as that of other policy tools in order to evaluate the effectiveness of EV related policy deeply.

The previous studies on EV diffusion policy impact assessment was limited on environmental impact analysis or economic impact only in micro level such as firm or consumer perspectives (Hofmann et al., 2016; Kromer and Heywood, 2007). Karplus et al. (2010) and Miyata et al. (2016) implemented CGE modeling to analyze EV diffusion policy impact. However, the former was only focused on environmental factor such as CO2 emission and oil consumption, and the latter was analyzed sales incentive (demand subsidy) policy only and did not considered the innovation factor included in EV policy. As a result, with the consideration of other policies such as R&D subsidy and sales incentives, it is important to analyze the policy impact of PPI for both EV development and diffusion.

2.5 Knowledge-based Computable General Equilibrium

Computable general equilibrium (CGE) models are systems of equation that depicts the general equilibrium of economy with consideration of several economic agents such as household, firms, government, and foreign sector and their interaction (Choi, 2002). Because CGE models describes the entire economy with various economic indicators, it is widely used to analyze impact of economic policy (Hosoe et al., 2010). Based on the general equilibrium theory, CGE models consider the spillover effect between economic agents as important factor of economy. Recently, with the growing interest in innovation policy for economic growth, CGE models with innovation or R&D factor have been developed. However, since it is difficult for standard CGE models to depict R&D investment or knowledge accumulation, there have been some studies on constructing knowledge-based CGE models to analyze innovation.

Goulder and Schneider (1999) constructed numerical general equilibrium models with the concept of induced technological change in order to investigate the effectiveness of CO2 abatement policies. Induced technological change is that technological progress is generated from R&D and it reflects the change of the policy related to that technology. Their CGE models depicted the R&D production explicitly, with the industries of conventional energy fuels, alternative energy fuels, energy-intensive materials, other materials, investment goods, and consumer goods. In addition, as production inputs, they defined knowledge capital separately, with physical capital and labor. In production equations, they reflect the fact that knowledge spillover influences on the production volume with other intermediate and production input. Knowledge consists of industry-specific knowledge which accumulated by intra-industry R&D and industry-wide knowledge which accumulated by total R&D expenditure. The benchmark data they used was US economy in 1995. In conclusion, Goulder and Schineider addressed that there is a significant change of the impact on GDP costs of CO2 abatement policies between the case of considering induced technological change and the case of non-considering it.

Diao et al. (1999) constructed the CGE models based on endogenous growth theory which developed by Romer (1986) and Grossman and Helpman (1991). Their model also described R&D production sector separately and R&D sector produces new designs. R&D sector utilize two primary inputs of labor and other durables with given stock of knowledge. The other production sectors use three inputs which are labor, other durables, and differentiated capital. Differentiated capital is generated by capital production sector and linked with the amount of knowledge stock. They used the data of Japanese economy from 1992 and concluded that the influence of trade liberalization policy on domestic R&D activity is not clear but the policy made spillover effect of foreign knowledge.

Ghosh (2007) investigated Canadian economy with CGE models which divided the production sector into final output production and new designs production by R&D and differentiate capital input. R&D sector produces new designs and new variety of capital from the designs. It used Global Trade Analysis Project (GTAP) Database version 5 which revealed in 1997 and analyzed the subsidy policy on designs production or capital usage and trade liberalization. Ghosh asserted that direct subsidy for design production was most effective way for productivity enhancement in the Canadian economy.

Bye et al. (2009) analyzed the policy impact of R&D subsidy, capital subsidy, and investment subsidy on R&D production, wealth distribution and growth with knowledge-based CGE model. Their model distinguished the industry sector with R&D industry, differentiated-capital industry, and final goods industries. It regards the production result or R&D industry as patents. Economic growth is also generated endogenously with the productivity of production sectors and love-of-variety effects. The study asserted that demand subsidy for R&D capital goods did not generate large economic growth or enhancement of social utility because of the low demand elasticity of R&D capital goods among final goods production sector.

Verbic et al. (2009) developed knowledge-based CGE model with consideration of education and human capital. In the model, the utility of household was influenced by the stock of human capital and its usage between work and study. Human capital is accumulated by public and private investment for human capital and education time by households. Human capital is used as input for production. They analyzed Slovenian economy, and compared various scenarios, which are income tax, share of private investment in education, corporate tax, industry-investment in human capital, and government education spending, for education expenditure, human capital expenditure, labor supply, and real GDP. The conclusion was that increasing the same amount of R&D as the amount reduced in corporate tax is most effective in human capital expenditure.

Bor et al. (2010) investigated the case of Taiwan with CGE model. The model characterizes as the distinction of labor and explicit definition of R&D capital as production input. R&D capital is generated from private and public R&D investment, and labor divided into eight groups: managers, professionals, technicians, clerks, service workers, salespeople, operators, non-technician, and manual workers. The result was that public R&D investment had positive effects on macroeconomic indicators in short-run but its effects diminished in the long-run.

In conclusion, there were some studies to analyze R&D or innovation in terms of CGE framework. However, most of them analyzed R&D subsidy or R&D tax incentives which are supply-side innovation policy tools. In other words, there is no previous study on the policy impact assessment of PPI or demand-side innovation policy with CGE model. This study tries to investigate the innovation policy focusing on PPI and considering other innovation policy tools simultaneously.

Chapter 3. Methodology

3.1 Construction of Social Accounting Matrix

In order to construct CGE model, it is necessary to create social accounting matrix (SAM) with the data of the benchmark year. This study developed SAM with the input-output data from the Bank of Korea in the year of 2010 and supplementary data from System of National Account (SNA) revealed by Korea National Statistical Office (KNSO). This study investigates the case of PPI for EV industry. In order to analyze PPI for EV industry, SAM should be modified with specification of EV industry and public procurement account.

3.1.1 Overview of SAM

A social accounting matrix depicts the macroeconomic snapshot of the comprehensive economic system considering the interaction between the economic agents (Pyatt and Round, 1985). The basic structure of SAM is as in Table 4. In each column of SAM, the expenditure is recorded, so the sum of each column indicates the total expenditure. On the other hand, in each row, the income is recorded, so the total income is indicated as the sum of each row. Therefore, each cell indicates the flow of money between related economic agents.

Table 4. Structure of social accounting matrix

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Production</td><td colspan="2">Production Factors</td><td colspan="2">Institutions</td><td>Investment</td><td colspan="4">Tax</td><td colspan="2">ROW</td><td>Total</td></tr>
<tr><td>(1)</td><td>(2)</td><td>(3)</td><td>(4)</td><td>(5)</td><td>(6)</td><td>(7)</td><td>(8)</td><td>(9)</td><td>(10)</td><td>(11)</td><td>(12)</td><td>(13)</td><td></td></tr>
<tr><td rowspan="2">Production</td><td>Domestic (1)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Imported (2)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Production Factors</td><td>Labor (3)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Capital (4)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Institutions</td><td>Household (5)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Government (6)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Investment (7)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Tax</td><td>Indirect tax (8)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Corporate tax (9)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Income tax (10)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tariff (11)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">ROW</td><td>Export (12)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Import (13)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

For the purpose of the study, SAM can be constructed as different form, but in order to catch the macroeconomic picture well, SAM generally includes production activity, production factors, institutions, investment, tax, and rest of world sections.

The data in order to create SAM is from input-output table (I-O table) and SNA generally. The Bank of Korea has released the I-O table of Korea from 1960 every 3-5 years to 2005, and published annually after 2005. I-O table includes demand of each industry which are intermediate demand, employees' income, operating surplus, fixed capital depreciation in a row. Similarly, supply of each industry which are intermediate input, consumption, investment, export and import is recorded in a column. In addition to I-O table, various data from SNA such as tax revenue, transferred income, and balance of payment is included in SAM.

3.1.2 Concept of knowledge-based SAM

Because this study uses knowledge-based CGE model, SAM should also be constructed with the account related knowledge explicitly, which called knowledge-based SAM. There were some studies which tried to construct SAM with knowledge account. Wing (2003) assumed that some industries which had high R&D intensity did R&D investment and the others did not, and divided the investment into physical capital and knowledge capital for those industries. Lecca (2009) estimated knowledge flow between the industries using the patent data, and reflected it in SAM. This study generated knowledge-based SAM with the same method with Yang et al. (2012) and Oh et al. (2014). Table 5 depicts the structure of knowledge-based SAM.

The significant difference from basic SAM and knowledge-based SAM is that the latter explicitly defines knowledge as production factors and R&D investment for knowledge capital formulation.

The R&D expenditure is recorded as intermediate demand in I-O table. Therefore, it is necessary to capitalize it in order to create knowledge as production factors explicitly. The Bank of Korea divided the industries in 168 categories as small specification[1], and there are industries named “research institution” and “R&D in companies” among them. Therefore, R&D expenditure for each industry can be calculated as sum of its spending on “research institution” and “R&D in companies” industries. After calculation, in order to create knowledge production factor, the amount of R&D expenditure should be deleted from intermediate input and added as knowledge production factor.

As the process of capitalization of R&D expenditure in a row, the same amount should be capitalized in a column in order to match the total amount. However, because SNA 2008 recommended to record all expenditure including R&D for the purpose of sales and profit as intermediate demand, it cannot be capitalized the entire amount of R&D expenditure as knowledge capital formation. In basic specification which the Bank of Korea divided the industries in 403 categories, there are four accounts related to R&D,

[1] The Bank of Korea releases I-O table as four version of specification of industries, which are 28 industries as large specification, 78 industries as medium specification, 168 industries as small specification, and 403 industries as basic specification.

“public research institution”, “non-profit research institution”, “industry research institution”, and “R&D in companies”. Among them “industry research institution” account is the industry for the purpose of profit, so it excluded from the capitalization process. In other words, the sum of “public research institution” and “non-profit research institution” account is capitalized as public knowledge capital formation, and “R&D in companies” is capitalized as private knowledge capital formation in a column.

In addition to them, R&D investment which is not current expenditure in R&D should also specified. R&D investment is divided into the investment for machinery, land and building, and computer software, and they are recorded in capital formation in I-O table. According to Survey of Research and Development in Korea, 2010 by Korea Institute of Science and Technology Evaluation and Planning (KISTEP), only the sum of the investment for machinery and land and building is recorded. Therefore, this study assumed that investment on machinery is done for the industries of “general machinery”(gm), “electronic machinery”(em), “precision machinery”(pm), “transportation equipment”(tm), and “other manufacturing products”(om). By adjusting the proportion of capital formation for those five industry, the amount of knowledge capital formation can be calculated as Eq. (1).

$$KC_i = MA\ (FC_i\ /\ (FC_{gm} + FC_{em} + FC_{pm} + FC_{te} + FC_{om})) \cdots\cdots \text{Eq. (1)}$$

(KC_i : R&D investment for the industry I, FC_i : total capital formulation of industry i

MA : total amount of investment on machinery, i = gm, em, pm, te, om)

Table 5. Structure of knowledge-based social accounting matrix

			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	Total
Production	Domestic (1)																		
	Imported (2)																		
Production Factors	Labor (3)																		
	Capital (4)																		
	Knowledge (5)																		
Institutions	Household (6)																		
	Government (7)																		
Investment	Physical capital (8)																		
	Knowledge capital	Private (9)																	
		Public (10)																	
Tax	Indirect tax (11)																		
	Corporate tax (12)																		
	Income tax (13)																		
	Tariff (14)																		
ROW	Export (15)																		
	Import (16)																		
Total																			

For the investment on land and building, its amount is subtracted from capital formation of “construction” industry, and added in knowledge capital formation. For the investment on computer software, because the Survey did not include in-house software investment but I-O table included it, the sum of the amount from Survey and in-house software investment is excluded from capital formation and added in knowledge capital formation. After creating knowledge capital formation account, this study divided it as private and public account.

3.1.3 Specification of new emerging industry and public procurement

In order to analyze PPI for the new emerging industry, it is necessary to specify the targeted industry for PPI policy. This study investigates PPI for EV industry. However, EV industry is not recognized in I-O Table in Korea, so basic and knowledge-based SAM do not have the industry account named “EV industry”. Instead, there is industry account named “transportation equipment” which includes vehicles, ships, and airplanes. The production of EV is also included in this account. Therefore, EV production and demand information should be excluded from “transportation equipment” to separate account in order to analyze EV as targeted industry for policy experiment.

There are some ways to specify new industry from existing industry account in SAM (Miller and Blair, 2009). This study assumes that EV is only used for final consumption, not for intermediate demand. It means that there is no amount for each cell of EV industry in a column. In a row, the intermediate input in EV industry is recorded as cost structure of EV production. Leurent and Windish (2015) compared the cost structure to produce EV and conventional vehicle. For the production factors, Leurent and Windish (2015) suggested the total cost for the value added, and this study assumes that the proportion of cost structure between labor, capital, and knowledge is same between EV and traditional transportation equipment. In addition, this study regards that EV industry has same tax structure with transportation equipment industry.

The sum of “EV industry” row is total production volume of EV. In Korea, there were some EVs produced from 2012, and there was very low production volume of EV in 2010 which is the benchmark year. In order to analyze new emerging industry in SAM or CGE model, it is necessary for that industry to have enough production volume which can be regarded as the stage of market creation. This study assumed that the year of emergence of EV industry is 2014, since the number of total EV diffused slowly increased from 2010 to 2014. By this reason, this study uses the production volume of EV in 2014 as benchmark data. Figure 6 illustrates the process of specification of EV industry in SAM, and the shadowed part of Table 6 is added account for EV industry.

Basic and knowledge-based SAM have an account named “Government”. The demand of government and public institution is recorded in a cell of “Government” account in a row. Since public procurement is done by public institution, it is also recorded as the demand of government. However, different from the demand of household, Korean I-O table does not record the demand of government as industry. In other words, there are the amount of government demand only four industries in a row of "Government" which are "Real estate and business service", "Public administration and defense", "Education and health", and "Social and other services". All these four industries include the firm which managed by public institution or government. It means that the Bank of Korea records the government demand as user-based method not supplier-based method in I-O table. For example, if public elementary school purchased the paper as public procurement contract, it is recorded for not "Press and copy" industry but "Education and health". Therefore, in order to analyze PPI for new emerging industry, it is necessary to specify the amount of public procurement by supplier-based, not user-based.

