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Essays on the Role of Public Demand in Innovation Policy

: Rationale and Impact Assessment of Public Procurement for Innovation

혁신정책 내 공공수요의 역할에 관한 연구
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Abstract

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Technological innovation is a major driving force for economic growth. Accordingly, many countries have implemented various innovation policies to promote innovation in the private sector. Interest in the demand-side innovation policy, which focuses on the commercialization and diffusion of technology development results, has increased in recent years. Public procurement for innovation (PPI), the consumption of the public sector for innovative products or services that still have an insufficient private market, has received attention from various countries as a representative demand-side innovation policy tool. Various academic studies have proved that PPI stimulates innovation activity

and generates commercially successful innovation. However, most studies have analyzed the policy impact of PPI at the micro-level by comparing the outcomes of the firms with PPI and those without. There has been no attempt to analyze the economy-wide impact of PPI. Therefore, in this study, a theoretical and empirical analysis framework has been established to analyze the national economic impact of PPI.

Previous studies on the policy impact of PPI have shown that PPI has diverse paths of influence on the innovation efforts and production and consumption activities. However, due to the lack of a theoretical analysis framework capable of synthesizing the results suggested in a vast amount of existing literature, there is a limitation in that the policy impact of PPI is understood as context-specific. This impact could be highly dependent on the characteristics of a country, government, industry, and implementation cases. Therefore, this study identifies the impact paths of PPI by reinterpreting the qualitative and quantitative results of existing studies from a system perspective. Specifically, based on major discussions on the source of innovation, including technology-push and demand-pull perspectives, this study built an analysis framework that understands the policy impact of PPI regarding interactions between various actors in the innovation system, including suppliers, consumers, and the government. Additionally, based on this, the type classification and generation of taxonomy for PPI were conducted to classify the various policy implementation cases in Korea and other countries. Finally, the theoretical framework and taxonomy were validated by analyzing the PPI of the Korean electric vehicle.

Based on the established theoretical framework, this study attempted to confirm the economy-wide impact of PPI. First, the policy evaluation for PPI at the firm level was conducted from additionality. According to the econometric methodology analysis, PPI generally positively impacted the firms' productivity and expanded investment on innovation activity for the firms with PPI contracts. Second, based on the results, this study analyzed the economy-wide impact of PPI using the computational general equilibrium model. Through the computational general equilibrium model that expresses the behaviors and interactions of various economic actors in the form of equations, it was possible to reflect the impact paths of PPI interpreted from the viewpoint of the innovation system. In this study, based on the Telecommunications Management Information Platform model, specialized in ex-ante quantitative policy evaluation of innovation policy, a computational general balance model was constructed. The model explicitly reflected the impacts of PPI in equation systems. The policy simulation results confirmed that PPI positively impacts expanding industrial output and, ultimately, economic growth in the long run when PPI replaces a certain portion of ordinary public procurement. However, it was also found that the adverse effect in macroeconomic indicators may occur at the early stage of policy implementation due to the negative effects that PPI can cause on the public sector.

By establishing a theoretical and empirical framework for analyzing the comprehensive policy impact of PPI, this study attempted to derive implications for confirming the role and potential of PPI as innovation policy tools. Particularly, by providing an analytical framework that can comprehensively interpret the results in the literature, this study investigated the impact of PPI, understood in a fragmented way theoretically. This study contributes to the literature by adding the scope and depth of related research. Empirically, this is the first study to quantitatively present the economy-wide impact of PPI with a general equilibrium perspective and real macroeconomic data. Moreover, it provides a methodology for evaluating innovation policy, including PPI, to secure ex-ante policy evidence, and is valuable. Thus, this study presents an empirical and methodological basis for the science of innovation policy by obtaining a theoretical and methodological framework, which enables finding policy evidence and impact paths.

Keywords: Public Procurement for Innovation, Innovation Policy, Propensity Score Matching, Policy Impact Assessment, Computable General Equilibrium
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Chapter 1. Introduction

1.1 Research background and motivation

Technological innovation is a major driving force for economic growth, and the importance of R&D activities that induce technological innovation has increased. Accordingly, governments of each country are inducing the expansion of R&D activities and diffusion of R&D results, which is the innovation, in the private sector through various policies. These policy measures are collectively expressed as innovation policy. The innovation policy tools that have been most widely used are subsidies and tax grants for private R&D activities. Due to various causes, including market and system failure, the level of private R&D investment is generally low compared to the socially optimum level, and public R&D support plays a role in preserving these differences and raising the level of private R&D investment. Although some studies have highlighted that public R&D support weakens the motivation for innovation in the private sector or creates a crowding-out effect that replaces in-house innovation activities with a publicly funded budget, these policy measures are generally used by the private sector. Therefore, they expand investment in R&D and innovation.

However, several scholars and policymakers have presented the limitations of these policy measures. This is because it was revealed that the development of technology through R&D does not guarantee the commercial success of products using the technology (Edler & Fagerberg, 2017). In general, public R&D subsidies and tax grants are classified as supply-side innovation policies because their main goal is promoting technology development. Thus, these policy measures focus on supporting R&D and innovation investment by the private sector. However, the policy does not impact the demand and consumption aspects of products using developed technologies.

The importance of demand and consumption in innovation has been emphasized in the past. Various studies have highlighted that factors related to demand, such as consumer participation or guarantee of potential demand, played a significant role in developing innovative products or services that were commercially successful. Particularly, from the innovation system perspective, theoretical discussions, such as emphasizing the consumer's role in addition to the supplier's technology development efforts to induce innovation (Boon & Edler, 2018; Intarakumnerd et al., 2002; Lee & Park, 2006; Lema et al., 2018; Xue, 1997), are active. Additionally, this means that innovation policy needs to consider demand and consumption as policy targets or goals and interest in suppliers' technology development efforts.

Consistent with this trend, interest in the demand-side innovation policy focusing on the diffusion of innovation has recently increased. Among the various demand-side innovation policy measures, procurement for innovation (PPI) has recently attracted global attention, including regulations and purchase subsidies. PPI is an interpretation of public procurement—the purchasing behavior of the public sector—from the innovation policy perspective. It aims to promote innovation diffusion by purchasing innovative products or services in the public sector. Prior research has highlighted that public procurement can lead to the active diffusion of innovation. These studies conclude that public procurement activities more effectively promote innovation activities and diffusion than existing R&D subsidies or tax grants.

However, despite a long history of academic and policy interest in PPI, a theoretical framework is lacking (Kundu et al., 2020). Although there has not been a complete theoretical consensus on the definition of PPI, results and implications drawn by various literature related to PPI are fragmented due to the absence of an academic framework. It is because most of the studies examining PPI's policy impact are restricted to the analysis of specific cases or additionality analysis at the firm level.

Considering the significance of PPI as a demand-side innovation policy and the role of demand as a driving force for innovation, the policy impact of PPI needs to be comprehensively analyzed from a system perspective. This is because the effect of PPI goes beyond simply increasing inputs or outputs of policy beneficiaries and affects the behaviors and interactions of various economic agents within the innovation system. Therefore, to understand and grasp these impact paths, a theoretical framework for PPI is necessary. It is essential to form a typology or taxonomy of PPI policy used in various ways.

Despite the importance of PPI as an innovation policy and the policy interest of each government, few studies examine the impact of PPI from an economy-wide perspective. This can be attributed to the lack of a theoretical framework for PPI. To analyze the economy-wide impact of a policy, a general equilibrium viewpoint that considers the interactions of various economic actors is essential. However, the results from various studies on PPI's effects are fragmented. This makes it difficult to comprehensively capture the policy impact of PPI from the general equilibrium perspective. However, considering that PPI is one of the innovation policy measures and aims to contribute to national growth through industrial output expansion, analyzing the economy-wide impact of PPI is necessary from an academic perspective.

In summary, PPI has long been recognized for its importance in academic and policy terms. Still, research conclusions related to policy impact have tended to be fragmented due to the absence of a theoretical framework. Additionally, few studies have attempted to assess the economy-wide impact of PPI. This means that it is necessary to prioritize the identification and typology of the impact paths of PPI to capture its various impact generation channels. By establishing the theoretical framework, the various impacts of PPI can be understood as the interaction of the agents in the innovation system, which can be the theoretical basis for constructing a model for analyzing the economy-wide impact of PPI. The analysis of the economy-wide impact of PPI from the general equilibrium perspective indicates the empirical linkage of the theoretical framework. It will affect the improvement of the decision-making process in the overall innovation policy, including PPI.

1.2 Research purpose and outline of the study

This study aims to analyze the economy-wide impact of PPI. It includes developing a theoretical framework of PPI, evaluating PPI policy at the firm level, and quantitative analysis of PPI's policy impact using the computable general equilibrium (CGE) model. Chapter 2 examines the background and the necessity of this study through a review of related theoretical and methodological literature. This study first presents demand as a driving force of innovation. There has been an active debate over the source of the driving force of innovation since the mid-20th century. The technology-push perspective emphasizing scientific and technical discovery, and the demand-pull perspective, focusing on the potential use of the innovation results, have co-existed. In recent years, with the revitalization of the innovation system theory, there is a growing recognition that these two perspectives are equally important for the generation of commercially successful innovation. The rationale of the demand-side innovation policy and PPI is based on the theoretical background for the role of innovation demand. The demand-side innovation policy is implemented to lead the commercialization of successfully developed technology and innovation diffusion. PPI is one of the representative tools of the demand-side innovation policy. Chapter 2 examines the academic trials on policy rationalization of PPI and summarizes various cases and empirical studies that analyze the policy impact of PPI inducing innovation. The results of these studies can be used to build the theoretical framework of PPI in Chapter 3. Chapter 2 includes a methodological and theoretical background. The methodological background includes the literature on policy impact assessment regarding additionality used in the empirical analysis in Chapter 4 and the study on the CGE model used in the ex-ante policy evaluation in Chapter 5. The additionality perspective has been used to evaluate various innovation policy measures by observing the change in firms' input, output, and behavior from the innovation policy perspective and using it as an index of policy evaluation. The CGE model describes the economy as a set of equations from general equilibrium and is widely used as an ex-ante policy evaluation methodology for various policies such as environment, agriculture, trade policies, and innovation policy. This methodological review in Chapter 2 secures the theoretical consistency of the empirical analysis in Chapters 4 and 5 and enables a comparative analysis of the empirical analysis results.

Next, in Chapter 3, fragmented research related to PPI is summarized, and a theoretical framework for the PPI policy analysis is established. Specifically, the various impact paths of PPI are analyzed from a system perspective and classified into four types based on the developed theoretical framework. Presently, differentiated impact paths for each type are identified by considering the differences in policy goals and operating methods. Finally, in the case of the Korean electric vehicle (EV), the framework analyzes PPI and the type of PPI with impact paths. The theoretical framework established in Chapter 3 makes it possible to summarize the effects of PPI in the interaction of various economic agents by introducing a systemic viewpoint. It provides an academic base for deriving policy implications from micro- or macro-level policy evaluation studies for PPI in the future.

In Chapter 4, the policy impact of PPI is analyzed at the firm level. This study follows the various impact paths of PPI presented in Chapter 3 and investigates its impact by focusing on the indicator of productivity to consider these paths comprehensively. This is because productivity is an important mediator in industrial development and national economic growth. It is a major intermediate output of private innovation activities and product development. Despite the long history of discussions about the policy impact of PPI, few studies have explored the relationship between PPI and productivity improvement. Therefore, the empirical analysis in Chapter 4 has important academic significance. In the empirical analysis process, the additionality concept and propensity score matching (PSM) methodology, widely used in policy evaluation for innovation policy measures, including R&D subsidies, are used to compare the results with existing studies. Additionally, the impact of PPI on industrial productivity is also empirically analyzed. Finally, the results of existing research on the policy impact assessment of PPI policy are updated.

Chapter 5 details the methodology and results from the simulation analysis for conducting the economy-wide impact assessments of PPI, the final goal of this study. This study analyzes the economy-wide impact of PPI using the CGE model. Specifically, it uses the Telecommunications Management Information Platform (TEMIP) model (Hwang et al., 2020), specializing in evaluating innovation policy as a backbone model. Here, various impact paths of PPI presented in Chapter 3 are simplified and reflected in the model's equation to present the economy-wide impact of PPI. In this process, the current research results and the numerical values drawn in Chapter 4 can be used. The simulation analysis obtains results by comparing the base scenario in which PPI is not performed and the policy scenario in which PPI is in progress. Thus, the empirical analysis results in Chapter 5 function as a result of PPI's policy evaluation and check the excellence of PPI as an innovation policy. Further, they prove the possibility of establishing and utilizing PPI's ex-ante policy evaluation methodology and help derive relevant theoretical and policy implications.

Finally, Chapter 6 summarizes the key findings from Chapters 2 to 5 and presents theoretical and policy implications, limitations, and future studies for broadening the academic scope of PPI-related studies. Figure 1 illustrates the flow from Chapters 1 to 6 as a research framework.

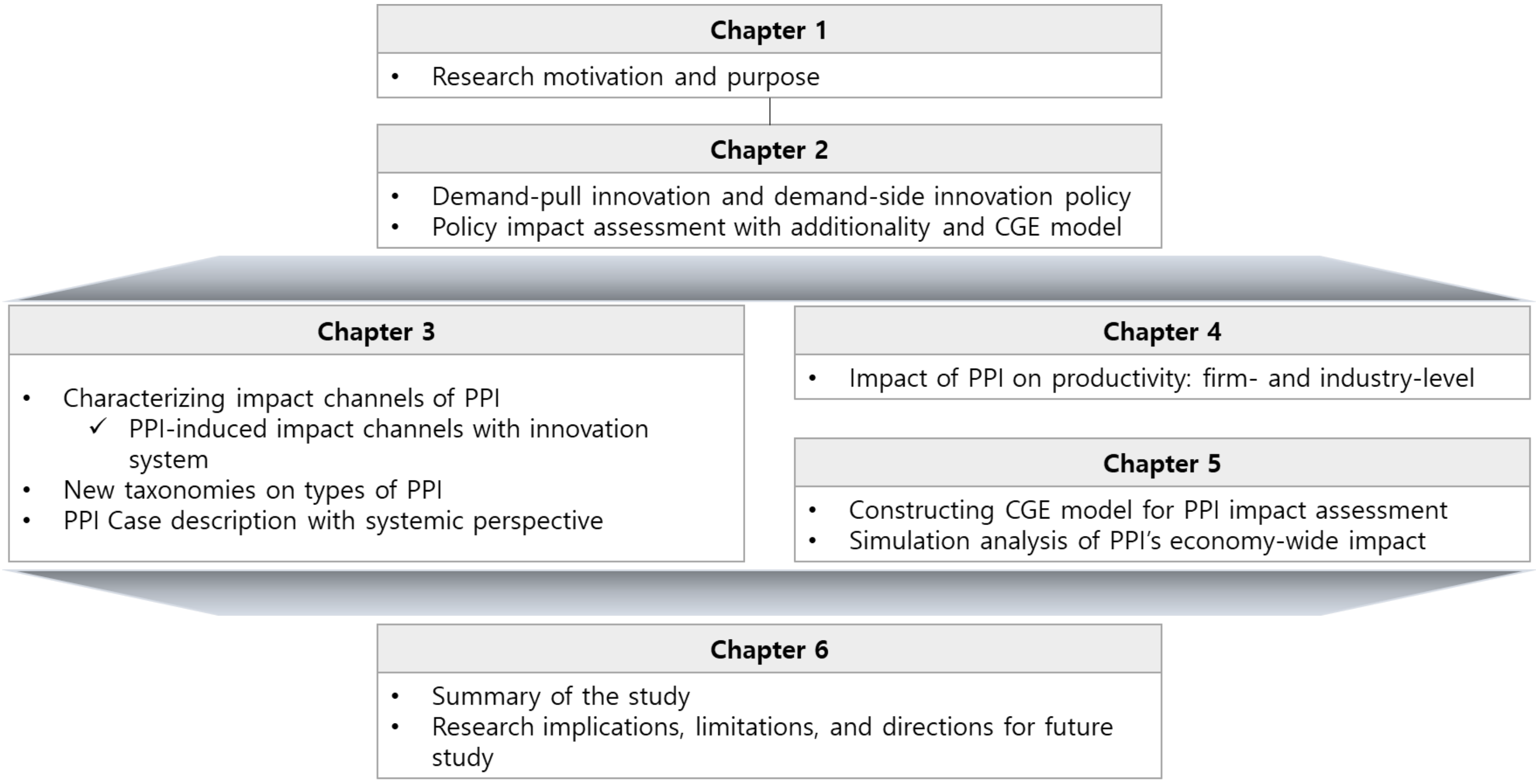

Figure 1. Research framework of the study

Chapter 2. Literature Review on Theoretical and Methodological Background

2.1 Theoretical background

2.1.1 The role of demand for innovation

2.1.1.1 The debate on the role of demand for innovation

Research which has tried to clarify the driving force of innovation can be broadly divided into two perspectives. First, there are scholars who have emphasized the role of science and technology and the people who make innovative products or services, which they focused on the supply-side or technology-push. On the other hand, the others said that market demand and innovation driven by consumers who use the innovative products or services are the main sources of innovation, which they tried to find the driving force of innovation in demand-side or demand-pull. In the 1960s and 1970s, there were sharp debate between these two arguments, vast amount of literature both theoretical and empirical way have been conducted to find the factors which induce innovation either from the supply-side or demand-side.

Most early discussions about the source of innovation start from a technology-push perspective. This links to the linear model of innovation that has been widely accepted since Bush (1945). It pointed out that the emergence of innovation is achieved through the steps from basic research, applied research to development research (Voss, 1984).

Therefore, from the perspective of linear model, new discovery is the most important factor in innovation. Until the 1960s, it was widely accepted that innovation occurs through a linear model, and, consequently, the rationale that technology development from scientific discovery is the source of innovation was widely used in the related literature (Chidamber & Kon, 1994).

On the contrary, the first major study emphasizing the role of demand in innovation is the work of Schmookler (1966). Through his analysis of various industries such as railroads, agriculture, petrochemicals, and paper industry, he argued that market demand is the main factor in successful innovation. He used patent statistics as invention outputs, suggesting that demand facilitates research for exploration in new directions. Later, the study of Langrish et al (1972) also pointed out that major innovations emerge from consumer needs.

Since then, a number of studies have appeared to show the logic that demand stimulates innovation through various cases and empirical analysis. Rothwell et al. (1974) revealed that satisfaction of consumer needs was the main source of innovation which achieved commercial success. Their study is worthwhile to be notified because it overcomes the limitation of Schmookler (1966) which did not confirm the commercial outcome of the invention. In addition, von Hippel (1976) analyzed the cases of 111 scientific instruments and pointed out that over 80% of innovations reflected demand-side factors such as inventions from consumers, prototyping and field testing. He later suggested the concept of a lead user and stated that product developers can obtain information on product improvement from the opinions of leading consumers and make additional innovations through them (von Hippel, 1986). Ettlie & Vellenga (1979) also investigated 34 innovation cases and concluded that more than half of innovations were driven by market demand and only 4% of innovations are driven by technological opportunities. Table 1 suggests additional literature on demand-pull perspective of innovation emergence in early period.

Table 1. Additional literature on demand-pull perspective of innovation emergence

Research	Context	Method	Results
Myers & Marquis (1969)	Five industries[1] in U.S.	Interviews	Recognition of demand is a more important factor in emergence of innovation than that of technical opportunities.
Gruber (1969)	U.S. Steel industry	Data analysis	For the firm, it is important for utilizing new technology to focus on marketing and production than R&D.
von Hippel & Finkelstein (1979)	Automated clinical chemistry analyzers	Case study	The differences among several analyzers were because each firm had different strategy for users to involve innovation process.
Scherer (1982)	U.S. Manufacturing	Econometrics (Regression)	Patented invention is strongly related to value-added.

[1] Railroads, railroad-equipment, housing (construction), computer, peripheral equipment of computer

Through this debate, scholars came to an agreement that both supply and demand factors influence the emergence of innovation. Mowery & Rosenberg (1979) pointed out that it is very difficult to separate these two aspects to reveal the driving force of innovation, and Dosi (1982) also mentioned that technological discovery and demand capture have a complementary effect on the emergence of innovation. Later, along with the criticism of the linear model of innovation, the debate about the driving force of innovation with the advent of the interaction model of innovation (Kline & Rosenberg, 1986) and the theory of innovation systems (Lundvall, 1985; Freeman, 1987) was finalized to accept that both factors were important for the innovation process.

2.1.1.2 Impact of the demand for stimulating innovation

Early studies that emphasized the role of demand in innovation have since proven their worth through various empirical analyzes after the 1980s. It was taken for granted that the role of demand or consumers in innovation was important, and accordingly, theoretical and empirical studies on the various influence paths of demand that promote innovation were started. It can be summarized the impact pats of demand for stimulating innovation into three aspects after the review of related literature.

2.1.1.2.1 Incentivizing the investment by reducing uncertainty

First, the potential demand induces innovation motivation by lowering the demand and technological uncertainty of developers who want to innovate. In general, suppliers face various types of uncertainties in the process of doing innovation (Hurst, 1982). Suppliers need information on demand in their innovation activities, and the more innovative markets, the more difficult it is to obtain sufficient information (Edler, 2016; Nemet, 2009). It is difficult for suppliers to immerse themselves in large-scale, cost- and time-intensive innovations in situations where future profitability is not guaranteed amid insufficient information. The expression “The valley of death”, which is depicted in Figure 2, is used to refer to the phenomenon that the actually developed technology does not go through the commercialization stage and thus does not lead to actual innovation (Klitsie et al., 2019; Markham et al., 2010). The main reason for the firms to experience such difficulty is low investment motivation from high risks, uncertain market demand, and the need for large-scale investments (Nemet et al., 2018).