(Before)

	Production					
	S1	S2	...	S15 Transportation equipment	...	S27
Production				A1		
Production Factors				A2		
Tax				A3		
Total				A		

(After)

	Production						
	S1	S2	...	S15 Transportation equipment	...	S27	S28 Electric vehicle
Production				A1-EVOUT*INT*Si			EVOUT*INT*Si
Production Factors				A2-EVOUT*DV*Si			EVOUT*DV*Si
Tax				A3-EVOUT*DT*Si			EVOUT*DT*Si
Total				A-EVOUT			EVOUT

Figure 6. Process of specification of EV industry in SAM[2]

[2] EVOUT: total production volume of EV industry
INT: proportion of intermediate inputs in the total sales of EV
DV: proportion of the production factors in the total sales of EV
DT: Proportion of tax in the total sales of EV
Si: proportion of sales made by industry 'i' related to EV

Table 6. Structure of SAM with electric vehicle account

			Activity				Factor inputs			Institution		Investments			Tax	ROW		Total
			Domestic		Imported		Labor	Capital	Knowledge	Household	Govern-ment	Physical Capital	Knowledge capital			Export	Import	
				EV		EV							Private	Public				
Activity	Domestic Intermediates	Ordinary																
		EV																
	Imported Intermediates	Ordinary																
		EV																
Factor inputs	Labor																	
	Capital																	
	Knowledge																	
Instituti-ons	Household																	
	Government																	
Investments	Physical Capital																	
	Know. Capital	Private																
		Public																
Tax																		
ROW	Export																	
	Import																	
Total																		

KNSO releases all public procurement contract with suppliers and users. Based on this data, this study extracts public procurement from government demand. “Public procurement” account is generated as one part of institution. The cell between “Public procurement” and “Government” records the total amount of public procurement, and each cell in “Public procurement” row records the volume of public procurement with supplier-based. The shadowed cell in Table 7 is cell related to public procurement.

3.2 Construction of Knowledge-based Computable General Equilibrium Model

CGE models are macro-economic simulation models which contains the procedure to achieve general equilibrium for all goods and services markets by considering all the economic actors and their interaction in the model (Kim and Kim, 2010). In numerical way, CGE models is the system of simultaneous equations with a number of variables which indicates economic indicators. This study uses knowledge-based CGE model which is based on the knowledge-based SAM addressed in Section 3.1. In this section, the structure and equation systems of knowledge-based CGE model which this study uses are introduced. The basic equations of this model are introduced in Hong et al. (2015) and Jung (2015), and this study modifies the model fit into the policy impact assessment of PPI policy.

Table 7. Structure of SAM with public procurement account[3]

		Activity	Factor inputs			Institution			Investments			Tax	ROW		Total
		Intermediate	Labor	Capital	Knowledge	Household	**Govern-ment**	**Public Procurement**	Physical Capital	Knowledge capital: Private	Knowledge capital: Public		Export	Import	
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] TP: total volume of public procurement

3.2.1 Structure of knowledge-based CGE

The significant difference between standard CGE model and knowledge-based CGE model is that knowledge-based CGE model explicitly describes the knowledge as one of the production factors and the knowledge capital investment different from physical capital investment. In addition, knowledge-based CGE model accounts the spillover effect of the knowledge stock. Knowledge spillover makes industry-specific knowledge accumulated by R&D investment affect the productivity of other industries (Hwang and Lee, 2014).

The model is mainly divided two parts, which are demand and supply. In demand part, total domestic demand is generated by the sum of private consumption, government consumption, investment for both physical capital and knowledge capital, and intermediate demand. The knowledge capital investment is done by private sector or public sector. Domestic demand is the sum of demand for imported goods and that for domestic goods. In supply part, total domestic supply is come from value-added which is generated by production factors and intermediate inputs. There are three production factors, labor, capital and knowledge. Knowledge is produced by R&D investment and value-added for knowledge formation which is generated by labor and capital only. Domestic products can be consumed in domestic market or in foreign market as export. Figure 7 describes the structure of the knowledge-based CGE model.

Figure 7 depicts the equation structure of the model with several economic variables.

However, for the economy-wide perspective, there are many concepts which Figure 7 does not include but related to knowledge and innovation. Figure 8 describes the economic structure of the knowledge-based CGE model in broader perspective. According to Figure 8, knowledge-based CGE model mainly considers the concept of innovation with various economic actors and activity such as production, production factor, government, capital and R&D investment, tax, and rest of world.

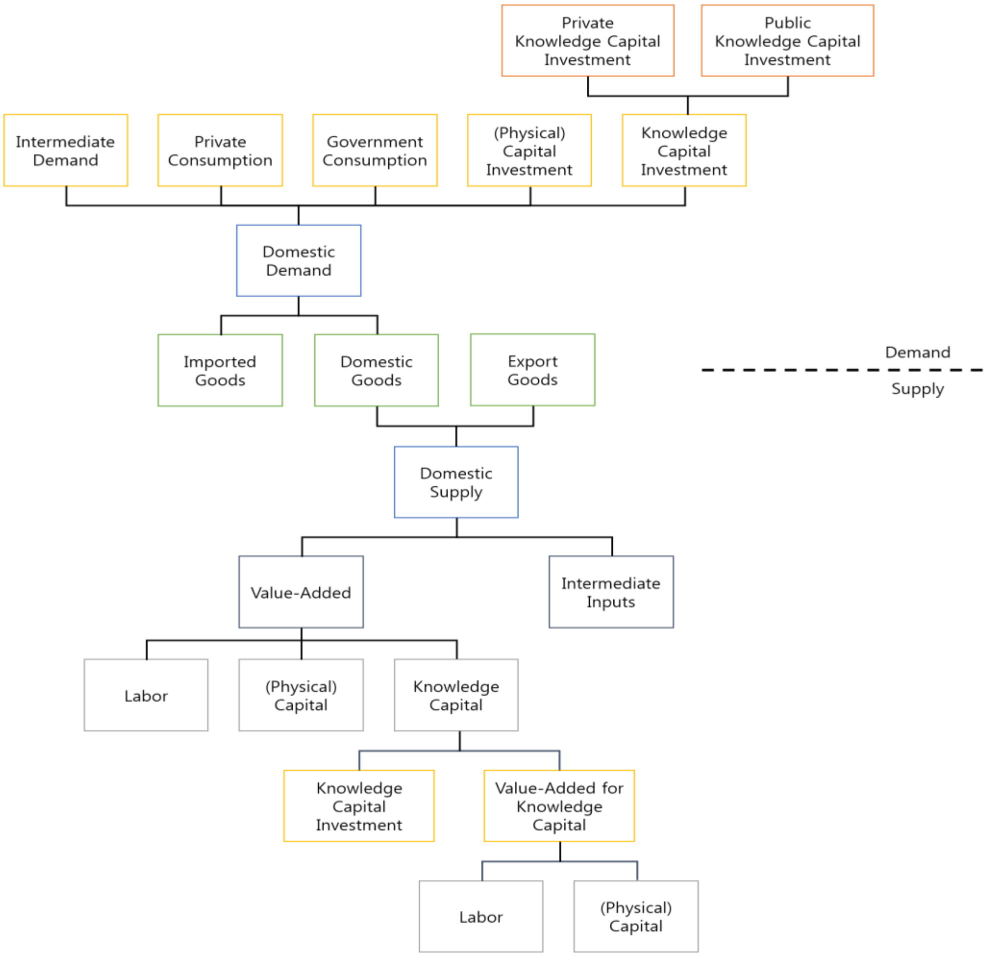

Figure 7. Equation structure of knowledge-based CGE model

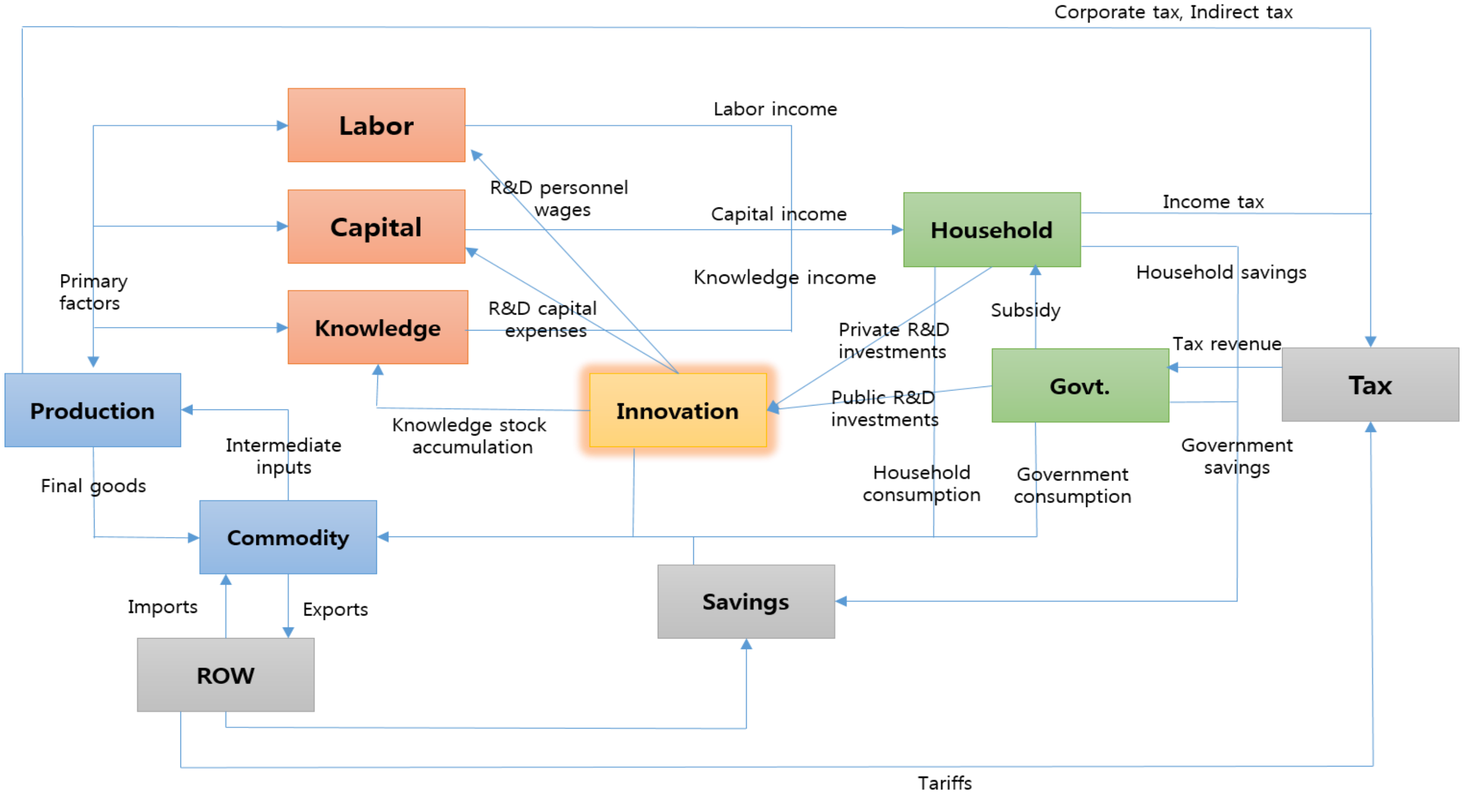

Figure 8. Economic structure of knowledge-based CGE model

source: Jung (2015)

3.2.2 Equation of knowledge-based CGE model

3.2.2.1 Variable description

In the CGE model, there are numerous variables and equations which depict the economic activities. Table 8, 9, and 10 shows the variables and parameters which the knowledge-based CGE model contains.

Table 8. Sets and indices description

Sets / Indices	Definition
i, *j*	Sectors and goods (*i*, *j* = 1, 2, …, 29)
rdt	Type of R&D (private and public)
n	Type of production factor (labor, capital, and knowledge)
t	Time (year)

Table 9. Variables description

Variables	Definition
L_i	Labor of sector *i*
K_i	(Physical) Capital of sector *i*

H_i	Knowledge of sector *i*
$X_{i,j}$	Intermediate demand of sector j produced in sector *i*
VA_i	Composited value-added of sector *i*
AVA_i	Value-added requirement coefficient of sector *i*
Z_i	Final output (Domestic supply) 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 (Domestic demand) of sector *i*
XP_i	Private consumption for sector *i*
XG_i	Government consumption for sector *i*
PP_i	Public procurement consumption for sector *i*
TXG_i	Total government consumption for sector *i*
XV_i	(Physical) Capital investment for sector *i*
$XVRD_{rdt,i}$	Knowledge capital investment for sector *i* with type *rdt*
RL_{rdt}	Labor in knowledge capital formation for type *rdt*
RK_{rdt}	(Physical) Capital in knowledge capital formation for type *rdt*
RVA_{rdt}	Composited value-added in knowledge capital formation for type *rdt*
RDZ_{rdt}	R&D investment for type *rdt*

$SPCOEF_i$	Spillover coefficient in sector *i*
$INTINDSP_i$	Interindustry spillover in sector *i*
$INVPRD_i$	Private R&D investment in sector *i*
INVGRD	Public R&D investment
INVK	(Physical) Capital investment demand
INVRES	Investment resource
SP	Private saving
SG	Government saving
ST	Total saving
HG	Public knowledge stock
TG	Government transfer to household
SF	International trade balance
LS_t	Labor stock in time *t*
KS_t	(Physical) Capital stock in time *t*
$INVK_t$	(Physical) Capital investment demand in time *t*
$H_{i,t}$	Knowledge of sector *i* in time *t*
$INVPRD_{i,t}$	Private R&D investment in sector *i* in time *t*
HG_t	Public knowledge stock in time *t*
$INVGRD_t$	Public R&D investment in time *t*

PL	Factor price of labor
PK	Factor price of (physical) capital
PRD_i	Factor price of knowledge capital in sector *i*
PVA_i	Price of composited value-added in sector *i*
PZ_i	Price of final output (domestic supply) 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 good (domestic demand) in sector *i*
$PWEi$	World price of export in sector i
$PWMi$	World price of import in sector i
$PINVK$	Price of (physical) capital investment demand
$PRDZ_{rdt}$	Price of R&D investment for type *rdt*
$PRVA_{rdt}$	Price of Composited value-added in knowledge capital formation for type *rdt*
TZ_i	Production tax (Indirect tax) in sector *i*
TL_i	Tax for labor (Income tax) in sector *i*
TK_i	Tax for physical capital (corporate tax for physical capital) in sector *i*
TH_i	Tax for knowledge capital (corporate tax for knowledge capital) in sector *i*
TM_i	Import tariff in sector *i*

HINC	Household income
HLINC	Household income from labor
HKINC	Household income from physical capital
HRINC	Household income from knowledge capital
GINC	Government income
$EVSTG_{i,t}$	EV stock in public sector at time t ($i = 29$)
$EVSTP_{i,t}$	EV stock in private sector at time t ($i = 29$)
lr_i	Learning rate for EV production ($i = 29$)

Table 10. Parameters description

Parameters	Definition
$ax0_{i,j}$	Intermediate input requirement coefficient of sector j produced in sector i
$ava0_i$	Composited value-added requirement coefficient in sector i
$\beta 10_i$	Share parameter in CES production function for labor in sector i
$\beta 20_i$	Share parameter in CES production function for physical capital in sector i
$\theta 0_i$	Scale parameter in CES production function in sector i
ρ	CES exponent
$\alpha 0_i$	Household consumption share parameter for industry i
$\tau 0^Z_i$	Production tax (Indirect tax) rate in sector i