However, if future demand is guaranteed, demand uncertainty decreases because expectations for future profitability arise. Through the sharing of information, the uncertainty arising from demand is resolved (Lee & Park, 2006). By forecasting future demand, suppliers can predict the returns and profits of potentially manufactured products by technology development, which enables more challenging investments in innovation (Herstatt & von Hippel, 1992; Myers & Marquis, 1969). Guiso & Parigi (1999) showed that, through empirical analysis of Italian companies, the higher the uncertainty in demand, the lower the investment motivation of the company, resulting in a slower capital accumulation. Czarnitzki & Toole (2011) also found that the higher the market uncertainty, the more R&D investment is decreasing. In the case of Edler & Georghiou (2007), it has been mentioned that specifying potential demand in the public sector can promote private innovators' investment in R&D for commercialization. In other words, it can be said that potential demand affects the motivation for innovation through uncertainty, which is closely related to the investment status and the possibility of success in the process in which technology development is manifested as an actual innovation.

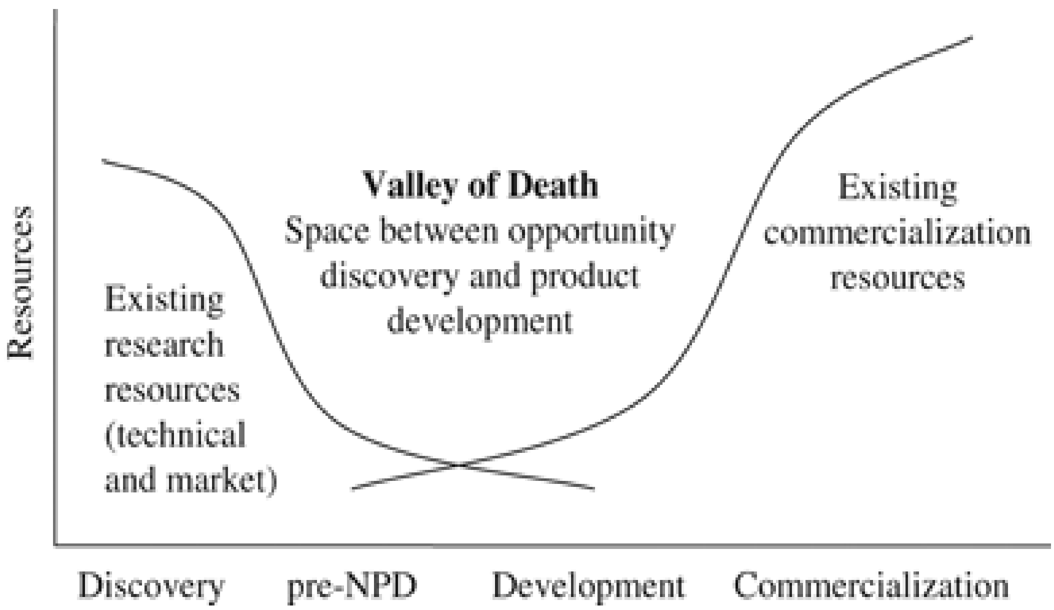

Figure 2. The Valley of Death (Source: Markham et al., 2010)

In addition, actual demand and consumption, not potential demand, also have a great influence on suppliers' innovation activities. In this case, the actual demand can be composed in various forms ranging from demand or consumption specific to the developed product to the size of the related market. The larger the actual demand or consumption, the more active the R&D and innovation investment of the supplier becomes. García-Quevedo et al. (2017) revealed that, through an empirical analysis, if suppliers feel that the actual demand for the product they want to develop is insufficient, there is a negative impact on the amount of investment in R&D and whether or not to invest. Piva & Vivarelli (2007) also showed that short-term and long-term sales have a positive relationship with corporate R&D investment in an analysis of Italian companies. However, it was also pointed out that the degree of positive relationship can vary greatly depending on the characteristics of the firm. Dawid et al. (2020) also emphasized the importance of the demand side for fostering new products or new industries, as the degree of R&D concentration of companies was closely related to the previous year's sales.

On the other hand, Fontana & Guerzoni (2008) analyzed the relationship between the overall market size and innovation activities. As a result of the analysis, it was found that the larger the market size, the more the company's innovation activities are promoted, and showed that the trend is stronger in process innovation than product innovation. In addition, Blume-Kohout & Sood (2013) pointed out that the R&D investment in the drug class, which had a high market share, was greatly expanded as a result of observing the change in R&D investment according to the institutional change, focusing on the pharmaceutical industry.

In sum, with additional empirical literature described in Table 2, it can be seen that in general, when the demand and consumption amount is high, the motivation of the supplier to invest in innovation increases, and accordingly, the probability of actual innovation being created also increases.

Table 2. Additional literature on the role of demand and consumption on innovation

Research	Context	Method	Results
Kleinknecht & Verspagen (1990)	Netherlands firms	Econometrics (Regression)	The size of the market is positively related with the firm’s R&D activity, and vice versa.
Åstebro & Michela (2005)	Selected innovations of Canada[2]	Econometrics (Regressions)	Demand instability is one of the key factors of reduced survival rate of innovation.
D’Este et al. (2012)	UK firms	Econometrics (Regression)	The firms experiencing the barriers related to market structure, demand, and cost of innovation activity are suffer from termination of the innovation
Stucki (2019)	Green innovation of Austria, Germany, and Switzerland	Econometrics (Regression)	High commercial uncertainty was one of the main barriers of green product development of the firms.

[2] This study use the innovations supported by Canadian Inventors Assistance Programme.

2.1.1.2.2 Providing knowledge and information from lead user

The concept of lead user, first appearing in von Hippel (1986), evolved in many forms and demonstrated the role of demand in innovation. Urban & von Hippel (1988) recognized lead user as having the characteristics of capturing general needs that may arise in the market proceed to other consumers and providing solutions to improve them. In other words, leading consumers are those who are qualified and motivated enough to contribute enough to the product development process (von Hippel, 1988).

There have been various examples and empirical studies on the role of lead users in the emergence of innovation. Urban & von Hippel (1988) showed that the idea of developing a new product was constructed based on data from lead users through the case of computer-aided systems for the design of printed circuit boards (PC-CAD). In addition, Lilien et al. (2002) analyzed the case of 3M and argued that the expected sales of products developed by providing ideas from lead users are more than eight times higher than those of products that have gone through a general process.

In the case of Mahr & Lievens (2012), the impact of leading consumer opinions in the virtual community on innovation was analyzed through Nokia's case. As a result of the analysis, it was found that the opinions of leading consumers have a significant effect on product development when a solution can be proposed, and it is suitable for improving new functions, but not for improving design or usability. Beyond this, it is also confirmed that firms introduce solutions that have already been developed by consumers, leading to the diffusion of innovation (Baldwin et al., 2006; Franke & Shah, 2003). In addition, examples of successful development of commercialized products have been analyzed through listening to the opinions of lead users (Kaiser & Müller-Seitz, 2008; Lakhani & von Hippel, 2003). It emphasizes the role of consumers in connection with concepts such as participating open innovation (Chesbrough, 2003) and co-producer (Wikström, 1996).

Table 3 illustrates additional studies focused on lead users in innovation process. The importance and role of lead users are commonly notified academically, and the studies are broadening to the managerial strategy to utilize the lead user and method for obtaining organized lead user community recently (Brem et al., 2018).

Table 3. Additional literature on lead user innovation

Research	Context	Method	Results
Schreier & Prügl (2008)	Consumer sports industry	Econometrics (Regression)	Lead users stimulated innovation not only generating idea for new products but also adopting commercial products faster than general consumers.
Hienerth & Lettl (2011)	Selected cases from medical and sporting equipment manufacturing	Case study with interviews	Users can form community and participate in innovation process by requiring and promoting development of prototype and providing information to reduce the gap between lead user and general consumers.
Roy (2018)	Industrial Robots	Data analysis	Lead user helps disruptive technology to become a definitely disruptive innovation

2.1.1.2.3 Increasing awareness by labeling and signaling effect

According to Rogers (1962), reactions of consumers to innovation are not homogeneous, and individuals can embrace innovation at different times. This implies that information transfer may occur between consumers according to the precedent relationship between the use of innovation. In this case, demand not only raises the level of awareness of innovation among potential consumers, but also becomes a certification that signals that the product is “innovative” by those who have used it first. Sometimes public or privately issued real labeling drives demand for innovation. In this case, preemptive consumption can be used as a means of acquiring awareness and promote other people's innovative purchasing behavior (Morrison et al., 2000; Urban & von Hippel, 1988). Especially with regard to innovative products, the prior knowledge of consumers has a great influence on consumption decisions (Lin & Chen, 2006). Since the level of knowledge differs depending on the surrounding environment, such as the living area and the level of education, the possibility of raising awareness through acquiring information from the surroundings is also different (Ali & Rahut, 2019).

In fact, in the environmental sector, there are cases in which various types of certifications help consumers to gain awareness of their products, thereby affecting related innovations (Cuerva et al., 2014; Kammerer, 2009; Müller, 2002). Even if it is not such an actual certification, demand itself plays the same role as certification. If the sale of a product is initiated by public demand, there is a tendency to increase the probability of success in commercialization as demand expands to private consumers faster than other products. (Bauer et al., 2010; Payne et al., 2013). Figure 3 shows the three pathways that the above demand affects innovation and corporate growth.

Technology-push and demand-pull innovation has been studied for a long time through theoretical and empirical research. In particular, with the development of innovation system theory, as interest in the interaction of various actors in the system increases, the academic understanding of demand-pull innovation that occurs in this process has also increased. When the role of demand and consumers as a driving force of innovation is synthesized, it can be divided into categories such as reducing uncertainty through securing potential demand, inducing investment motivation by actual consumption, innovation by leading consumers, raising awareness and signaling effects.

The innovation policy, which is the main object of analysis in this study, has also been developed by utilizing various policy tools along with debates on technology-push and demand-pull innovation. The next section summarizes research related to innovation policies that have been developed based on these discussions.