$\tau 0^L_i$	Tax for labor (Income tax) rate in sector i
$\tau 0^K_i$	Tax for physical capital (Corporate tax for physical capital) rate in sector i
$\tau 0^H_i$	Tax for knowledge capital (Corporate tax for knowledge capital) rate in sector i
$\tau 0^M_i$	Import tariff rate in sector i
$\mu 0_i$	Government consumption share parameter for industry i
$\lambda 0_{j,i}$	Interindustry spillover stock weight from sector j to sector i
$spc0_i$	Scale parameter in interindustry spillover function in sector i
$rdelas_i$	interindustry R&D stock elasticity in sector i
$grdelas_i$	Public R&D stock elasticity in sector i
$\varphi 0$	Scale parameter in CES knowledge capital production function
$\psi 0$	Share parameter in CES knowledge capital production function for labor
$axrd0_{rdt,i}$	Intermediate input requirement coefficient in knowledge capital formation of sector i for type rdt
$ayrd0_{rdt}$	Composited value-added requirement coefficient in knowledge capital formation for type rdt
ε	Exchange rate
g_t	Population growth rate in time t
$rkdep$	(physical) capital depreciation rate
$rhdep$	Knowledge capital depreciation rate
$evig_i$	The share of EV PPI for total government expenditure (i = 29)

$bsub_i$	Sales incentive for EV purchase (i = 29)
$psub_i$	Production (R&D) incentive for EV purchase (i = 29)
lpc_i	Scale parameter in learning function of EV production (i = 29)
$evgelas_i$	Public EV stock elasticity (i = 29)
$evpelas_i$	Private EV stock elasticity (i = 29)

3.2.2.2 Production

Firms require intermediate inputs and the production factors such as capital and labor. Here, knowledge is added for the production factors to develop and produce the goods. With three production factors, composited value-added is generated. In other words, output of each industry is produced with the function of intermediate inputs and composited value-added. The model uses Leontief production function which assumes the impossibility of substitution between production factors. It means that composited value-added and intermediate inputs cannot be substituted in the production process. The production function of each industry's output is expressed by Eq. (2).

$$Z_j = \min [\, X_{1,j} / ax0_{1,j}, X_{2,j} / ax0_{2,j}, \ldots, X_{n,j} / ax0_{n,j}, VA_j / ava0_j \,] \quad \text{Eq. (2)}$$

$$Xi,j = ax0_{i,j} \cdot Z_j \quad \text{Eq. (3)}$$

$$VA_j = AVA_j \cdot Z_j \quad \text{Eq. (4)}$$

$ax0_{1,j}$ and AVA_j are the intermediate inputs and composited value-added required to produce one unit of products in industry j, respectively. Eq. (3) and Eq. (4) are equations introduced in order to incorporate Eq. (2) into the model.

Composited value-added is generated by the integration of labor, capital, and knowledge. The generating function of composited value-added is the constant elasticity of substitution (CES) function. Since CES production function does not require the elasticity of substitution is 1, various studies on innovation impact analysis use it (Shin. 2005). Although CES production function is generally used for only two production factors, Sato (1967) mentioned the possibility of introducing CES production factor when there are more than two production factors. The generation function of composited value-added is depicted as Eq. (5).

$$VA_i = \theta 0_i \cdot (\beta 10_i \cdot L_i^{-\rho} + \beta 20_i \cdot K_i^{-\rho} + (1 - \beta 10_i - \beta 20_i) \cdot H_i^{-\rho})^{-1/\rho} \quad \cdots\cdots \text{Eq. (5)}$$

3.2.2.3 Household and government

Household gains the income with supplying labor, capital and knowledge. Labor income is indicated in Eq. (6), which is the sum of wage from production activities and that from knowledge capital production activities. Similarly, Eq. (7) indicates the capital income which acquires from both production activities and R&D activities. Eq. (8) describes the knowledge income from production activities. Finally, the household income is the sum of three incomes, indicated in Eq. (9).

$HLINC = \sum_{i} (L_i \cdot PL) + \sum_{rdt} (RL_{rdt} \cdot PL)$ ······ Eq. (6)

$HKINC = \sum_{i} (K_i \cdot PK) + \sum_{rdt} (RK_{rdt} \cdot PK)$ ······ Eq. (7)

$HRINC = \sum_{i} (H_i \cdot PRD_i)$ ······ Eq. (8)

$HINC = HLINC + HKINC + HRINC$ ······ Eq. (9)

Using the income, household spends it into consumption, save it, or give it to government as transfer payment. Eq. (10) depicts the decision of the amount of spending on consumption of household.

$XP_i = \alpha 0i \cdot (HINC - SP - TG) / PQ_i$ ······ Eq. (10)

Government income is from the tax. This model defines various types of tax such as indirect tax, direct tax, and tariff. Indirect tax is imposed to the producers based on the output. Direct tax is imposed to the household based on the income, and it consists of labor income tax, capital income tax, and knowledge income tax. Tariff is the tax for the imported goods. Eq. (11) to Eq. (15) indicates the equation for the tax.

$TZ_i = \tau 0^{Z}{}_{i} \cdot Z_j \cdot PZ_i$ ······ Eq. (11)

$TL_i = \tau 0^{L}{}_{i} \cdot L_j \cdot PL$ ······ Eq. (12)

$TK_i = \tau 0^{K}{}_{i} \cdot K_j \cdot PK$ ······ Eq. (13)

$TH_i = \tau 0^{H}{}_{i} \cdot H_j \cdot PRD_i$ ······ Eq. (14)

$TM_i = \tau 0^{M}{}_{i} \cdot M_j \cdot PWM_i$ ······ Eq. (15)

Government income is the sum of all tax income and transfer payments from household. Eq. (16) depicts the equation of gathering government income.

$$GINC = (\sum_i (TZ_i + TL_i + TK_i + TH_i + TM_i)) + TG \quad \cdots\cdots \text{Eq. (16)}$$

Government uses its income into government expenditure and public procurement. The remaining amount after government spends is government saving. Eq. (17) and (18) indicates the government consumption and income.

$$XG_i + PP_i = TXG_i \quad \cdots\cdots \text{Eq. (17)}$$

$$TXG_i = (1 + evig_i) \cdot \mu 0_i \cdot (GINC - SG - \sum_j ((ax0_{i,j} \cdot bsub_i \cdot PQ_i) / PQ_i) \quad \cdots\cdots \text{Eq. (18)}$$

3.2.2.4 Knowledge

This study introduces the concept of knowledge spillover which is that the knowledge stock in each industry influences on the productivity of other industries with no cost. The model considers the amount of spillover effect as proportion to the volume of intermediate transactions between the industries which captured in I-O table (Terleckyj, 1980). Eq. (19) indicates the knowledge spillover effect between the industries. Although Eq. (19) depicts the knowledge spillover of private knowledge stock, there is also spillover effect for public knowledge stock. Guellect and Potterie (2001) suggested that the productivity of each industry is influenced by the public knowledge stock because it is used for each industry without rivalry and exclusiveness. Eq. (20) indicates the total spillover effect generated by knowledge stock from other industries and public knowledge stock. This study employs the value of each elasticity (rdelas and grdelas) from previous literature, Cho (2004) and Hwang et al. (2008) respectively. Finally, Eq. (21) depicts the change of productivity by knowledge spillover. In other words, thanks to knowledge spillover, more output is generated with the same amount of production factors used as before.

$$INTINDSP_j = \sum_{j\, j \neq i} \lambda 0_{j,i} \cdot H_j \quad \cdots\cdots \text{Eq. (19)}$$

$$SPCOEF_i = spc0_i \cdot INTINDSP_i^{rdelas_i} \cdot HG^{grdelas_i} \quad \cdots\cdots \text{Eq. (20)}$$

$$AVA_j = ava_i \,/\, SPCOEF_i \quad \cdots\cdots \text{Eq. (21)}$$

In order to do R&D activities, intermediate demand for R&D and production factors such as labor and capital is required. Composited value-added for knowledge capital production is generated by labor and capital with CES function. In addition, knowledge capital is produced by Leontief function between intermediate demand and composited value-added. Eq. (22) to (24) indicates the production function in R&D activities.

$$RVA_{rdt} = \varphi 0 \cdot (\psi 0 \cdot RL_{rdt}^{\ -\rho} + (1 - \psi 0) \cdot RK_{rdt}^{\ -\rho})^{\ -1/\rho} \quad \cdots\cdots \text{Eq. (22)}$$

$$XVRD_{rdt,i} = axrd0_{rdt,i} \cdot RDZ_{rdt} \quad \cdots\cdots \text{Eq. (23)}$$

$$RVA_{rdt} = ayrd0_{rdt} \cdot RDZ_{rdt} \quad \cdots\cdots \text{Eq. (24)}$$

3.2.2.5 Investment and savings

In this model, investment is divided into physical capital investment and knowledge capital investment. The total amount of investment is sum of two investments. This study assumes that total amount of investment is same as total amount of savings, and the savings are gathered from private sector, government, and trade balance. Eq. (25) to (28) indicates the investment and savings account in this model.

$$INVRES = \sum_i (XV_i \cdot PQ_i) + \sum_i (RDZ_{rdt} \cdot PRDZ_{rdt}) \quad \cdots\cdots \text{Eq. (25)}$$

$$ST = SP + SG \quad \cdots\cdots \text{Eq. (26)}$$

$$INVRES = ST + SF \quad \cdots\cdots \text{Eq. (27)}$$

$$SF = \sum_I (PE_i \cdot E_i) - \sum_i (PM_i \cdot M_i) \quad \cdots\cdots \text{Eq. (28)}$$

3.2.2.6 Foreign trades

The country sells its products to other countries and buys the goods from others, which are export and import respectively. In export, price is influenced by the world price of the product and the exchange rate. On the other hand, in import, price is influenced by not only world price and the exchange rate but also the tariff. Eq. (29) indicates the price determination of export goods, and Eq. (30) depicts that of import goods.

$$PE_i = \varepsilon \cdot PWE_i \quad \cdots\cdots \text{Eq. (29)}$$

$$PM_i = \varepsilon \cdot (1 + \tau 0^M{}_i) \cdot PWM_i \cdots\cdots \text{Eq. (30)}$$

Domestic demand is the sum of domestically consumed inter-country produced goods and imported goods. Domestic supply or output is the sum of domestic goods consumed inside the country and exported goods. Eq. (31) and (32) indicate the domestic demand and supply.

$$PQ_i \cdot Q_i = PM_i \cdot M_i + PD_i \cdot D_i \quad \cdots\cdots \text{Eq. (31)}$$

$$PZ_i \cdot Z_i = PE_i \cdot E_i + PD_i \cdot D_i \quad \cdots\cdots \text{Eq. (32)}$$

3.2.2.7 Learning by doing

By learning by doing or learning effect, the producers can experience cost and performance improvement in technology, and it makes the private consumers be more likely to demand their products (Krzyzanowski et al., 2008). As mentioned in Section 2.2, learning effects let the producers to invest more on commercialization effort with reducing the unit cost, and it leads to further expansion of the market of innovative products. For EV industry, since EV industry is new emerging industry, it is important for EV makers to experience learning effect to reduce the unit cost of production in the early stage of scale-up and commercialization.

This model sets the equation which reflects learning effect. The equation is constructed as the relationship between the production cost and cumulative volumes of sales. In other words, the unit cost of production in time t is determined by the first unit cost of production at benchmark year and the cumulative sales from benchmark year to time t, as Eq. (33) and Eq. (34) suggests. This relationship was already presented in several studies which investigated the technology development path of EV (Karkatsoulis et al., 2014; Mayer et al., 2012; Krzyzanowski et al., 2008). The learning rate is different from the technology or products, and this study employs the learning rate of EV technology from the studies of Krzyzanowski et al., (2008) and IEA (2012). In addition, public and private EV stock elasticity is assumed to be same with public R&D stock elasticity. Finally, learning coefficient influences on the input requirement coefficient, which illustrates TFP of EV production, as Eq. (35) depicts.

$$lpc_i = 1 / ((EVSTG_{i,t} \cdot evgelas_i) \cdot (EVSTP_{i,t} \cdot evpelas_i)) \quad \text{Eq. (33)}$$
$$lr_i = lpc_i / ((EVSTG_{i,t} \cdot evgelas_i) \cdot (EVSTP_{i,t} \cdot evpelas_i)) \quad \text{Eq. (34)}$$
$$ava_i = ava0_i / lr_i \quad \text{Eq. (35)}$$

3.2.2.8 Dynamics

In order to investigate the policy impact over time, it is important to implement dynamics in the model. This model sets the dynamic features of the production factors, which are labor, capital and knowledge is accumulated over time. First, this model set the labor stock of benchmark year as the sum of labor as production factors in production activities and knowledge capital production activities. The dynamics of the labor stock reflects the population growth rate. Eq. (36) and (37) indicates the dynamic procedure of accumulation of the labor stock.

$$\sum_{i} L_i + \sum_{rdt} RL_{rdt} = LS_0 \quad \cdots\cdots \text{Eq. (36)}^4$$

$$LS_{t+1} = (1+ g_t) \cdot LS_t \quad \cdots\cdots \text{Eq. (37)}$$

For the capital stock, the depreciation is generated with time. The dynamics of the capital stock reflects the depreciation rate of physical stock and additional investment, as Eq. (38) depicts.

$$KS_{t+1} = (1 - rkdep) \cdot KS_t + INVK_t \quad \cdots\cdots \text{Eq. (38)}$$

There is also depreciation for the knowledge stock. Therefore, the dynamics of the knowledge stock reflects the knowledge capital depreciation rate and the additional knowledge investment, similar with physical capital. Because there are two sources of knowledge stock, private and public. Private knowledge stock is accumulated as Eq. (39) indicates and public stock is accumulated as Eq. (40).

$$H_{i,\,t+1} = (1 - rhdep) \cdot H_{i,\,\mathrm{t}} + INVPRD_{i,\,t} \quad \cdots\cdots \text{Eq. (39)}$$

$$HG_{\,t+1} = (1 - rhdep) \cdot HG_{\mathrm{t}} + INVGRD_{i,\,t} \quad \cdots\cdots \text{Eq. (40)}$$

[4] When t=0, it means the case of benchmark year.

Chapter 4. Economy-wide Impact of Public Procurement for Innovation: the Case of Electric Vehicle

4.1 Path of the Economic Impact of PPI for EV

In Section 2.2., it is addressed that it is important to find the impact path of innovation policy, especially PPI, in order to construct the frameworks of policy impact assessment in economy-wide perspective. Moreover, this study draws the causal loop of policy impact of PPI in that Section. Although the causal loop in Section 2.2 generally captures the causal relationship among policy, waypoint variables of economy and technology, and final target variable which is GDP, it should be modified in order to link it with quantitative model. The modified causal loop describes the economic and technology variables which is included in knowledge-based CGE model and their causal relationships. Figure 9 is the causal loop of PPI policy impact for EV sector.

PPI for EV industry increases the output of EV industry in two ways, directly and indirectly. First, because PPI means the purchase of certain products in government expenditure, it means the increase of public demand. This affects the total government expenditure directly. Since public demand increases, sales of EV increases. On the other hand, as Section 2.2 suggested, PPI can stimulate the private demand indirectly in several paths, and it leads the output growth of EV industry.

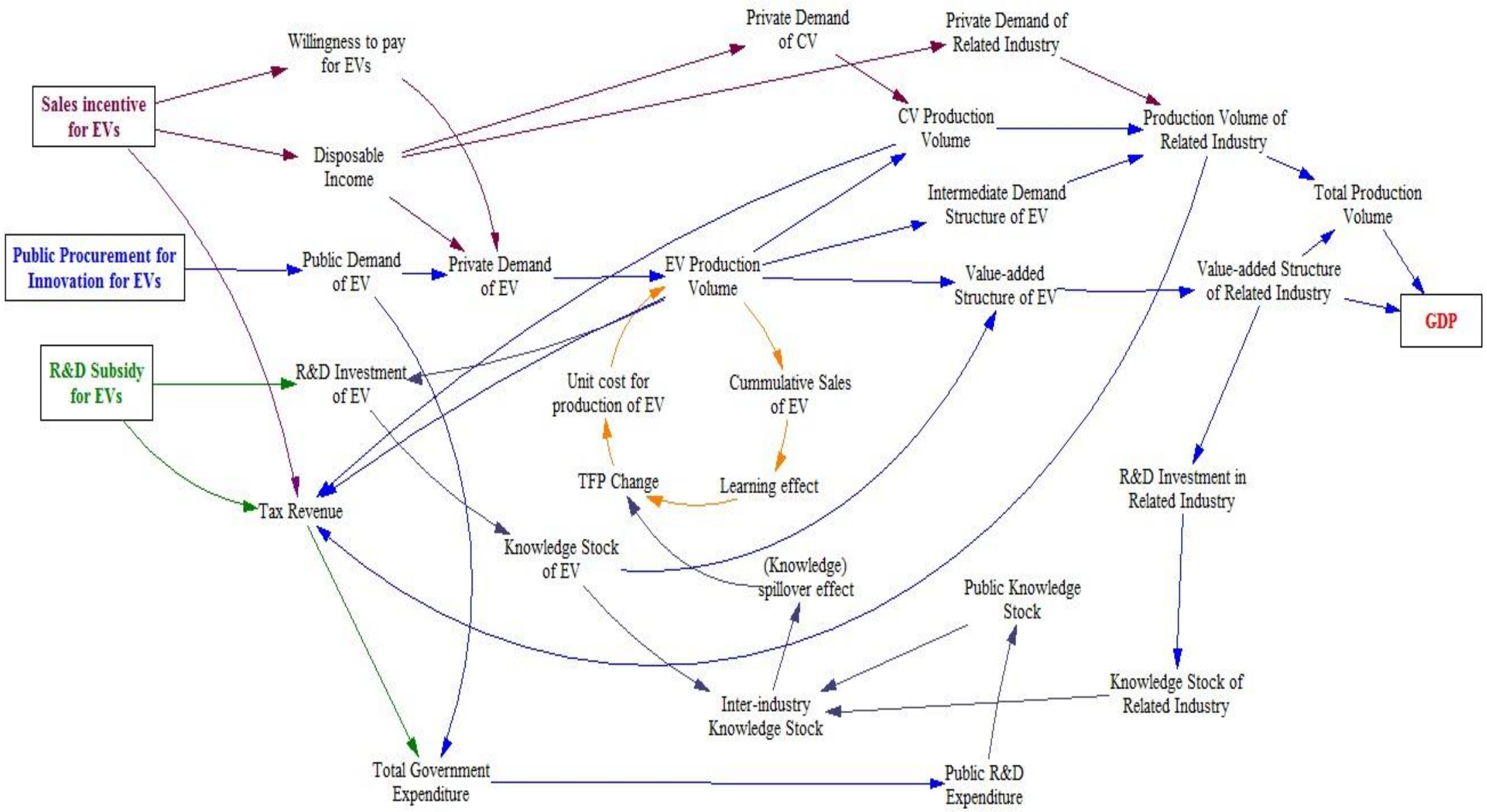

Figure 9. Causal loop of innovation policy impact for EV industry

From the increase of EV industry's output, this study investigates three main impact paths of PPI in Figure 9. First of all, by growth of public and private demand for EV, the output of the related industry is also changed. It is because there are some industries which EV industry uses their output as intermediate input, and there are also some industries which are in relation of substitution or competition with EV industry. Moreover, consumption habit of private sector can also be changed due to the emergence of demand for new products. As a result, these relationship generates the change of GDP or other macro-economic variables. In other words, PPI for EV industry make changes of other industries' output and total gross output.

Next, due to the growth of EV sales, the structure of composited value-added which is the combination of labor, physical capital, and knowledge is changed. The EV makers require more production factors in order to produce EV more than before. Especially, the increase of knowledge makes the accumulation of industry-specific knowledge stock by additional R&D investment. As a result, with public R&D investment, it can be increased the amount of knowledge spillover effect, and it finally leads the improvement of TFP and unit cost of production of EV.

Finally, the increased output of EV makes learning effect in production process. It means that the unit cost of EV production reduces with the accumulated sales of EV, which means the improvement of total factor productivity (TFP). Improvement of costs and quality can lead the further expansion of EV market and sales.

In addition, R&D subsidy and sales incentive also has its own impact paths and this study merged them into the causal loop for PPI policy impact. First of all, R&D subsidy policy for EV sector influences on the R&D and innovation investment of EV industry. The change of R&D investment affects the knowledge stock of EV, and it leads the change of private knowledge stock and value-added structure of EV sector, as PPI does. Secondly, Sales incentive affects the preference of private sector on EV with willingness to pay for EV purchase and household disposable income. These two factors influence on the private demand of EV. The change of disposable income affects the consumption structure of household, including the demand for the products of EV-related industries. This leads the change of production volume in those industries. Finally, R&D subsidy and sales incentive policy commonly reduce the total tax revenue of the government. The reduced tax revenue affects the total government expenditure, and this leads the change of public R&D investment, and ultimately public knowledge stock.

This study tries to link the qualitative and quantitative method for policy impact assessment. The causal loop which is Figure 4 and Figure 9 describes the qualitative analysis of policy impact of PPI in general and in specific to EV industry respectively. In Section 4.3, the quantitative results for policy shock with PPI is presented. The quantitative results which this study analyzes are based on the qualitative causal loop, and they can be regarded as the numerical evidence of qualitative approach for policy impact assessment.

4.2 Scenarios

This study mainly focuses on the policy impact assessment of PPI for EV industry. However, as mentioned in Section 2.3 and 2.4, there are other innovation policy tools for new emerging industry or especially EV industry. It is important to consider the possibility of the implementation of other policy tools because their effect can influence on the total policy impact as hidden treatment (Guerzoni and Raiteri, 2015). Therefore, this study considers R&D subsidy for EV-related technologies and private sales incentive for EV purchase as additional innovation policy tools.

Therefore, this study first investigates the case of implementation of PPI only, which is scenario 1-1, 1-2, and 1-3. In addition, policy experiments will be done with other innovation policy tools such as R&D subsidy and sales incentive from scenario 2-1 to 2-6. Table 11 illustrates the policy scenarios for CGE analysis. The sum of the reduced amount due to R&D subsidy and sales incentive is same for all scenarios between 2-1 and 2-6.

The scenarios in this study reflects the current and planned EV technology and diffusion policy of each country, mentioned in Section 2.4. Many countries are implementing public procurement, R&D subsidy, sales incentive policy for EV. Norway gives relatively the most volume of purchasing subsidies including tax incentives, reduction of road charges, and Denmark, China, France, Japan and US follows (Amsterdam Roundtable Foundation & McKinsey & Company The Netherlands, 2014). According to Kang (2015), the rate of sales incentive by the price of new EV in Japan is

15%, but it only includes the direct incentives and tax grants. This study recalculated the rate of sales incentive by the average EV price with consideration of all incentive tools, and it is concluded that some countries such as Norway, Denmark, and Japan gives the purchasing subsidy as the rate of 60~70% at most, and others such as France, UK, and US subsidies the rate of 15~25% by average car prices. This study adopts these recalculated rate of sales incentives as the scenario setting. For R&D subsidy, this study adopted the same scale of reduced money with the sales incentives. In other words, high R&D subsidy is reduced the same scale as the amount of the case in high sales incentives. Since the amount of government expenditure is fixed, this study only investigates the scenario of policy mix between the low R&D subsidy and high sales incentive or high R&D subsidy and low sales incentive.

For the private demand, this study employs the estimates from Chae et al. (2011). They constructed the methodology for demand forecast of EV and estimated the demand of total vehicle and electric vehicle in 2020, 2025, and 2030. They concluded that EV will form 15.47% of total vehicle in 2030, compared to the 0.04% of 2015. This study employs the figure they suggested for the year of 2020, 2025, and 2030 and assumed that the private EV demand grows linearly between the years from 2010 to 2020, from 2020 to 2025, and from 2025 to 2030.

Table 11. Policy scenarios

Scenario	Public procurement for innovation	R&D Subsidy	Sales Incentives
Targeted policy variables	EV PPI share of total government expenditure	Production tax of EV industry	Indirect tax for EV goods
Base Scenario (BAU)	No Policy Shock		
Scenario 1-1	10% increase until 2030	-	-
Scenario 1-2	50% increase until 2030	-	-
Scenario 1-3	100% increase until 2030	-	-
Scenario 2-1	10% increase until 2030	Same scale as the amount of sales incentive of 70% reduction	25% reduction until 2030
Scenario 2-2	10% increase until 2030	Same scale as the amount of sales incentive of 25% reduction	70% reduction until 2030
Scenario 2-3	50% increase until 2030	Same scale as the amount of sales incentive of 70% reduction	25% reduction until 2030
Scenario 2-4	50% increase until 2030	Same scale as the amount of sales incentive of 25% reduction	70% reduction until 2030
Scenario 2-5	100% increase until 2030	Same scale as the amount of sales incentive of 70% reduction	25% reduction until 2030
Scenario 2-6	100% increase until 2030	Same scale as the amount of sales incentive of 25% reduction	70% reduction until 2030

4.3 Simulation Analysis

As addressed in Section 4.1, this study mainly focuses on the policy impact of PPI for GDP, the related industries' output, knowledge stock and spillover, and learning effect. Next four subsections illustrate the quantitative changes with each policy scenario.

4.3.1 Economy-wide impact and EV industry

First of all, the representative macro-economic indicator, GDP (gross domestic production), is investigated. In scenario 1-1, 1-2, and 1-3, which implements only additional PPI for EV, the growth rate of GDP increases compared to the base scenario. However, the growth rate decreases as the volume of PPI for EV rises. Figure 10 depicts the simulation results on GDP for the scenario 1-1, 1-2, and 1-3. In particular, as PPI implements, the public and private demand for EV expands, and it stimulates the GDP growth. This study employs the data for private EV demand forecast in 2020, 2025, and 2030 and assumes the private demand for EV increases linearly in the periods of 2010 to 2020, 2020 to 2025, and 2025 to 2030. For each period, PPI always encourages the expansion of GDP in the early years, but the effect of PPI diminishes after some years. This is because PPI for EV also has negative impact on the other industries' output and value-added. In other words, after some years, PPI cannot generate the expansion of EV production as much as before and influences on the output of other industries negatively, so the GDP expansion effect reduces. However, despite the negative impact on other industries, PPI for EV generally stimulates more economic growth than the case of no policy.

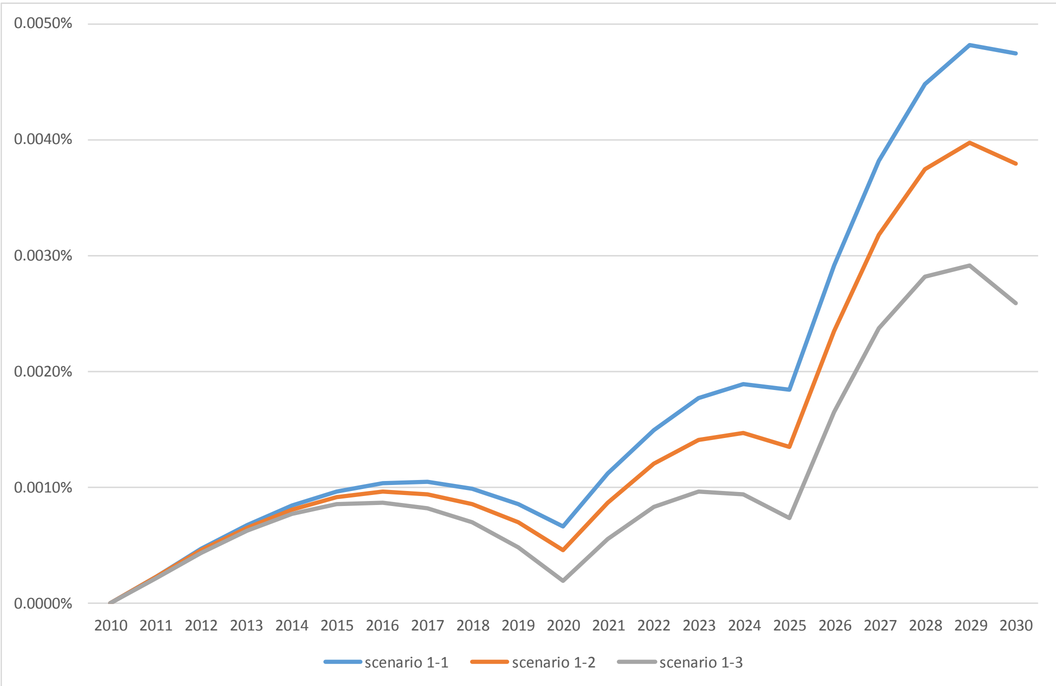

Figure 10. Change of GDP in scenario 1-1, 1-2, and 1-3

(unit: %, compared to BAU)

The analysis results show that PPI induces the GDP growth effect. This study additionally simulates the case of policy mix among PPI, R&D subsidy, and sales incentives whether it generates more or less GDP growth effect. Figure 11, 12 and 13 depict the GDP growth path from scenario 2-1 to 2-6.