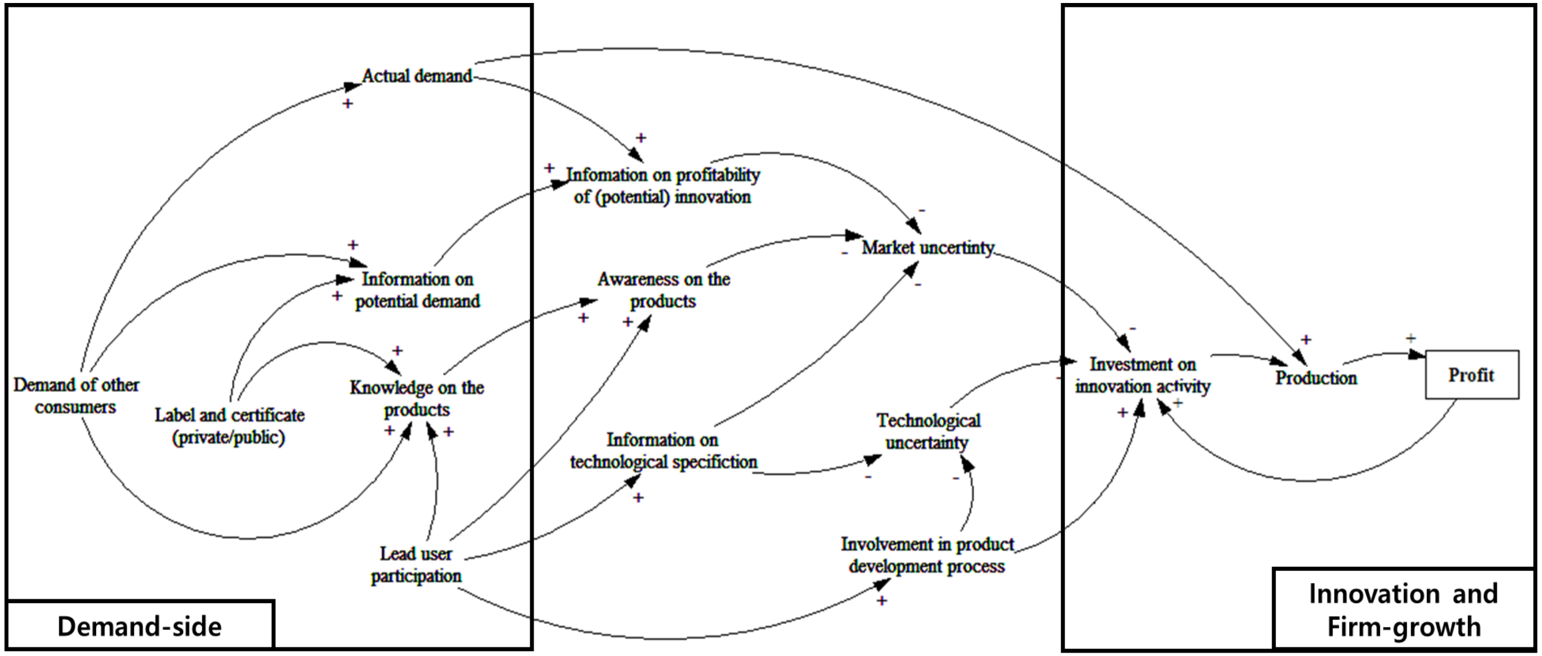

Figure 3. Impact paths of demand for stimulating innovation and firm-growth

2.1.2 Demand-side innovation policy and public procurement for innovation

2.1.2.1 The rationale of demand-side innovation policy

The history of the use of policies for the development of science and technology and the creation of innovation is very long (Nelson & Langlois, 1983). In general, since knowledge created through R&D has the characteristics of public goods, private R&D investment is determined at a lower level than the social optimum level (Jones & Williams, 1998). This means that the government's policy intervention is necessary to generate sufficient R&D and innovation activity for economic growth. Accordingly, many countries have implemented innovation policies in the form of subsidies for private innovation activities (Lundvall & Borrás, 2005). In recent years, beyond the concept of such a market failure, innovation policy has been accepted as a means to overcome system failure from the viewpoint of an innovation system (Freeman, 1995; Lundvall, 1992). Although there are various theoretical backgrounds for each period, the necessity of innovation policy is steadily emphasized along with discussions on the importance of innovation for economic growth.

There are various means of innovation policy, which are generally divided into supply-side innovation policy and demand-side innovation policy (Edler & Georghiou, 2007). Supply-side innovation policies mainly focus on R&D and technology development activities, and include measures that have traditionally been widely used, such as R&D subsidies and tax grants. On the other hand, demand-side innovation policies have interest in the diffusion of innovation outcomes and include policy measures such as public procurement, regulation, and purchase subsidies. Edler & Georghiou (2007) classified various innovation policy measures into supply-based measures and demand-based measures, respectively, and Table 4 below summarizes them.

Along with increasing interest in demand as a driving force of innovation, theoretical discussions on demand-side innovation policy began after the 1980s. The debate pointed out that demand-side policy measures are more effective in promoting and diffusing innovation than supply-side measures including R&D subsidies and tax grants which have been the most widely used measures until now (Dalpé et al., 1992; Geroski, 1990; Rothwell & Zegveld, 1981). Rothwell (1984) compared the government's procurement policy with R&D subsidy to show that the procurement policy induces innovation in more areas. In addition, Edquist & Hommen (1999) linked the rationale of demand-side innovation policy with innovation system perspective and concluded that innovation policy should be engaged in the process of diffusion of innovation as well as development of novel technology. Blind et al. (2004) also pointed out that regulatory and standard policy play a role in creating a leading market, so they need to be used as innovation policy measures.

Table 4. Categorization of various innovation policy tools

Categories	Tools	Contents
Supply-side innovation 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 innovation 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 for demand Awareness and training

These studies have commonly emphasized the path through which demand-side policy measures influence the diffusion of innovation outcomes compared to supply-side policy measures. Edler et al. (2012) pointed out three things as the rationale for demand-side innovation policy measures: 1) inducing innovation motivation by overcoming system failures, 2) setting the scope of innovation for policy needs, and 3) promoting activities for commercial development by acquiring potential lead markets. Aschhoff & Sofka (2009) also evaluated that public procurement, one of the representative demand-side innovation policy measures, promoted interaction between suppliers and consumers to, ultimately, provide suppliers with the possibility of securing profits through innovation. In other words, different from the supply-side innovation policy which focuses only on the development of technology, the demand-side innovation policy can be said to induce innovation in the private sector by having interest in the commercial success and social diffusion of the developed technology.

Among various measures of demand-side innovation policy, it is pointed out that public procurement for innovation (PPI), which uses public purchasing, which is a consumption for the activities of the government and public institutions, as a means of innovation policy is very effective in inducing innovation (OECD, 2011). OECD countries use about 13% of gross domestic product (GDP) for public procurement (OECD, 2019), and public demand is pointed out as one of the main sources of demand for various industries including construction, health, and transportation (Edler & Georghiou, 2007). This means that public procurement has a high proportion of government expenditures, and the potential to be utilized as a means of innovation policy is also abundant.

PPI is used by various names such as innovative public procurement, public procurement of innovation, and public technology procurement in various studies (Kalvet & Lember, 2010; Lawther & Martin, 2005; Rolfstam, 2007; Uyarra & Flanagan, 2010), In general, it refers to public purchasing activities for innovative or technologically improved products that have not yet been developed or that have not secured a sufficient volume of market even if they have been developed (Georghiou et al., 2014; Timmermans & Zabala-Iturriagagoitia, 2013).

Despite the significance of public procurement in the national economy and interest in demand-side innovation policy, research to explore the theoretical background of PPI has been started relatively recently. Edler & Georghiou (2007) is the first attempt to establish the concept of PPI and to examine the possibility of inducing innovation by PPI through the case of the European Union. Later, Uyarra & Flanagan (2010) and Uyarra et al. (2014) proposed an appropriate governance form of PPI to induce innovation linked with policy design. Recently, PPI has been drawn interest from policy makers and scholars to use it not only for stimulating private innovation and diffusion of innovative results but also for other policy goals including solving social problems, diversifying industries, and setting long-term economic growth agenda (Chicot & Matt, 2018; Edquist & Zabala-Iturriagagoitia, 2012; Kattel & Mazzucato, 2018; Uyarra et al., 2020; Wesseling & Edquist, 2018).

In sum, it can be seen that PPI plays a role in increasing the depth of innovation policy by recognizing the public sector as a consumer to overcome the limitations of supply-side policy measures, and emphasizing the role of inducing demand and consumer innovation (Choi et al., 2011).

2.1.2.2 Policy impact of demand-side innovation policy

2.1.2.2.1 Impact of demand-side innovation policy

Despite the theoretical discussions on demand-side innovation policy, studies analyzing its policy impact are relatively few compared to supply-side measures. One reason for this may be the lack of data on public procurement, regulations, standards to be analyzed in empirical way. compared to financial support measures such as R&D subsidies and tax grants. In addition, since demand-based policy measures affect the overall process of innovation from technology development, scale-up, commercialization, to diffusion, it is necessary to consider the changes in various interactions that occur within the innovation system what makes the policy impact assessment of demand-side innovation policy difficult (Uyarra, 2016).

Analysis of the impact of demand-side policy measures has been conducted since the 2010s, focusing on environmental and energy policy. Emissions trading system (ETS) and environmental standards are representative demand-side measures, and the main research interest was to confirm the possibility of eco-friendly innovation through the policy. Peters et al. (2012) and Schleich et al. (2017) revealed that through research on solar power and wind power generation, respectively, innovation effects such as patent application and knowledge spillover appeared through demand-side policy including regulations. Lee, Shin, and Lee. (2020) analyzed the solar photovoltaic (PV) sector and concluded that the demand induced from the policy promoted production activities and played a positive role in patent generation.

In addition, there are some studies aimed at examining the impact of demand-side innovation policy measures in specific industry. Prieger (2002) pointed out that more services would have been provided to consumers if the regulations were not implemented in the mobile communication service sector. Tuerpitz (2003) attempted to confirm through case analysis that the label system changes the information asymmetry faced by the supplier but failed to obtain a significant result due to the difference in the characteristics of companies and industries between each case. There is little empirical analysis, but Wakke et al. (2016) observed that, through a study of German companies, in the case of manufacturing, firms that participated in the standard policy showed higher their managerial performance and productivity growth than those that did not. On the other hand, it was pointed out that the innovation impact of regulations and standards differs depending on market conditions, and sometimes the direction of innovation and each direction may be different (Blind et al., 2017).

In the case of demand-side innovation policy measures such as regulation, certification, and standards, the policy evaluation has shown that there is a relationship between policy intervention and innovation, but there are few studies which have revealed the direction of policy effect with quantitative evidence. This is because these measures stimulate various elements within the innovation system, such as the way policies are designed and operated, and changes in corporate participation and behavior. Therefore, recent research has a tendency to focus on the conditions of policy governance and the structuring of the innovation system to activate the innovation system (Băzăvan, 2019; Jiang et al., 2020; Karakaya et al., 2018; Tidd, 2021).

2.1.2.2.2 Impact of public procurement for innovation

Academic research on the innovation impact of public procurement has been conducted steadily from the past. However, the most studies relied on case analysis showing that general public procurement, which did not explicitly reflect the contents of the development of new products or technological improvement in the contract, helped to create innovation. It is relatively recent to begin to analyze public procurement of products that do not exist yet or innovations that have not been secured in the market. This is because data on the outcomes of public procurement were not sufficiently secured before (Lember et al., 2014), and, consequently, the quantitative evaluation study of PPI was started based on a survey.

A study to examine the innovation effect of general public procurement through case analysis has focused on the success of innovation, such as product diffusion and market formation. Dalpé et al. (1992) surveyed Canadian patents and products and found that 25% of innovative products were first-time consumers in the public sector. Westling

(2000), by synthesizing the cases of products that have successfully spread the market including photocopiers, low-power light bulbs, and high-efficiency TVs, pointed out that there is a common feature of those innovation that initial public demand created the market. Palmberg (2004) also investigated the case of commercialized innovation projects and concluded that nearly half of the projects were made by public procurement. In a recent case, there is a study pointing out that the defense procurement program for a Brazilian aviation company had a positive effect on the development of the company's technical capabilities and the overall development of the civil aviation industry (Francelino et al., 2019). Table 5 adds some case studies which reveals the innovation impact of public procurement.

Table 5. Additional literature on innovation impact of public procurement

Research	Context	Results
Vecchiato & Roveda (2014)	Lombardy, Italia	Public procurement helped to make the products which is adjusted to special needs or international standards.
Torvinen & Ulkuniemi (2016)	School property procurement of Finland	Public procurement which involves end users in the process of innovation increased the usefulness of public service from procurement.
Sparrevik et al. (2018)	Net-zero energy building in Norway	Public procurement stimulates the interaction among stakeholders during procurement process and finally helped to have innovative solutions

Attempts to quantitatively analyze the effects of PPI are increasing in recent years. Guerzoni & Raiteri (2015) attempted an analysis using data from a survey of European Union countries in Gallup. In this study, it was shown that when the relationship between various innovation policy measures is controlled, PPI has a positive impact on promoting innovation activities of the firms compared to other measures. The analysis of the effects of PPI has been mainly conducted by comparing performance with supply-side policy measures including R&D subsidies. Most of the studies, which summarized in Table 6, empirically confirmed that the innovation effect of PPI is higher in terms of the occurrence of innovative products and improvement of management performance, similar to the trends of existing theoretical analysis and case studies (Czarnitzki et al., 2020; Park, 2020; Radicic, 2019; Saastamoinen et al., 2018; Stojčić et al., 2020). However, when policy makers decide the innovation policy implementation, not only PPI but also other innovation policy measures are considered, so there are studies confirming the possibility of maximizing the effect through linkages between them (Caravella & Crespi, 2020; Ghazinoory et al., 2019; Meissner & Kergroach, 2021).

In the case of PPI, the nature of demand-side policy measures focuses on the diffusion of innovation, and many studies that have attempted empirical analysis have seen changes in product development status and management performance of policy beneficiaries. However, in some studies, various influence paths of PPI were recognized and policy impacts were analyzed using other variables. It was confirmed that PPI has a positive effect on patent applications, which are intermediate products of innovation (Crespi &

Guarascio, 2019). Raiteri (2018) also compared the generality of patents between the firms with public procurement and those without using US patent data. In this study, it was shown that the firm implemented public procurement produced patents with a higher generality than those that did not. In addition, it was confirmed through empirical analysis that PPI also affects the possibility of obtaining external funds (Dai et al., 2021) and eco-friendly conversion of product production (Ghisetti, 2017).

Table 6. Empirical evidence of innovation impacts of PPI

Research	Context	Results
Saastamoinen et al. (2018)	Finland	PPI was positively related with higher profit from new products or services of SMEs.
Radicic (2019)	US and European countries	PPI had higher treatment effect in product innovation than supply-side public support in both manufacturing and services sector.
Czarnitzki et al. (2020)	Germany	Public procurement induced creating new products and increasing revenue, especially in incremental innovation.
Park (2020)	Korea	There was higher proportion of the firms experiencing innovation outputs in the group of PPI-implemented firms than those without.
Stojčić et al. (2020)	8 Central and East European countries	PPI had more effects on generating innovation and improving managerial performance than financial supports.

Recently, with growing interest in PPI has increased, and research on its policy characteristics and applicability, which is different from general public procurement, continued. In the case of Bleda & Chicot (2020), market formation was understood as a dynamic evolutionary process and explained through case analysis that public procurement influenced this evolutionary process. Li (2017) analyzed the governance structure of China's innovation policy and presented a framework for evaluating governance suitable for the expression of innovation through PPI. In addition, Divella & Sterlacchini (2020) analyzed the relationship between cooperation with research institutes or universities and discussing ways to participate in PPI of SMEs compared to large corporations through a comparison between Italy and Norway. These studies can be seen as attempts to propose a framework for policy evaluation of PPI in a situation where academic consensus on the concept, theoretical background and taxonomy of PPI has not yet been reached.

Many studies investigating the impact of the PPI as an innovation policy have pointed out that it had a significant effect to stimulate the innovation, but there are several obstacles to the practical use of the PPI in actual policy implementation process. This is linked to the basic characteristics of public procurement. Since the main source of the budget for public procurement is the tax collected from people (Park et al., 2010), it is necessary to take consider the effective and rationale use in budget spending. In other words, public institutions should have the balance in strategic use of PPI between procurement itself and stimulating innovation including the conflict between price and quality (Delina et al., 2021; Edquist & Zabala-Iturriagagoitia, 2020). The social use of PPI mentioned in the last paragraph also finds its logical basis in the public nature of public procurement, and it can be said that recent academic interest on PPI should consider the difficulties of PPI in actual policy implementation process.

On the other hand, PPI itself has various risks in its implementation process. European Commission (2010) has summarized these risks into five categories, which can be found in Table 7. These risks prevent the intended innovation in the process of PPI or become a factor that hinders the diffusion of innovation, and if these risks are repeatedly realized, the possibility of PPI's policy use will be significantly decreased. However, most of the identified risks can also arise from the private sector's innovation or the use of supply-side innovation policy tools. Therefore, the government's role in implementing the PPI is to minimize these risks. For example, in the case of technological risk, the impact can be reduced by communicating clear and feasible requirements when public institution decide the demand specification (Wanzenböck et al., 2020). Market risk can be solved when the public institution promotes coordination among various actors related to the innovation and addresses the innovativeness and usefulness of innovation results to the market properly (Uyarra & Flanagan, 2010). It is closely related to the public sector’s policy capability. It is needed for the public institution to break away from traditional policy practices and build a flexible public institution organizational culture suitable for the implementation of PPI (Uyarra et al., 2014; 2020).

Table 7. Types of risks in procurement of innovation

Type	Description
Technological risks	The risks that lead to imperfect completion including under or false performance of the procured goods and services.
Organizational and societal risks	Organization risks: the risks from organizational process which may result in failure or under-deliver of procurement Societal risks: the risks related to a lack of acceptance by the users of the new or changed public service delivered in society
Market risks	Demand-side market risks: the risks when the private markets are not large or responsive enough to justify production capacity investment of the suppliers. Supply-side market risks: the risks of disruption and delayed operations from political instability and volatile labor market
Financial risks	The risks and uncertainty in meeting the expected costs and capacity to secure the funds needed
Turbulence risks	The risks arise from unexpected situation when the procurement involves large scale-projects or numerous actors in the process

In sum, the role of demand and consumers in the process of innovation is very important, and the impact paths of its influence on innovation are diverse. From this, the need for a demand-side innovation policy including public procurement, regulation, and purchase subsidies was raised in addition to the existing supply-side innovation policy measures. It is known that demand-side innovation policy is more effective in inducing innovation than supply-side policy through various theoretical analysis and case studies.

PPI, a representative policy measure of demand-side innovation policy, induces suppliers' innovation motivation by purchasing innovative products or services from the public sector, leading to innovation investment and improvement of management performance.

PPI is expected to function as a major innovation policy tool, considering the share of public procurement in the national economy. It implies that continuous academic interest in analyzing the policy impact of PPI is required. However, until now, the analysis of the performance of PPI has mainly been limited to proving the relationship between fragmentary policy input and some variables including revenue, patent application, and R&D investment, and this is due to the lack of a consensus concept and theoretical analysis framework for PPI. Therefore, this study tries to confirm that the importance of PPI research through literature studies up to now and to find out that it is necessary to provide a theoretical analysis framework and to evaluate economy-wide policy impact integrating various effect paths.

2.2 Methodological background

2.2.1 Innovation policy impact assessment

2.2.1.1 Estimating treatment effect and propensity score matching

A typical way to empirically analyze the impact of a policy is to compare the targets that received the policy implementation and those who did not (Buisseret et al., 1995; Georghiou, 2002). However, since the statistics after the policy implementation is dependent on the characteristics of the target as well as whether or not the policy is implemented, a simple comparison is not suitable to see the policy impact (Oh, 2014). For this reason, it is necessary to use the fictional results assuming when the target who did not participate in the policy did the policy in comparing the target who received the policy input with the target who did not. However, it is very difficult to measure the hypothetical results of subjects not receiving policy input, and various empirical analysis methodologies have been proposed for this (Fisher, 1935; Quandt, 1972; Rubin, 1974).

Among them, the most basic method is Before-After-Estimator (BAE) (Heckman & Smith, 1999). BAE assumes that the results after the point of policy implementation of the target who did not implement the policy can be replaced with the results before the policy. Through this, it is possible to compare the results of the targets that performed the policy and the targets not performed after the policy. BAE requires that outcome variables prior to the policy point are independent of policy and that potential outcome variables are not volatile over time. If there are changes in policies due to unobservable factors including macroeconomic shocks, and changes in behavior of agents, the evaluation of government policy by the BAE may be distorted (Heckman et al., 1999).

To control the volatility of the potential outcome variable over time, the difference between the time period of the outcome variable can be reflected. Heckman et al. (1999) suggested difference-in-differences (DID) method to compare the difference of outcome variables before and after the policy of targets with the policy and those without. This can eliminate the influence of factors that are not observed, such as economic fluctuations, and ultimately control the resulting selection bias (Heckman et al., 1998).

In addition, matching is mainly used as a method for securing the independence between the outcome variable before the policy and the policy input. Matching is a method to search for targets without policy which have similar characteristics to those with policy implementation, and there are various methods such as multivariate matching (Rubin, 1976) and propensity score matching (PSM) (Rosenbaum & Rubin, 1983) (Oh, 2014). In this study, PSM method which utilizes the propensity score calculated by capturing and combining various factors that influence whether or not the agents get implemented the policy is used. PSM finds targets without policy implementation that are probabilistically similar to those with policy, so that the difference in results between the two can only be used to show the effect of the policy (Rosenbaum & Rubin, 1983). There are also several methods of matching after calculating the propensity score. In general, nearest neighbor matching (NNM), which finds the target with the closest score, and caliper matching, which matches all targets without policy within a certain range from the score of those with policy, and Kernel matching, which gives weight to targets without policy whose scores are close to those of those with policy are used (Becker & Ichino, 2002; Cochran & Rubin, 1973; Heckman et al., 1998; Caliendo, 2006).

2.2.1.2 Policy impact assessment with additionality

In innovation policy impact assessment, the most widely used concept to analyze the policy impact is additionality. Additionality is to look at the differences caused by the innovation policy for the policy targets such as companies, industries, factories, or people. It is largely divided into input additionality, output additionality, and behavioral additionality (Dai & Zhao, 2021; Georghiou, 2002; Clarysse et al., 2009).