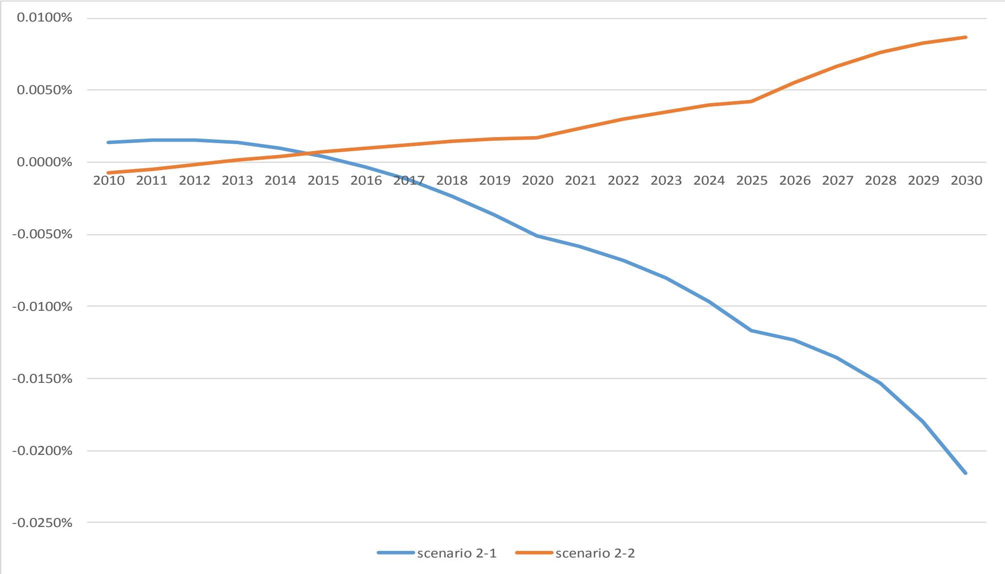

Figure 11. Change of GDP in scenario 2-1 and 2-2

(unit: %, compared to BAU)

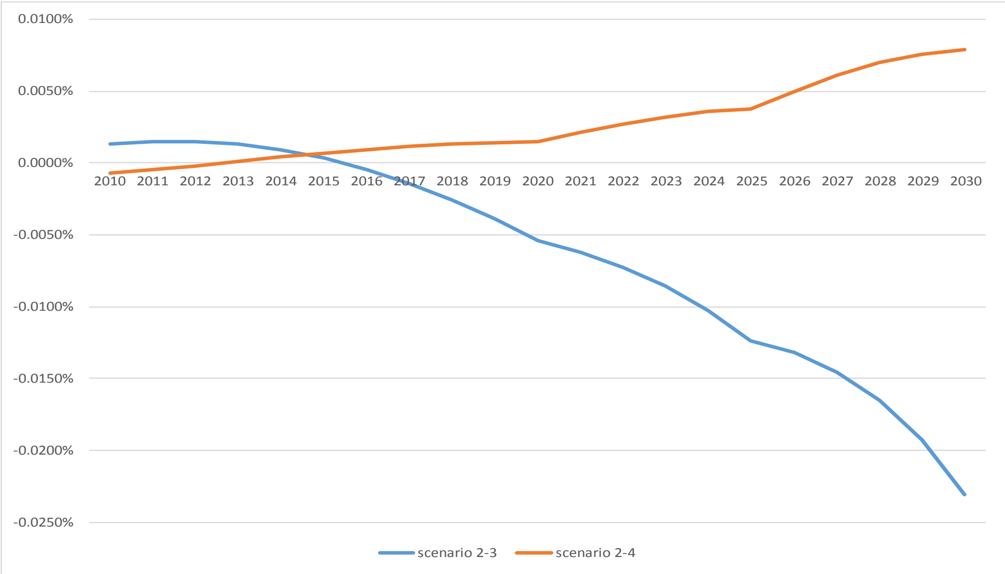

Figure 12. Change of GDP in scenario 2-3 and 2-4

(unit: %, compared to BAU)

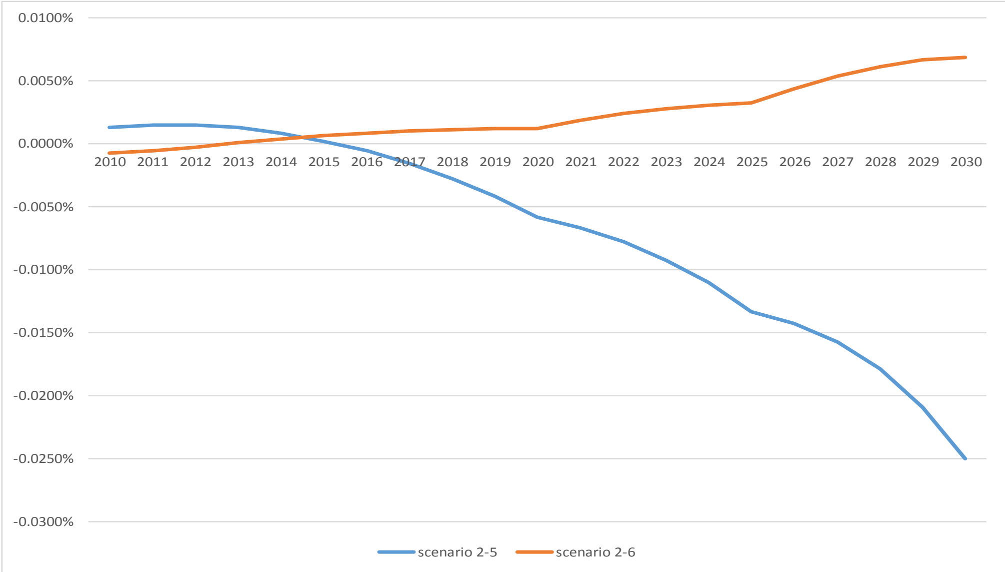

Figure 13. Change of GDP in scenario 2-5 and 2-6

(unit: %, compared to BAU)

The policy experiments from scenario 2-1 to 2-6 addresses that the trend of GDP increase could be different because of the R&D subsidy and sales incentives. Scenario 2-1, 2-3, and 2-5 are common in context of R&D subsidy and sales incentives, which the R&D subsidy is implemented larger than sales incentive. In those cases, the GDP reduces due to the innovation policy mix. It means that the policy mix among large R&D subsidy and low sales incentive for EV industry cannot generate EV production expansion effect as much as the loss of the output from the other industries. On the other hand, when there are larger sales incentives than R&D subsidy, which are the scenario 2-2, 2-4, 2-6, the direction of GDP trend is changed into increasing, which is same as PPI only scenarios.

Figure 14 is the comparison graph of GDP growth rate in 2030 comparing to the base scenario. Commonly, the policy mix between low R&D subsidy and large sales incentive on EVs generates more positive impact on GDP than the PPI only scenarios. On the contrary, when EV industry gets large R&D subsidy and low sales incentives, GDP reduces compared to the base scenario. These results imply the significance of policy mix fit into the economic and technology environment of the targeted sector for the impact assessment for not only the industry itself but also the economic-wide indicators.

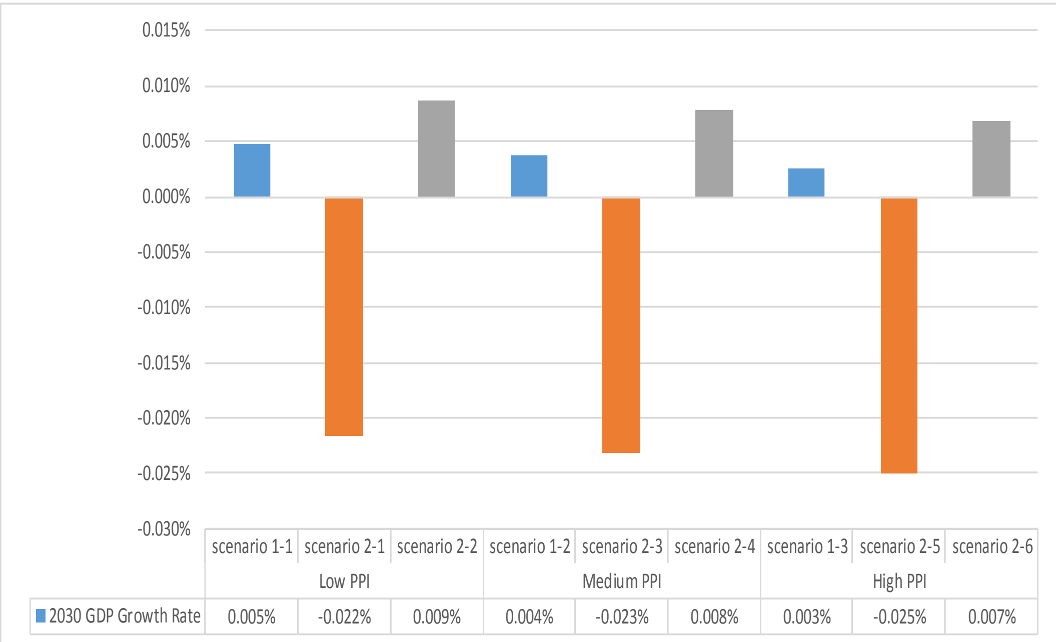

Figure 14. GDP growth rate in 2030 for each scenario

(unit: %, compared to BAU)

This study also investigates the factor which influences on GDP change. In the knowledge-based CGE model this study uses, GDP is linked with the value-added from each production factor, labor, capital, and knowledge. Figure 15, 16, and 17 depicts the change of household income from each factor in 2030 compared to the base scenario. For the scenario 2-2, 2-4, and 2-6, which generates the most GDP expansion effects, all incomes from labor, capital, and knowledge increases. On the other hand, for the scenarios which induces negative impact on GDP, only the income from knowledge increases comparing to the base scenario. Knowledge income rises the most in those scenarios because of the highest R&D subsidy. Lastly, for the PPI only scenarios, the incomes from labor and knowledge rises.

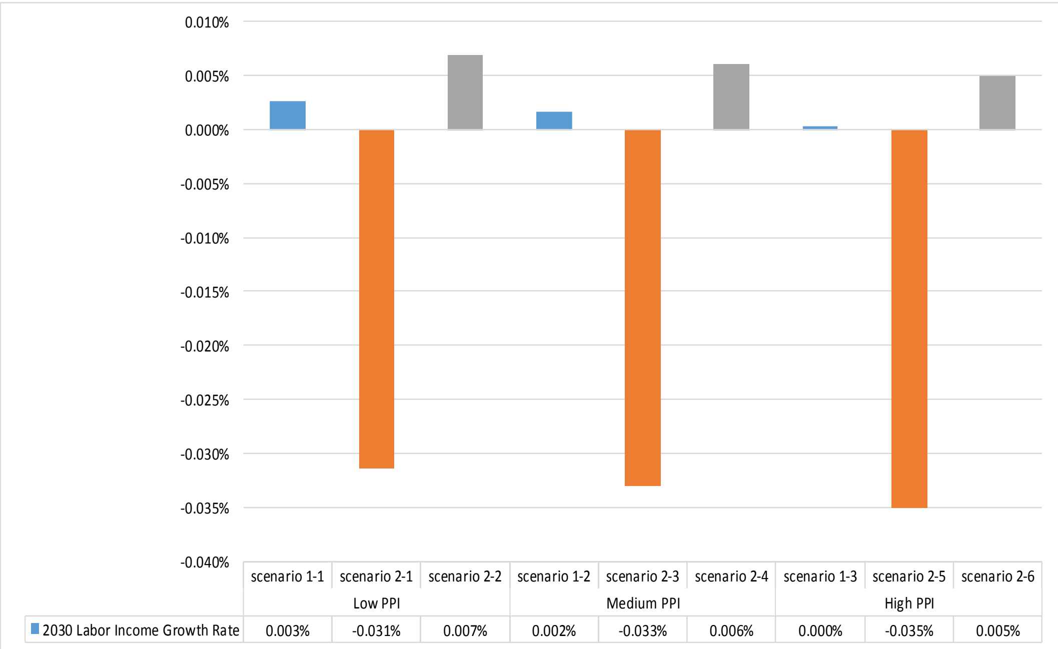

Figure 15. Labor income growth rate in 2030 for each scenario

(unit: %, compared to BAU)

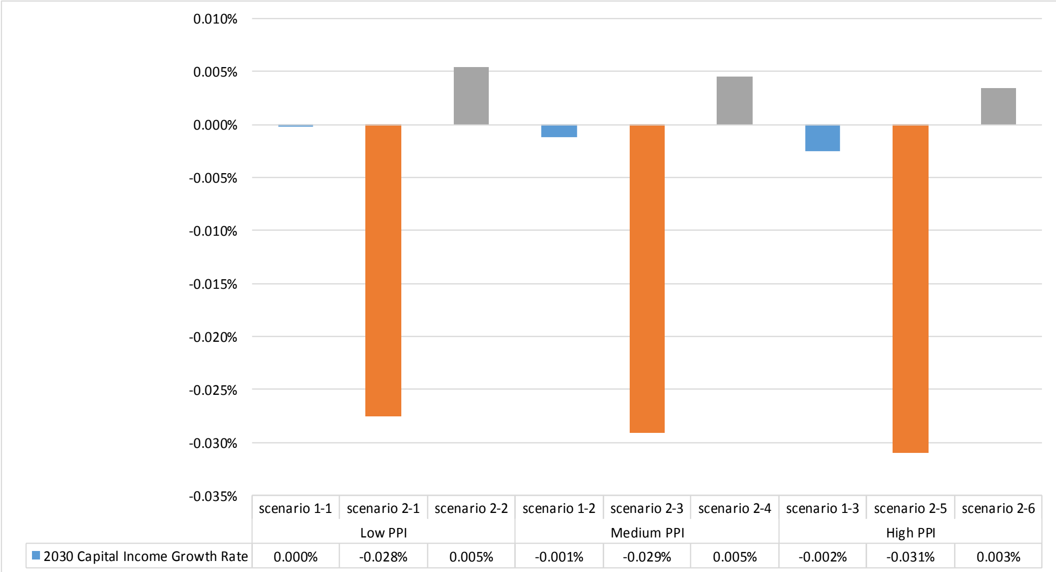

Figure 16. Capital income growth rate in 2030 for each scenario

(unit: %, compared to BAU)

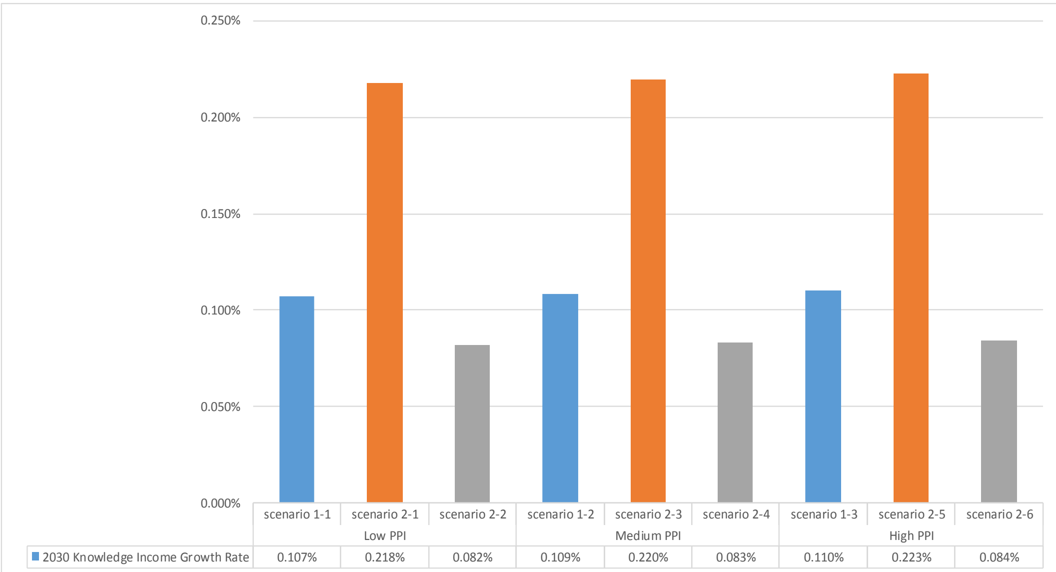

Figure 17. Knowledge income growth rate in 2030 for each scenario

(unit: %, compared to BAU)

Figure 18 compares the structure of household income in 2010 and 2030. The structure is significantly similar among all scenarios including the base scenario. From 2010 to 2030, the portion of labor income increases and that of capital income decreases. In sum, since only the small portion accounts for the knowledge income, the main factor for GDP increases in the scenarios is the increase of labor income. The portion of labor income increases from 2010 to 2030, and the amount of it rises only in the scenarios which are simulated as GDP expansion effect.