2.2.1.2.1 Input additionality

First, input additionality checks the change in the input of the firm after innovation policy implementation, and the most observed variable is R&D investment. The primary goal of the innovation policy is to promote the innovation activities of the beneficiary firms, and R&D investment is one of the major variables representing the innovation activities of the private sector (Czarnitzki & Delanote, 2017; Orlic et al., 2019). Regarding the input additionality of innovation policy, extensive research has been conducted on various policy measures. A study by Herrera & Bravo Ibarra (2010) showed a positive correlation between R&D subsidy and private R&D investment through analysis of Spanish enterprises, Petelski et al. (2020) also pointed out in an analysis of Argentina that the firms that received public support for innovation activity had a higher R&D intensity than those that did not. On the other hand, in the research of Bassanini & Ernst (2002), it was also pointed out that there is no relationship between subsidy beneficiaries and private R&D expenditures overall. Marino et al. (2016) and Aristei et al. (2017) also showed that there is no substitute or complementary relationship between public R&D subsidy and private R&D investments through empirical analysis. Overall, in the case of R&D subsidies and tax grants, the existence of the effects may vary depending on the characteristics of the firms, industries, and countries and the type of policy implemented (Görg & Strobl, 2007; Lee, 2011; Paunov, 2012; Westmore, 2013). In addition, there has been attempts to analyze input additionality of other policy measures such as credit guarantee system (Oh et al., 2009), technology and R&D cooperation system (Watanabe et al., 2004), standards and certification system (Blind, 2006). The summarized results of studies which tried to investigate input additionality of various innovation policy measures are illustrated in Table 8.

With increased interest in diffusion of results in innovation process recently, investment required for scale-up and commercialization activities as well as innovation activities gets attention for key variables to investigate the input additionality of innovation policy, but much research has not been conducted on this. Clausen (2009) showed that receiving subsidies for product development had an impact on development-related activities such as facility investment. Santos (2019) also pointed out the positive relationship between innovation subsidy and investment expansion. In addition, Feldman & Kelley (2003) revealed that the firms that benefited from the US Advanced Technology Program were more successful in introducing external funding than those that did not.

Table 8. Literature on impact of innovation policy on input additionality

Research	Context	Method	Results
Lach (2002)	R&D subsidy in Israel	DID regression	Public R&D subsidy stimulated expansion of private R&D expenditure in SMEs.
Watanabe et al. (2004)	R&D cooperation system of Japan	Regression	Government-led R&D cooperation system was positively related to the economic growth, but the effects were decreased over 1990s.
Blind (2006)	Standard system of Germany	Regression	The firms with high intensity on R&D or import had a tendency not to participate in standard development organizations.
Oh et al. (2009)	Credit guarantee policy of Korea	PSM with kernel matching	Although the firms with credit guarantee experienced higher survival rate, they did not expand R&D investment.
Marino et al. (2016)	Public R&D support of France	PSM and DID	Public R&D support did not either reduce or increase private R&D investment.
Aristei et al. (2017)	R&D subsidy of EU countries	PSM with kernel matching	The firms with public R&D subsidy did not crowd-out its R&D expenditure and conduct additional R&D investment.
Freitas et al. (2017)	R&D tax grants in Norway, Italy, and France	PSM with NNM	The firms in the R&D-intensive industries have a tendency to increase their R&D input with R&D tax incentives.
Cerulli et al. (2020)	R&D subsidy in Trento, Italy	Regression with dose-response function	The amount of R&D subsidy and investment on intangible assets are related in inverted U-shape.

The input additionality of supply-side innovation policy measures is one of the representative research topics of innovation policy impact assessment. Several studies have pointed out that R&D subsidy and tax grants have influence on expanding private R&D investment and investment in production facilities, but some studies have contributed to the crowding-out effect of reducing the private sector's own R&D activities due to public support (Hud & Hussinger, 2015; Zhu et al., 2020). Accordingly, recent studies have shown that beyond the relationship between simple policy implementation and investment, the research topic and subject are diversifying including comparison between investment programs (Bellucci et al., 2019), the effect of repetitive and redundant support (Fiorentin et al., 2019), the relationship between subsidy amount and R&D cost (Srhoj et al., 2020).

2.2.1.2.2 Output additionality

The studies which tried to investigate output additionality of innovation policy can be broadly divided into technological output and management output. In the case of the technological output, it can be confirmed through the outcomes such as patents and research papers according to innovation policy implementation. In general, it is known that the firms that receive innovation policy measures such as public R&D subsidy benefit from patent applications and new product development compared to those that do not (Buchmann & Kaiser, 2019; Czarnitzki & Hussinger, 2018; Hyvärinen & Rautiainen, 2007; Li & Jaffe, 2017). However, there are some skepticism that measuring technological performance including patents as evaluation variables for innovation policy is not fit into policy objectives of innovation policy, which are firm growth and economic development (Georghiou, 2002). Therefore, much research have focused on managerial aspects including sales, profits, and productivity.

First, with regard to managerial performance, many studies point out that policy measures including R&D subsidies and tax benefits have a positive effect on profit and profit growth of the firm implemented. Vanino et al. (2019) has shown that the firm's profitability increases when performing public R&D projects, and Nilsen (2020) also pointed out that value-added growth of the firm is achieved through public R&D support. However, these studies had a limitation since they cannot distinguish the improvement of managerial performance was from the innovation or not. From this perspective, Huergo & Moreno (2017) showed that when conducting public R&D projects, profitability improvement through private R&D activities appeared, while Aoshima et al. (2013) also pointed out that government support could be a factor hindering commercialization. In the case of Europe, the situation of "European Paradox", which is private R&D investment increased due to large-scale R&D support policies centered on the European Union, but the commercialization was not successful, is argued (Dosi et al., 2006; Hammadou et al., 2014). A recent study empirically analyzed that these limitations have not been overcome (Radicic & Pugh, 2017).

Along with managerial performance, productivity is a variable that often appears in research on the output additionality of innovation policy. The direction of the impact of the innovation policy on productivity is presented in various ways. Girma et al. (2007) and Grilli & Murtinu (2012) pointed out that the firms received R&D subsidies had a higher rate of growth in total factor productivity (TFP) than those that do not. Cin et al. (2017) also showed that government subsidies have a positive effect on labor productivity through expansion of R&D investment through empirical analysis. On the other hand, Hall & Maffioli (2008) showed that there was no significant relationship between the benefits of public R&D subsidies and productivity.

Lastly, one of the main indicators for investigating the output additionality of innovation policy is employment. As the recent innovation policy is linked to economic and industrial policies (Soete, 2007), job creation is also included as one of the main goals of the innovation policy. However, there is no consensus on the employment impact of the innovation policy, and it was pointed out that the impact varied depending on the policy design and national characteristics (Bellucci et al., 2019; Hünermund & Czarnitzki, 2019). However, when considering employment limited to R&D personnel, it has been analyzed that R&D subsidies and tax benefits have a positive effect on hiring R&D personnel (Klímová et al., 2020; Teirlinck et al., 2021). Table 9 summarizes some selected studies which tried to assess output additionality of the innovation policy.

Table 9. Literature on impact of innovation policy on output additionality

Research	Context	Method	Results
Girma et al. (2007)	R&D grants of Ireland	Regression	The subsidy which supported productivity enhancement activity had a positive impact on TFP growth
Hussinger (2008)	Public R&D funding of Germany	Heckman selection model	R&D investment induced by public was positively related with the sales of new product.
Hewitt-Dundas & Roper (2010)	R&D subsidy of Ireland	Regression (Instrumental variable)	Public innovation support was a positive relation with new product generation in general.
Okamuro & Nishimura (2015)	R&D subsidy on university-industry collaboration in Japan	Regression	Public R&D subsidy on university-industry collaboration had an positive influence on innovation performance of the participants.
Czarnitzki & Delanote (2017)	R&D subsidy of Belgium	Regression	R&D subsidies are positively related to innovation output.
Hünermund & Czarnitzki (2019)	Multilateral R&D subsidy of Europe	PSM	The treatment effect of public R&D subsidy was heterogenous, but subsidy related to high-quality projects led higher employment and sales.
Klímová et al. (2020)	R&D subsidy of Czech Republic	Regression	Public R&D support was positively related to R&D personnel and expenditure.

To sum up, the impacts of innovation policy in the perspective of output additionality are presented differently from the studies. It is because there is a time-lag between the policy implementation and the manifestation of the impact on outcome is large. However, considering that the ultimate purpose of the innovation policy targeting private enterprises is the firm growth through improvement of productivity, empirical studies on output additionality is still valuable.

2.2.1.2.3 Behavioural additionality

Until now, most innovation policy measure was evaluated only from the viewpoint of input and output additionality. However, since innovation policy also affects behaviors and strategies of the firm related to innovation and R&D (Georghiou, 2002), impact assessment on those factors is also important in managerial and policy perspective, which can be called behavioural additionality. However, not many empirical studies on behavioural additionality were conducted before because it was difficult to quantitatively measure corporate behavior (Falk, 2007). However, there have been increasing attempts to observe behavioural additionality by focusing on specific behavior or strategy related to innovation such as enhancing internal innovation organizations and expanding R&D cooperation.

For example, Douglas & Radicic (2020) compared the R&D support programs of central and local governments in Spain and showed that local government policy further facilitated cooperation between government and business. Orlic et al. (2019) also focused on cooperation, confirming that the firms receiving public R&D support cooperate more with competitors, consulting agencies, and government agencies than those without public R&D support. In the case of Korea, government R&D subsidies promote cooperation, but it was analyzed that the relationship is reversed when the proportion of government subsidies among the total R&D investment of the firm exceeds a certain percentage (Ahn et al., 2020). This research trend is focused on confirming whether the innovation policy promotes the participation of the enterprises in the innovation system and contributes to the activation of the innovation ecosystem through mutual cooperation (Knockaert et al., 2019).

Besides cooperation, innovation policy can also deepen the innovation activity of the benefitted firm. Neicu et al. (2016) analyzed that the firm with R&D subsidy can concentrate more on the project related to development. Cho & Lee (2012) focused on Korean robot industry to check behavioural additionality of Korean governmental R&D subsidy and concluded that R&D subsidy contributed to capability enhancement of internal R&D personnel. In addition, research is also being investigated focusing on various variables related to corporate behavior and strategy, such as outsourcing of manufacturing processes (Dai & Zhao, 2021), changes in employment composition (Mitchell et al., 2020), and degree of risk taking (Schnellenbach & Schubert, 2019). Research on behavioural additionality can be one of the major topics since it reflects the change of corporate strategy on R&D from the perspective of innovation system.

In summary, many studies conducted at the firm level, have focused on the additionality of examining the differences between policy-beneficiaries and non-beneficiaries. As can be seen in 2.1.2, the major empirical analysis that has recently emerged regarding PPI is also composed of a similar framework. In this study, as part of a preliminary analysis to analyze the economy-wide impact of PPI, the impacts on expanding R&D investment (input additionality) and productivity improvement (output additionality) are examined in Chapter 4. Among them, the productivity improvement impact needs to be considered as a major variable in the impact assessment of PPI, as most of the research focuses on supply-side innovation policy measures. The research in Chapter 4 is analyzed using the PSM method widely used in the evaluation of demand-side innovation policy including PPI as well as supply-side innovation policy such as R&D subsidies and tax grants. By maintaining the methodological framework, the validity of the results and the consistency of reality can be secured.