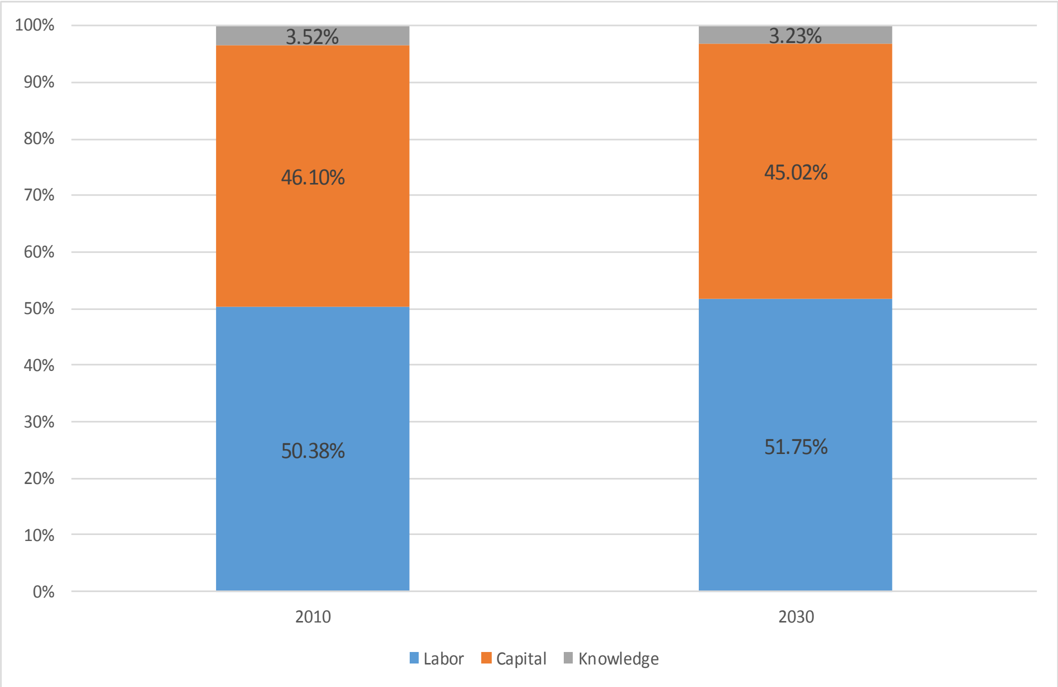

Figure 18. Structure of household income in 2010 and 2030 in the base scenario (unit: %)

In conclusion, since EV industry is new emerging industry and does not have large volume of production, the policy to stimulate EV industry might generate reverse effect for the GDP due to the negative influences on other industries when the policy mix is poorly designed. However, with the proper policy mix, the innovation policy for EV industry expansion stimulates the more economic growth thanks to the public and private demand expansion and output increase of EV sector.

Although GDP is the representative macro-economic indicator to capture the economic situation, it is important to investigate the production volume of each industry. It is because the policy for EV production and sales directly influence on the EV production volume, and the volume of intermediate demand for EV industry is changed, and, thus, the production volume of the sectors which the products are used for the intermediate input for EV production is affected. Moreover, as EV industry changes, the competitive sectors, such as conventional vehicle industry, or backward industry, such as distribution services, are also influenced.

First of all, this study analyzed the total production volume of whole industries. Figure 19 and 20 indicate the changes of total production volume for each scenario. Different from the GDP, the total production increases in all scenario, and, especially, the largest increases are found in the scenario 2-1, 2-3, 2-5, which low sales incentives and high R&D subsidy influences negatively on GDP.

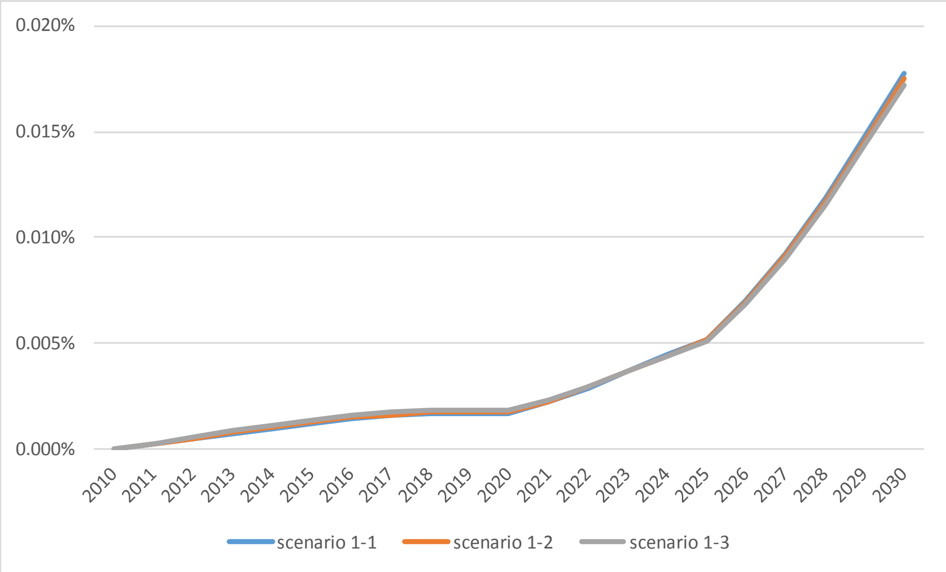

Figure 19. Change of total production volume from scenario 1-1 to 1-3

(unit: %, compared to BAU)

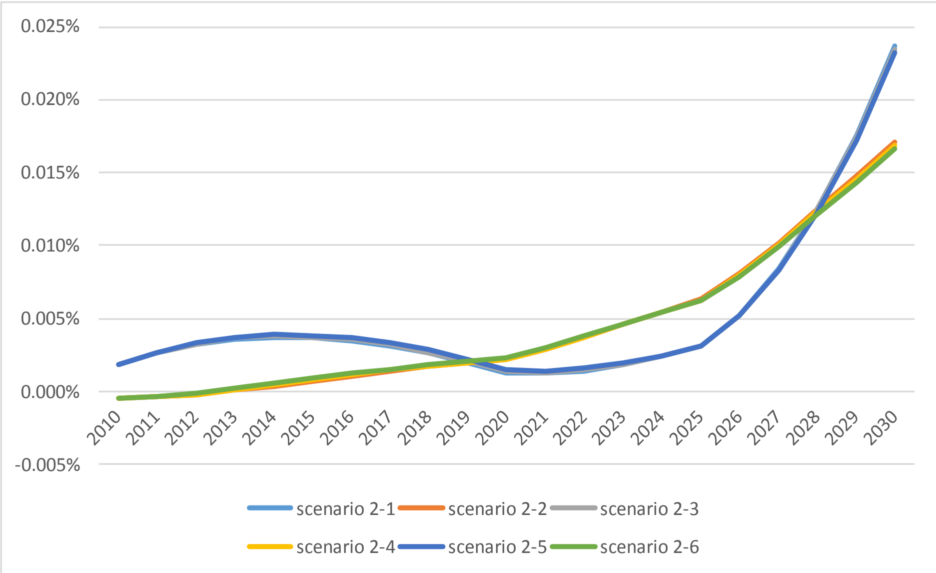

Figure 20. Change of total production volume from scenario 2-1 to 2-6

(unit: %, compared to BAU)

Next, the production volume of EV industry is analyzed. Because the goal for implementing PPI, R&D subsidy, and sales incentive for EV is the expansion of the EV industry. It is important to investigate whether the production volume of EV industry get larger or not, and it is shown in Figure 21 and 22.

For all scenarios, the expansion of EV industry output is found. It can be analyzed that the PPI only or innovation policy mix can achieve the main policy goal of EV industry promotion. In particular, there are the largest expansion in the scenarios with large R&D subsidy and low sales incentives. Since EV sector is infant industry, and it is important for the industry to be helped from the government for R&D and innovation effort to stimulate its production. This result is in contradistinction to the result in GDP impact assessment. In scenario 2-1, 2-3. and 2-5, GDP decreases compared to the base scenario, but EV output increases. Although EV industry is the main target sector for the policy implementation, GDP expansion or economic growth is the important and significant goal of all government policy. In sum, this policy mix excessively expands the EV industry and induces negative impact on other industries, and stimulates reverse effect on GDP ultimately.

The policy mix between low R&D subsidy and high sales incentives generates the lowest increase of EV industry output among all scenarios. However, for the economy-wide perspectives, this policy mix induces the largest positive impact on GDP. This result implies that the innovation policy for the certain industry sector can generate contrasting impact between the targeted one and macro-economy, and the policy impact should be analyzed comprehensively fit into the policy goal for each government.

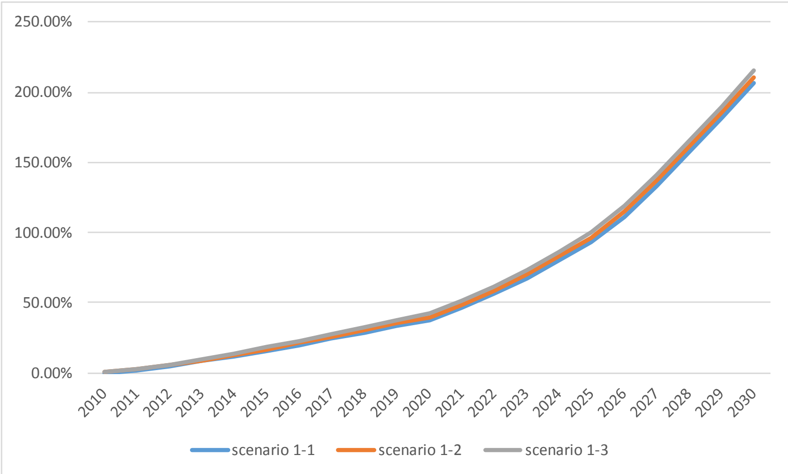

Figure 21. Change of EV production volume from scenario 1-1 to 1-3

(unit: %, compared to BAU)

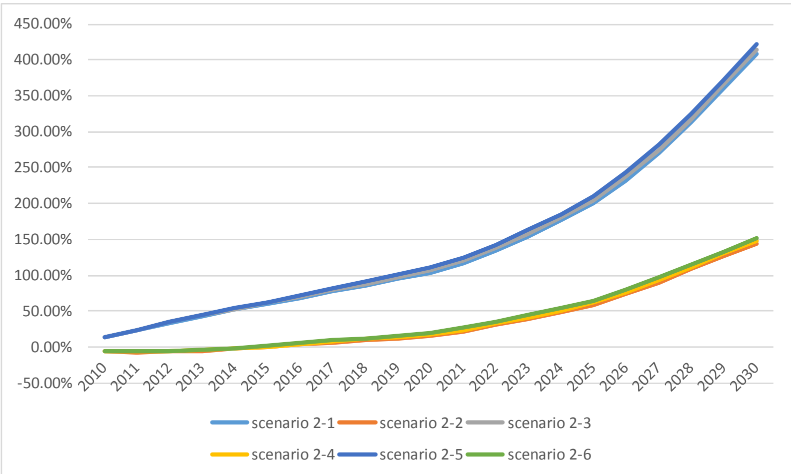

Figure 22. Change of EV production volume from scenario 2-1 to 2-6

(unit: %, compared to BAU)

In sum, in order to have the largest expansion of EV industry without GDP loss, the government can implement only PPI for EVs. The more PPI volume for EV increases, the more EV output is generated. On the other hand, if the government aims to stimulate economic growth at first by the promotion of EV sector, the innovation policy mix with ow R&D subsidy and high sales incentives can be used. EV output increases more with the expansion of PPI volume in this case also. However, GDP growth effect is mitigated when the government utilizes the large volume of PPI for EV. Therefore, as mentioned the very part before, it is important to analyze the economy-wide impact of innovation policy mix fit into the policy goal and purposes before the policy decision-making because the volume and direction of policy impact could be different from the policy mix structure.

4.3.2 Production volume of related industries

Next, it is worthwhile to depict the production volume of other related industry. GDP and macro-economic indicators reflects not only the change of EV industry but also that of the other industries.

First of all, conventional vehicle (CV) industry which is competitor of EV industry is analyzed. Since conventional vehicle is substitute for electric vehicle, the direction of the change of production volume is opposite between those two industry. Figure 23 describes the trends of CV production volume in major scenarios.

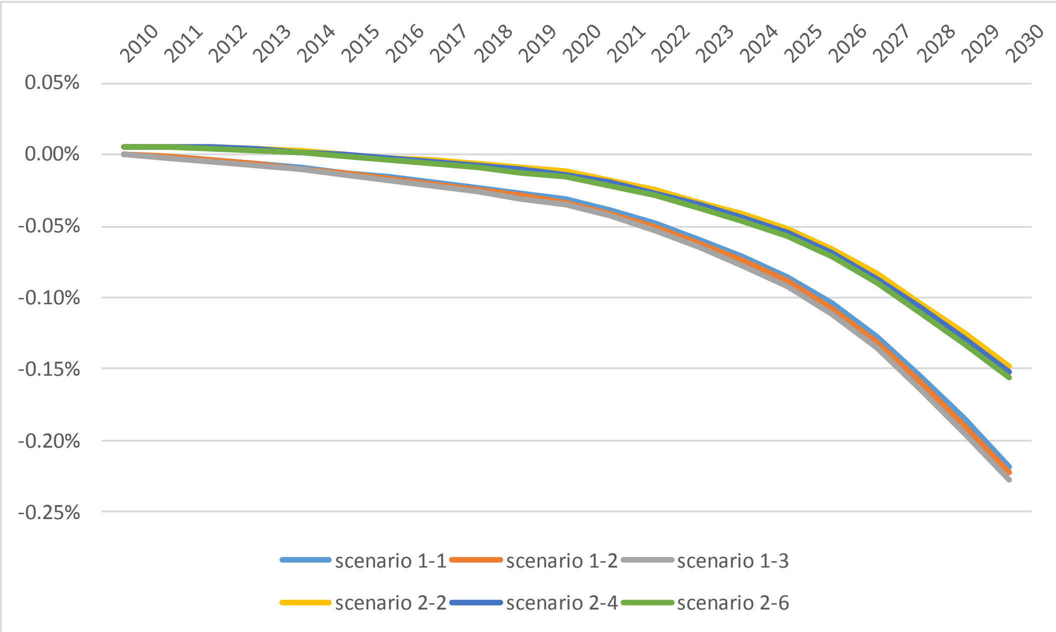

Figure 23. Change of CV production volume in major scenarios

(unit: %, compared to BAU)

Since CV can be replaced by EV and EV output is raised due to the innovation policy implementation, CV output decreases in all scenarios. The reduction volume of CV sector depends on the expansion of EV industry output.