2.2.2 Computable general equilibrium for innovation policy impact assessment

2.2.2.1 CGE model with innovation and R&D

Computable general equilibrium (CGE) model describes the general equilibrium of the economy with economic agents such as households, companies, governments and foreign countries and their interactions as a system of equations (Choi, 2002). Since CGE model presents various economic indicators by describing the entire economy, it has been widely used to analyze the effects of policy (Hosoe et al., 2010; Koo et al., 2019; Lee, Kang, and Woo, 2020). Along with the emphasis on the importance of economic growth from technology and innovation, there have been steadily attempts to analyze the economy-wide impact of innovation policy, and thus modified CGE model reflecting factors such as R&D and innovation has also been established.

Goulder & Schneider (1999) tried to investigate the effect of carbon dioxide reduction policy by constructing a mathematical general equilibrium model applying the concept of induced technological change. Induced technological change represents technological progress arising from R&D, which reflects the effects of technology-related policy. In this study, R&D production was described separately, and a model was constructed that defined the production factor of knowledge capital in addition to the traditional production factors such as labor and capital. In the case of knowledge, it was defined as an industry-specific production factor, and knowledge spillover due to the production expansion in the production function was also reflected. They showed that there was a difference in the cost-effectiveness of GDP of the CO_2 reduction policy between the models by comparing it with the model that did not reflect the concept of induced technological change.

A method of reflecting the elements related to innovation in CGE model by separately defining the R&D production sector and industry-specific capital was also introduced. In the case of Ghosh (2007), in addition to the general production sector, the design production sector, which is produced by the inputs of R&D and specialized capital, was defined. Bye et al. (2009) classified industries into three categories: 1) R&D industry, 2) specialized capital goods industry, and 3) final goods industry. The study analyzed the effects of various subsidy types such as R&D subsidy, capital subsidy, and investment subsidy through the CGE model. From the simulation results, it was confirmed that the policy impact of subsidy did not appear significantly due to the low elasticity of demand for R&D capital goods. In addition, various studies (Bor et al., 2010; Diao et al., 1999; Garau & Lecca, 2015; Yang et al., 2015) constructed and utilized CGE model that explicitly reflected the components of innovation or R&D. In addition, some confirmed the economy-wide effects of policy measures such as R&D subsidies, as the summarization of the results in Table 10.

Table 10. Literature on CGE model with innovation or R&D

Research	Context
Diao et al. (1999)	R&D production sector was described separately, and it produced new designs with the inputs of labor and knowledge stock.
Bor et al. (2010)	R&D capital was explicitly defined as production input, and it is generated from R&D investment and different kinds of labors.
Garau & Lecca (2015)	Induced technical change from the accumulated knowledge by R&D investment was reflected in the equations.
Yang et al. (2015)	TFP growth driven by R&D investment (or knowledge capital) was added.

2.2.2.2 Knowledge-based CGE model and TEMIP model

The CGE model used to analyze the economy-wide impact of PPI in this study is based on the TEMIP model (Hwang et al., 2020). The TEMIP model was constructed as a model specialized to assess the economy-wide impact of innovation policy through the use of data specifying the accumulation of knowledge capital by public and private R&D investments (Hwang et al., 2020). Here, for the construction of the TEMIP model, the research on the knowledge-based CGE model, which focused on the characteristics of R&D and innovation investment, accumulation of knowledge capital, and knowledge spillover, is summarized.

Hong et al. (2014) constructed a R&D-based CGE model that reflected the production factor of knowledge within industries and the productivity spillover effect of knowledge among industries. In this study, model validation was conducted through simulation of the model from the past point in time. Through this, they concluded that the R&D-based CGE model is more fit into the description of macro-economy in the countries which maintain high productivity growth such as Korea. Hong & Lee (2016) also analyzed the policy impact of R&D tax grants by dividing large firms and SMEs through a knowledge-based CGE model that similarly reflects knowledge factors. The results showed that support for SMEs has a greater economy-wide impact than support for large firms when the same amount of tax incentives is applied.

Jung et al. (2017) grasped the characteristics of R&D and knowledge accumulation centered on the substitutional relationship of production factors and reflected them in the CGE model. Specifically, by introducing the concept of skill-biased and capital-biased technological progress, the replacement rate by skill level of labor and that of capital and labor were reflected in the nesting structure of the CGE model to redefine the production structure of general and R&D industries. Yeo & Lee (2020) expanded these characteristics of technological progress to education and pointed out that the substitution relationship between labor and capital according to technological progress can be changed by education.

These studies attempted to understand R&D and innovation factors in terms of production factors and productivity spillovers and reflected them in the CGE model. The TEMIP model presented in Hwang et al. (2020) summarizes these factors, reflecting the characteristics of different private and public R&D, and was constructed by analyzing innovation policy impact assessment through the use of data reflecting knowledge production factors and investment.

This study utilized the CGE model based on the TEMIP model. However, the model is developed by reflecting the impact of PPI on productivity and R&D investment to assess PPI's economy-wide impact well. As discussed above, since PPI affects the interactions among the agents in the innovation system, or in the economy, and generates various impact paths, it is necessary to grasp the impact from the perspective of general equilibrium. However, most of the studies to analyze the impact of PPI remain in micro-level, or firm-level, studies, and most of them take partial equilibrium perspectives.

Therefore, in this study, based on the CGE model, the economy-wide impact of PPI is analyzed, and the possibility and performance of PPI as an innovation policy measures is introduced with policy implications for future policy implementation.

2.3 Research questions and contribution of this study

As discussed above, the role of demand and consumers in the development and diffusion of innovation have been constantly being emphasized, and interest in demand-side innovation policy is also increasing with this trend. Among the various demand-side innovation policy measures, PPI is being used in various countries in recent years. The importance of PPI as innovation policy have paid attention since the share of public procurement in the national economy is large and it has the various impact paths on the innovation process. In the meantime, through several cases and empirical analysis, it has been revealed that PPI has a higher positive impact on the introduction and diffusion of innovation and the growth of the firms and industries compared to traditional supply-side innovation policy measures such as R&D subsidies or tax grants.

However, despite the literature up to now, their results which analyze the policy impact of PPI are very fragmented, and empirical analysis remains at confirming the simple relationship between policy implementation and outcome of the beneficiaries. This is because there is no consensus framework for theoretical rationale for PPI impact assessment. PPI has an influence on not only the supplier, which develops technology, but also the behavior of the government, which is consumer of PPI contract, and furthermore, the private consumer. It implies that it is necessary to consider the policy impact of PPI with holistic view of innovation system.

The systemic thinking of PPI's rationale helps to categorize or classify the various cases of PPI and grasp each impact paths in more organized way. Therefore, in this study, first, the concept of PPI is redefined from the systemic viewpoint, and new taxonomy for categorizing PPI is proposed. In Chapter 3, the policy impact of PPI, which has been pointed out through various theoretical and empirical literature, is classified into its influence on the interaction among economic agents in the innovation system. It makes the identification of impact paths from each case of PPI possible. In addition, this study will set new taxonomy for PPI to categorize it into four types and provide a theoretical framework to analyze the policy impact of several PPI cases descriptively. Finally, the taxonomy and framework for PPI rationale is validated through case analysis.

Subsequently, in Chapters 4 and 5, the policy impact of PPI is quantitatively analyzed through empirical way. As can be seen in section 2.1.3, the number of studies which tried to investigate the impact of PPI at a firm- or industry-level has increased significantly recently. Most of these studies confirm input or output additionality of PPI applying the Roy-Rubin Method, which is a traditional policy evaluation methodology for innovation policy. The impact of PPI on generating private innovation has been confirmed through various empirical studies, but in the case of impact on productivity, little analysis has been conducted. This seems to be because PPI generally focuses on product development, but empirical analysis for PPI's impact on productivity is also an important research topic considering its influence path and various policy goals of innovation policy. In Chapter 4 of this study, focusing on this point, this study empirically finds the relationship between PPI and productivity improvement at a firm-level. This study intends to secure the theoretical consistency of the numerical results by using the PSM methodology widely used in policy impact evaluation. In addition, we will conduct empirical analysis on R&D investment and management performance improvement to confirm the results of existing research, and to clarify that PPI affects the overall innovation process as suggested in Chapter 3.

Finally, Chapter 5 analyzes the economy-wide impact of PPI through CGE model. CGE model is widely used to examine the economy-wide impact of various policies from the point of view of general equilibrium and is also highly utilized in innovation policy impact assessment. In this study, economy-wide impact assessment of PPI is performed with review of the development cases of CGE model which tried to include the factors of innovation, R&D, or knowledge into standard general equilibrium setting. It is worthwhile to assess economy-wide impact of PPI in general equilibrium perspective since it has various impact paths through innovation system, but there is little research tried to incorporate it in quantitative manner. Therefore, this study aims to present economy-wide impact of PPI from the general equilibrium perspective by constructing CGE model which includes the characteristics of innovation, R&D, and public procurement. The setting of CGE model will integrate the observations in micro-level studies and theoretical relationship in macro-level by explicitly reflecting the relationship between PPI and productivity or R&D investment which is presented in Chapter 4.

The analytic framework of PPI presented throughout this study is expected to add depth of theoretical analysis related to PPI or demand-side innovation policy. As Kundu et al. (2020) pointed out, various theoretical and empirical discussions on the policy impact of PPI has not been linked in comprehensive manner due to the vast policy scope and various impact paths of PPI. However, the analytic framework presented in this study understands the impact paths of PPI and helps to understand the taxonomy that systematizes various cases. This process is helpful for future study related to PPI to be the academic base. In terms of policy, this analysis framework can also be used to improve policy design and policy implementation method of PPI in order to generate its innovation impact sustainably.

On the other hand, quantitatively investigating the economy-wide impact of PPI is also expected to provide major policy and academic implications. As there are increasing complexity of society and innovation environment, it becomes to be more difficult to analyze the effectiveness of policy quantitatively. However, it is important for policy maker and practitioners to have rigid evidence on the policy impact (Dosso et al., 2018), and the related research draws growing interest both in policy and academic perspective. Despite the continued interest and emphasis on PPI or demand-side innovation policy in recent years, there is few policy evidences to justify the input of PPI as innovation policy from the previous studies. The quantitative impact assessment both in micro- and macro-level done in this study can function as methodological framework to provide ex-ante and ex-post policy evidence for designing and implementing innovation policy including PPI. It is important in terms of science of innovation policy (Gault, 2011) which emphasize the utilization of concrete policy evidence in decision-making and implementation process of innovation policy. In other words, although the numerical results expected to be drawn in Chapter 4 and 5 have important meaning for policy impact assessment of PPI yet, the academic framework link qualitatively captured impact paths in Chapter 3 and quantitative evaluation methodology including PSM and CGE in Chapter 4 and 5 to generate the rigid policy evidence for innovation policy is expected to draw attention from both policy and academic perspective.