There are industries which gives their products for EV industry as intermediate demand. In addition, there are also other industries which utilizes EV in their production activity. Although the SAM which this knowledge-based CGE model based on assumes that EV does not used for the intermediate input of other industry, service sectors can use EV with privately purchasing. This study mainly focuses on the electric products manufacturing, basic metal product manufacturing, and transportation services, which are representative forward and backward industries. As Figure 24 indicates, the direction of the change of electric products' production volume is opposite from that of EV production volume. It is because EV industry has low production volume, so the amount of intermediate demand is also small relative to other industries. In addition, since other industries' production volume is decreasing due to the innovation policies on EV, the production volume of electric products manufacturing is also less than base scenario.

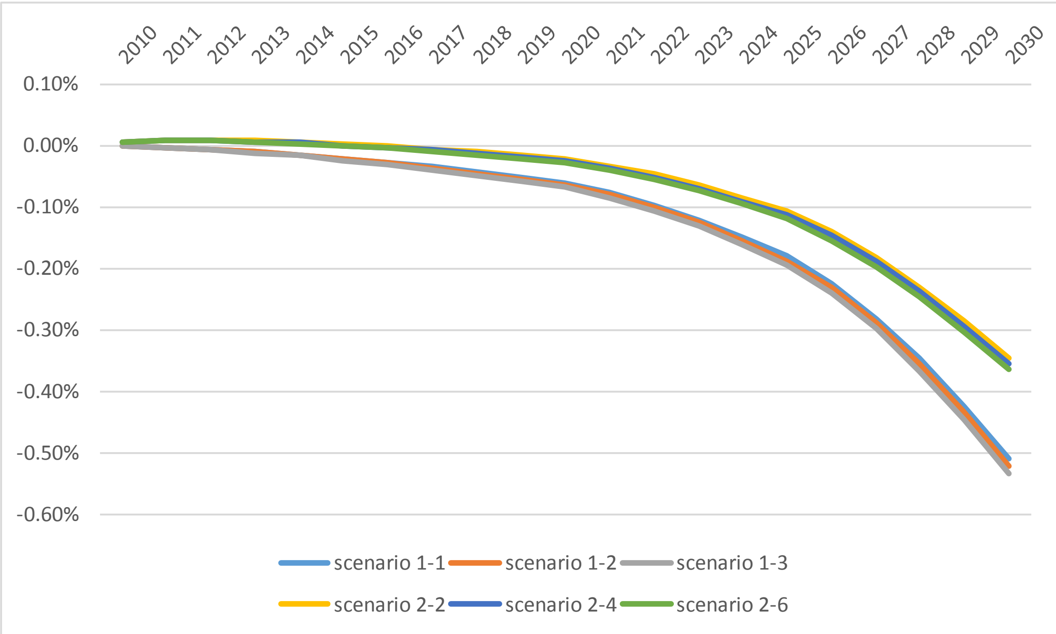

Figure 24. Change of electric products production volume in major scenarios (unit: %, compared to BAU)

On the other hand, basic metal products manufacturing is positively influenced by the expansion of EV industry. Basic metal product is one of the main backward industry for vehicle manufacturing, and this study implies that the industry expands with the replacement from conventional vehicle to electric vehicle. Figure 25 indicates the trends of production volume of basic metal products in major scenarios.

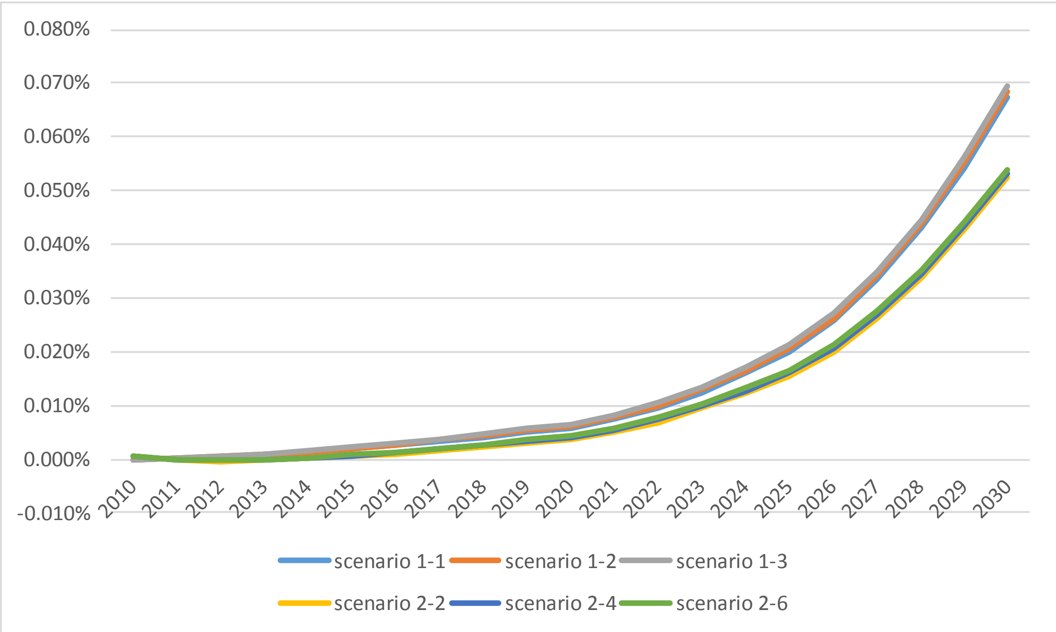

Figure 25. Change of basic metal products production volume in major scenarios (unit: %, compared to BAU)

For transportation service sector, the similar results with electric products are revealed. It is also because of the relatively low production volume of EV industry. In addition, since distribution service usually uses conventional vehicle with diesel or gasoline, the influences from CV industry is much higher. Figure 26 shows the change of distribution services' production volume in major scenarios.

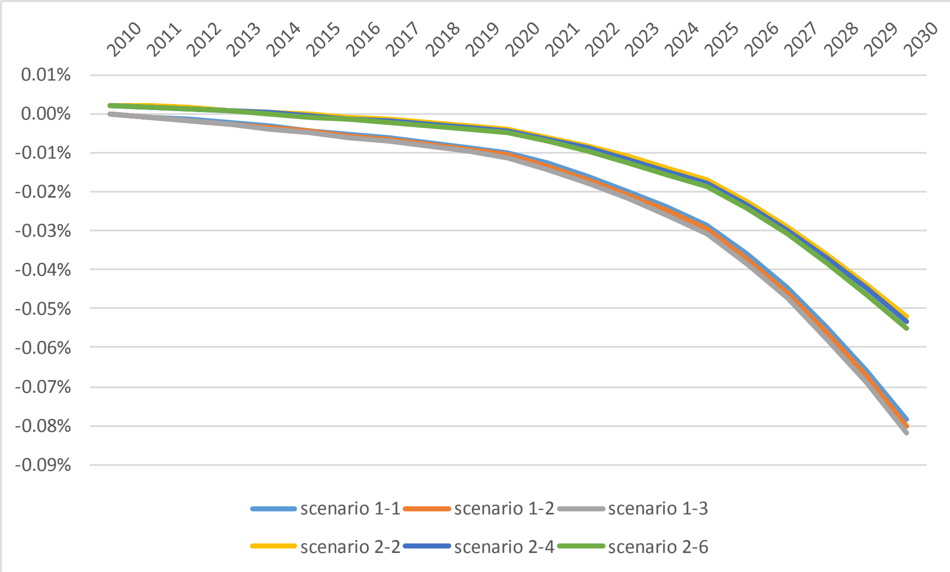

Figure 26. Change of transportation service production volume in major scenarios (unit: %, compared to BAU)

In conclusion, with investigation of GDP and production volume of each industry, it is important to analyze the economy-wide impact of innovation policy when the policy targets specific new emerging industry such as EV because other industries can be negatively or positively affected by the policy and it could generate reverse effect in macro-economic indicators.

4.3.3 Change of the knowledge stock

Although PPI and sales incentive are demand-side innovation policy, they also foster innovation effort of private suppliers in various ways, as mentioned in Chapter 2. R&D

subsidy mainly focuses on the inducement of R&D investment in private firms. In this part, the R&D stock and R&D investment in whole economy is investigated.

First of all, Figure 27 and 28 indicate the change of R&D stock in EV industry in each scenario. It is found that R&D stock in EV industry is more than base scenario in all scenarios. If there is high R&D subsidy, the increased amount of R&D stock gets much bigger. On the contrary, with low R&D subsidy, the R&D stock increases smaller than the other scenarios. In sum, as the production volume of EV industry increases, the more sales and profits are generated, and the EV makers increase their spending on R&D and innovation effort. The additional R&D investment leads the increase of R&D stock in EV sector. The R&D stock in EV industry has spillover effect on other industries R&D investment and production process also.

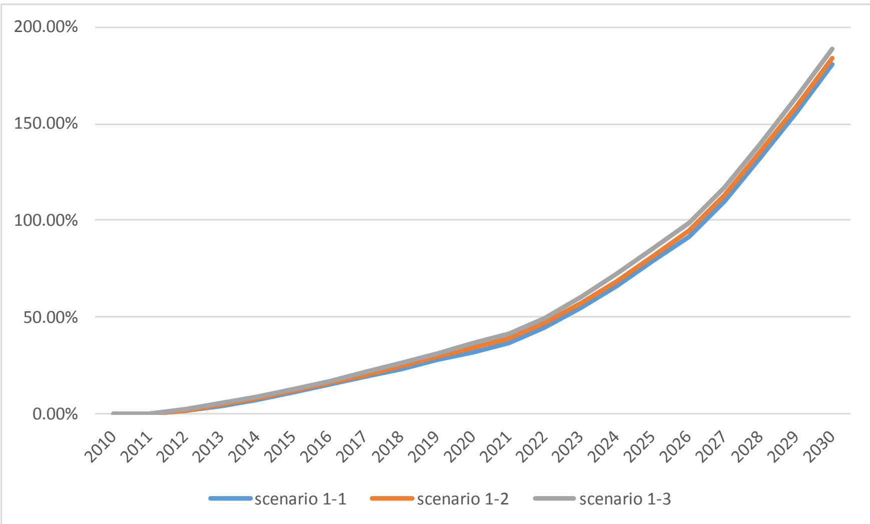

Figure 27. Change of R&D stock in EV industry from scenario 1-1 to 1-3

(unit: %, compared to BAU)

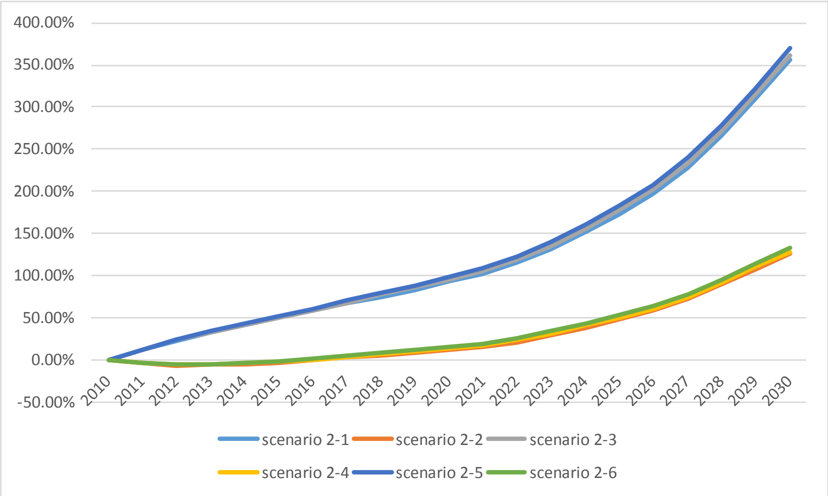

Figure 28. Change of R&D stock in EV industry from scenario 2-1 to 2-6

(unit: %, compared to BAU)

Next, total R&D investment including private and public is examined. In all scenarios, the private and public R&D stock decrease slightly compared to the base scenario. For private R&D in figure 29, most of the industries except EV, basic metal products, and others experiences the reduced amount of production volume compared to the base scenario, and it negatively affects the firms to reduce the investment on R&D and innovation effort. For public R&D in figure 30, since government budget is limited and innovation policy such as PPI, R&D subsidy and sales incentives require the additional government expenditure, the amount for the public R&D investment is reduced, and it leads the slight reduction of public R&D stock. However, the reduced percentage of private, public R&D investment is marginal value, and there is very small change of total R&D investment as figure 31 compares.

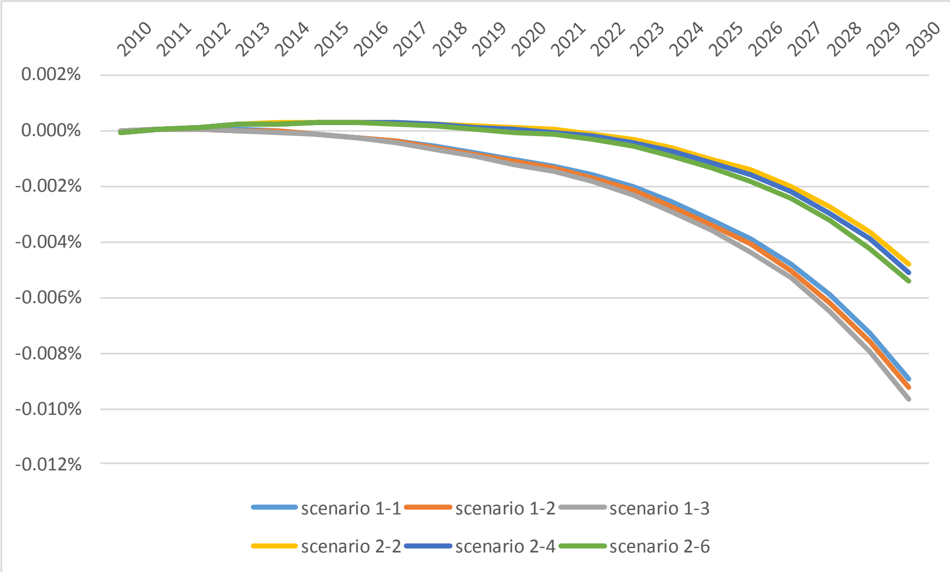

Figure 29. Change of private R&D investment in major scenarios

(unit: %, compared to BAU)

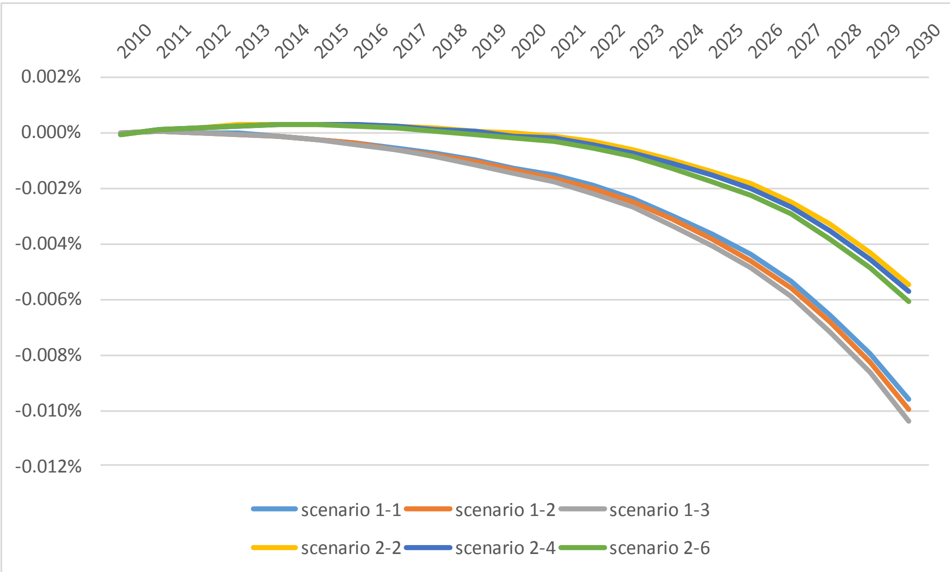

Figure 30. Change of public R&D investment in major scenarios

(unit: %, compared to BAU)

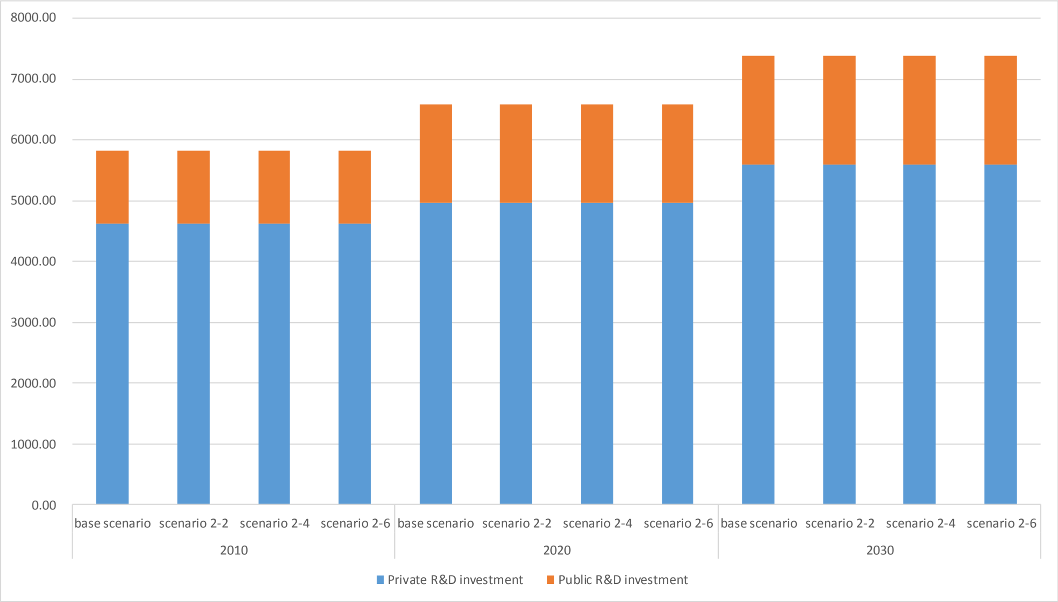

Figure 31. Change of total R&D investment in major scenarios in 2010, 2020, and 2030 (unit: billion Korean Won)

In conclusion, the innovation policy for the certain industry can have limited effect on the R&D investment of entire economy through the production and sales. The R&D stock of the targeted industry, which is EV industry, increases with the expansion of production volume.

4.3.4 Learning effect

The important factors of PPI for the production is that it makes economies of scale and learning by doing effect by increasing the accumulated production volume. Through

PPI, the private firms can experience faster growth of production volume, and it makes the firms achieves incremental innovation which is cost reduction and quality enhancement. The learning effect lets the producers to use less production factors such as labor, capital and knowledge for the same amount of production than before. Therefore, the effect can be shown by production factor requirement coefficient of EV industry. Figure 32 illustrates the learning effect of EV industry in major scenarios. By enlargement of production, the coefficient is decreasing, and it can be summarized that EV industry has achieved the productivity improvement. In all policy scenarios, it is found that the coefficient is decreasing with the expansion of EV sales despite the small difference of the results.

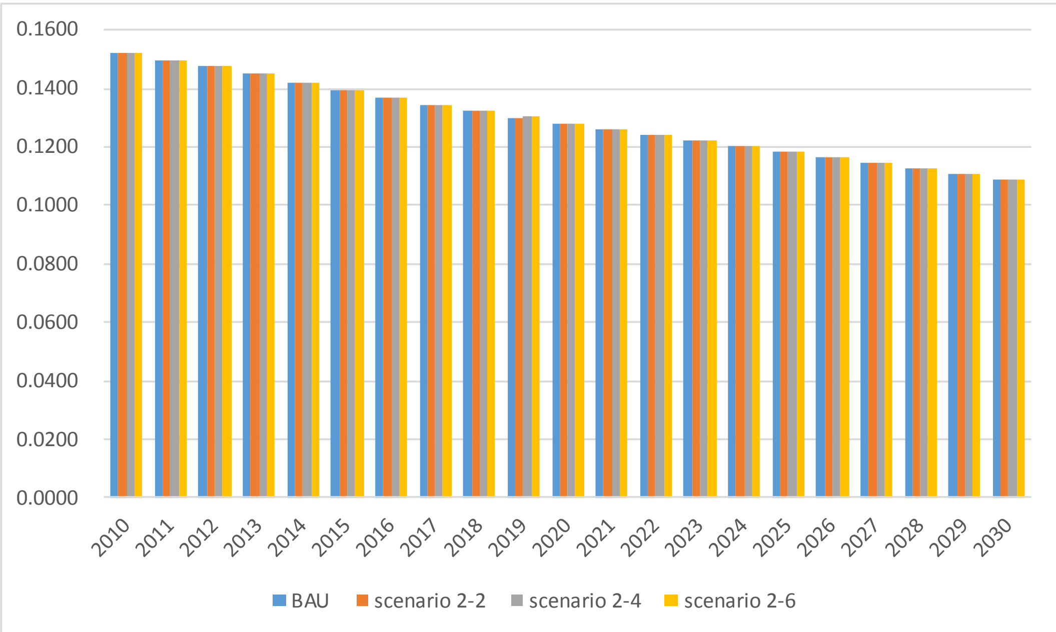

Figure 32. Change of factor requirement coefficient of EV industry in major scenarios

As a result, this study simulates the various policy scenarios on the innovation policy targeted EV industry, and concluded that the cases which are low R&D subsidy, and high sales incentive generate the desirable results which are simultaneous expansion of GDP and EV industry regardless of the volume of the PPI. Although there are GDP and EV industry growth in PPI only scenario, the policy mix with sales incentives and R&D subsidy could make the larger policy impact on GDP and EV production volume. The other scenarios cannot achieve either GDP growth or EV industry enlargement. By innovation policies, the other industries which are not target sectors are also influenced and their change make the difference of GDP. In innovation perspective, since the policy is only for EV industry and it is relatively small part for whole economy, the additional R&D activity generated by innovation policy is not found although the R&D stock of EV industry increases with the production volume. Public R&D is also stagnated because the government can experience the shortage of the budget for R&D investment due to various policies such as PPI, R&D subsidy, and sales incentives for EV fostering. By expansion of EV industry, EV firms experience economies of scale and learning by doing effect. In particular, thanks to learning effect, EV makers can reduce the amount of production factor required for the production process.

Chapter 5. Conclusion

5.1 Summary of the Results and Policy Implications

This study aimed to analyze the policy impact of PPI from an economy-wide perspective. In particular, 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 findings showed that PPI generated GDP growth and stimulated expansion of the EV sector simultaneously. However, a more positive effect was revealed in the cases of policy mix of PPI, high sales incentives, and low R&D subsidy. The reason for this was the small volume of the EV industry in the first stage. The R&D subsidy, which is supply-side innovation policy, for EV could not generate long-run positive production inducement effect for other industries. It rather draws reverse effect of related industries with reduced production volume despite fast growth of EV sector production in short-run. However, with demand-side innovation policy tools such as PPI and sales incentives, and despite the slow speed of EV industry growth, there was stable growth of GDP. For R&D, because of the stagnation of other industries and the shortage of government budget for R&D investment, the policies cannot generate higher public and private R&D investment than would be the case if there were no policy. Finally, thanks to the increase in production volume in EV industry, this industry experiences learning by doing and economies of scale, which reduces the production factor requirement.

In particular, this study 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.

5.2 Limitation of the Study and Future Study

Although this study investigated the policy impact of PPI policy from an economy-wide perspective with the integration of a qualitative and a quantitative approach, this study has some limitations. First, because of the absence of validated data for PPI, this study could not define PPI explicitly, different from ordinary public procurement. This problem has already addressed by other researches, such as Detelj et al. (2016) and Guerzoni and Raiteri (2015), which stated that the shortage of data limits the ability to fit the results into the real policy and market environment. Moreover, the data are not sufficient for the EV industry, since it is a new emerging industry. Second, although this study reflected the impact paths of PPI found by qualitative descriptions of the CGE model, the model needs to be validated further. Despite the validation of the knowledge-based CGE model in Hong et al. (2014), the model in this study also needs to be validated, since it adds new parameters and variables, such as PPI and learning coefficient. Finally, this study did not analyze either the social or the environmental impact of PPI policy. As the government also implements PPI to achieve social goals and EV affects the environment, it is worthwhile to analyze social and environmental effects of PPI

Therefore, the future study should investigate the social and environmental impacts of PPI in addition to the economic impacts. This study generated the taxonomy of PPI, the social purposes could be included differently from type to type. For example, in types 1 and 2 PPI, the social purposes of PPI are implicitly included in the innovation purposes, because the development of technology and product is the main goal. However, in type 3, since there is an existing product, the government explicitly reveals the social purposes of PPI to stimulate private demand. In sum, the social impact of PPI can be analyzed in respect of each type of PPI. Moreover, since EV affects the environment in certain ways such as through electricity generation and use, the environmental effects such as CO2 emission reduction or the change of energy mix could be investigated. Various studies have tried to analyze environmental policy impact with CGE modeling (Yeo et al., 2014; Hwang and Lee, 2015; Hwang et al., 2014; Hwang et al., 2014; Oh et al., 2015). Future studies can either employ or develop the additional module related to electricity and CO2 emission in this knowledge-based CGE model and investigate changes in energy consumption or environmental impact with the economy-wide impact of PPI or the innovation policy mix for EV.

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Abstract (Korean)

최근, 혁신적 생산자들로 하여금 충분한 수요를 보장해 주는 수요기반 혁신 정책에 대한 관심이 늘어나고 있다. 혁신지향적 공공구매는 대표적인 수요기반 혁신정책의 수단으로써, 혁신 및 신 산업 창출을 촉진하는 가장 효과적인 정책 수단으로 평가받고 있다. 여러 국가에서 정부 지출의 많은 부분을 공공구매에 사용하고 있으며, 에너지, 환경, 보건, 건설과 같은 다양한 산업 및 기술에 있어서 대부분의 공공 수요가 공공구매를 통해 이루어지고 있다.

그러나, 혁신지향적 공공구매에 대한 높은 관심 및 효과성에도 불구하고, 혁신지향적 공공구매의 정책 효과를 거시경제적 관점에서 분석하고자 한 시도는 많지 않았다. 혁신지향적 공공구매에 관한 대부분의 선행 연구는 사례 분석 또는 정성적 서술에 의존하고 있다. 그렇지만, 혁신지향적 공공구매는 직접적인 수요 증대 효과 뿐 아니라, 생산, 민간 수요, 혁신에 걸친 다양한 간접적인 경제적 효과를 가지고 있으므로, 혁신지향적 공공구매의 보다 정밀한 효과 분석을 위해서는 경제 전반을 통합하는 관점으로부터의 접근이 필요하다. 따

라서, 본 연구는 다양한 선행 연구를 통해 혁신지향적 공공구매의 경제적 효과의 다양한 경로를 파악하고, 이를 지식기반 연산일반균형 모형을 통해 정량적으로 분석하여 혁신지향적 공공구매의 거시경제적 효과를 살펴보고자 한다.

본 연구는 전기 자동차 산업에 대한 혁신지향적 공공구매를 포함한 혁신정책 조합의 경제적 효과를 지식기반 연산일반균형 모형을 통해 파악한다. 본 연구에서 사용하는 지식기반 연산일반균형 모형은 혁신지향적 공공구매 및 학습 효과를 반영하여 보다 현실적인 분석이 가능하도록 하였다. 지식기반 연산일반균형 모형을 통한 분석 결과, 전기 자동차 기술 및 산업에 대해 혁신지향적 공공구매와 함께 낮은 수준의 연구개발 보조금 및 높은 수준의 구매 보조금 정책을 시행하였을 경우 전기자동차 산업의 성장과 경제 성장을 동시에 이룰 수 있는 것으로 나타났다. 즉, 모든 정책 조합에서 전기자동차를 대상으로 한 혁신정책의 목표인 전기자동차 산업 성장 및 경제 성장이 동시에 이루어지지는 않는 것으로 나타났다. 이는 전기자동차 산업에 특화된 혁신 정책의 경우 정책 조합에 따라 다른 산업의 생산량에 부정적인 영향을 미칠 수 있기 때문이다. 정책에 의해 전기자동차 산업을 제외한 기타 산업의 생산량 증대가 거의 관측되지 않으며, 혁신지향적 공공구매로 인해 정부 연구개발 투자 재원

이 감소함에 따라 경제 전체의 연구개발 투자는 큰 변화를 보이지 않았다. 또한, 전기자동차 산업의 생산량 및 판매량 증대로 인해 규모의 경제 및 학습효과가 발현되어 전기자동차 산업에 있어서 생산요소 투입 계수의 감소 및 총요소 생산성의 증대가 관측되었다.

본 연구는 산업 특정 혁신 및 산업 정책의 결정 및 시행에 있어서, 사전적으로 거시경제적 효과를 확인할 필요가 있음을 제시하였다. 본 연구에서 활용된 지식기반 연산일반균형 모형을 통해 정량적인 수치를 통한 사전적 정책 평가가 가능하며, 이에 따라 다른 혁신 및 산업 정책의 정책 효과 분석에 활용될 수 있을 것이다.

주요어 : 혁신지향적 공공구매, 혁신정책, 정책 효과, 연산일반균형
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