Chapter 3. Revitalizing the Concept of Public Procurement for Innovation from a Systemic Perspective: Objectives, Policy Types, and Impact Mechanisms

3.1 Introduction

Traditionally, innovation policy initiatives of countries and regions have mostly come from the supply-side, with interventions such as fiscal measures, support for training and mobility, public financing of research and development (R&D), information and brokerage support, and networking measures (Vonortas, 2015; World Bank, 2010). However, recently, several countries experience the limitation of these policy instruments for fostering innovation and economic growth as technology development does not always lead to the expansion of the market demand for it. Demand-side innovation policy is based on the perspective that enough market demand for new technology should exist for finalizing the commercialization process. It is also noted that there are different ways in which demand spurs innovation through asking for new products and services, or being responsive to existing innovation (i.e., absorbing, adopting, using, and accepting innovations). In this regard, demand-side innovation policy covers all public actions to induce innovation and speed up the diffusion of innovation through increasing the demand for innovation, defining new functional requirement for products and services, and improving user involvement in innovation production.

Among policy instruments under the demand-side innovation policy, PPI has become one of major innovation policy tools in recent years. Generally, public procurement refers to the purchase of the public or government institutions for their own use. On the other hand, as a form of innovative procurement scheme, PPI refers to the procurement practices when the purchased solutions or products do not yet exist, but could be developed within a specific period of time by requiring innovative works to fulfil the public demand, while the regular one focuses on the already existing products or services whose characteristics are well known. Under the PPI scheme, public institutions can specify the features or characteristics of potential innovative goods and services with the form of the procurement contract including the information of price, quality, and performance. It is well known that this procurement scheme can induce innovation effect in various channels such as helping capability building of private suppliers, signaling the quality and innovativeness of procured products. As public procurement is associated with the public demand, the public institutions or governments can put in place selective, limited discourses that define mid- and long-term public needs with PPI scheme and relevant administrative strategies (Edler & Georghiou, 2007).

Despite of growing interests on the PPI as the innovation policy instrument, however, policy design of the public procurement for innovation has not been underpinned by a clear theoretical or empirical basis, rather based on anecdotal evidence (Georghiou et al., 2014). Policymakers and practitioners are increasingly interested in finding out how to use their sizeable procurement budgets to address multiple objectives (such as, promoting innovation, driving economic growth, improving delivery of public services), and investigating the channels by which direct and indirect impacts of PPI take place within the economic system. In order to design a procurement policy that may promote innovation activities effectively, it is essential to understand the mechanisms in which procurement policies have effects on innovation activities. However, studies supporting the significance of public procurement for innovation are rather fragmented, and mostly limited to specific case studies. Findings drawn from specific cases tend to provide context-dependent knowledge on the effects of PPI. It also makes it difficult to draw general conclusions on the impacts of PPI, and figure out the stylized facts about the role of the demand-side innovation policy.

Furthermore, as those previous studies are mostly based on specific case studies or surveys, they provide us only knowledge limited to the contribution of PPI to the first-tier suppliers (or, beneficiary groups) who provide innovative solutions or products to fulfil the public demand. However, innovation is perceived as a complex and interactive process influenced by many factors, including levels of intervention, and conditions of institutions, rather than a linear process. Therefore, a systems of innovation perspective is required to understand how the public procurement for innovation can and should work in a practical sense. So far, there has been lack of systematic understanding of how the procurement-related interventions shape the innovation process and interact with other components of the innovation system, which hinders the in-depth discussions on the potential offered and challenges posed in using PPI as the innovation policy instrument conceptually and in practice (Aschhoff & Sofka, 2009; Edler & Georghiou, 2007; Georghiou et al., 2014; Ghisetti, 2017).

Accordingly, it is noted that there should be an analytical framework to understand the contributions and impacts of PPI based on the systems of innovation perspective, to justify the increasing importance of demand-side innovation policy, and sizeable budgets on the PPI. Addressing a significant gap in our systematic understanding of the effects of PPI, this study firstly aims to propose a conceptual framework to systematically understand the direct and indirect impacts of PPI from the economy-wide perspectives by deducting stylized facts for PPI, impact mechanisms and channels of PPI on the basis of a wide range of findings of previous studies. When summarizing stylized facts on PPI's economy-wide impacts, I consider various economic actors including potential suppliers, consumers, government, and their interactions. Secondly, this study aims to investigate the specific PPI case, focusing on the PPI scheme oriented towards the electric vehicle (EV) market, and propose new taxonomies on the types of PPI. Based on these proposed taxonomies, it will be highlighted that the policy goals, impact mechanisms and impact channels of PPI can vary across countries according to the context of specific technical and demand conditions. Ultimately, this study expects to extend the knowledge of the economy-wide impacts of demand-side innovation policy, and enable a better understanding of the overall socio-economic effects of strategic procurement decisions.

3.2 Characterizing impact channels of PPI on innovation system

3.2.1 Systemic perspectives for the innovation policy

One of key rationales behind the interventions of innovation policies from systemic approaches is associated with the system failures occurred in the innovation systems (Laranja et al., 2008). A systemic perspective on the innovation process extend the roles of policy interventions beyond the neoclassical economic rationales that public policy is only legitimate in terms of market failures caused by sub-optimal resource allocations by private firms. Furthermore, this systemic perspective stresses out that innovation processes are described as dynamic learning processes within the conditions of networks (interactions) and capabilities of institutions. This implies that public intervention is legitimate when the complex interactions among institutions involved with innovation process do not function effectively (Woolthuis et al., 2005). In this regard, it is essential to look into various types of structural system failures, and shape the public policy interventions for innovation from the system perspective. For example, previous studies have tried to identify certain types of system failures such as, actor capabilities failures (i.e., the lack of appropriate competencies and resources at the organizational level), network failures (i.e., limited interactions and knowledge exchanges among actors), and institutional failures (i.e., lack of capabilities of institutions) to inform the decision-making process for innovation policy from the systemic perspective.

Applying this systemic approach to understand innovation process within the innovation system, this study firstly aims to illustrate the PPI-induced changes and its impacts on the innovation system. Based on the systematic review on fragmented evidence drawn from case studies and empirical findings, I propose synthesized framework to account for direct and indirect impacts of PPI from the systemic perspective. As noted in the previous section, most of the previous studies focusing on the PPI's impact assessments are lack of systemic approaches, which provides limited implications for policymakers to implement effective PPI-related policy interventions after understanding systemic changes, potential benefits and challenges brought about by PPI. Moreover, previous studies lacking systemic perspectives only give us context-specific, or case-specific implications, not provide us a guidance on more systematic assessment of the PPI. With those limitations of previous studies, in the next subsection I will present a conceptual framework which describes multiple interactions among actors and their involvements with innovation process within the innovation system. By describing the linkages between the PPI and the dynamics of these components, our proposed framework expects to aid the conduct of ex-ante, as well as ex-post assessment of PPI policies, which can further inform policy design, implementation, and learning.

In drawing upon stylized facts on the PPI's impacts on the innovation system, main institutions in the innovation system are considered as follows; private suppliers, private consumers, and the public institutions (i.e., government). In addition, the environmental conditions, such as norms, institutions, and cultures are considered as social factors outside of the agents. Figure 4 depicts the innovation system approach utilized in this study. In the following subsection, this study deducts stylized facts on impact mechanisms and channels of PPI policies from the system perspective, and synthesize those stylized facts within a holistic framework to generalize the PPI-induced changes within innovation system.

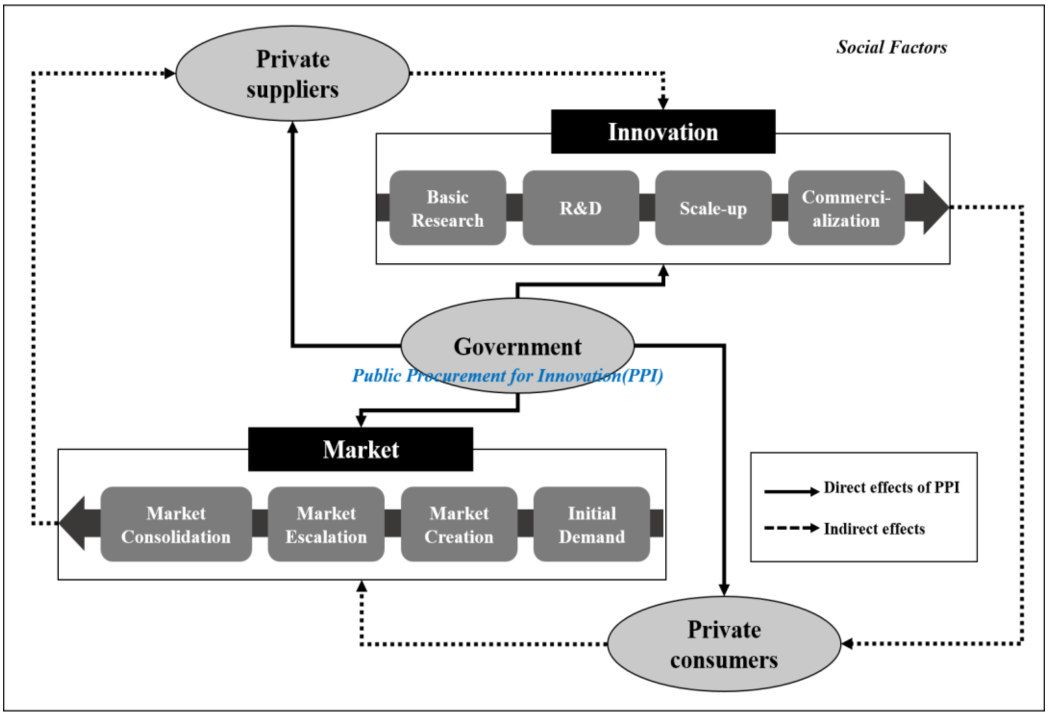

Figure 4. Innovation system approach for understanding PPI-induced impacts

3.2.2 Existing studies on taxonomy and types of public procurement as innovation policy

Studies on the effects of public procurement on innovation have been started since the

1980s, and there have been attempts to classify the types of public procurement as an science or innovation policy. First, Edquist (1996) pointed out that government procurement can be used as part of technology policy and emphasized that public procurement in this case corresponds to a policy tool operated in the demand side. In addition, the study classified the public procurement by focusing on technology development and technology diffusion, which are the main goals of technology policy. The study defined government technology procurement which public institution procured technology for its development. In addition, he addressed that ordinary public procurement for goods and services also can be the part of technology policy since it can stimulate the diffusion of technology. Although he classified the types of public procurement according to the goals of technology policy, there is a limitation in that he does not consider the market for results, another major element of innovation.

Uyarra & Flangan (2010) classified public procurement into four types according to characteristics of market demand and production process, referring to the purchasing portfolio model of Kraljic (1983). According to Figure 5, market demand is divided into general demand and dedicated demand, which means the demand is specifically focused on a specific group or situation. The production process is classified according to whether a specialized process is required to produce the goods or services or not. Although this study attempted to classify the taxonomy of public procurement in terms of supply and demand, it had limitations in that it did not explicitly consider innovation and did not suggest a policy impact path for each type.

		Characteristics of production process	
		Specialized process	Standardized process
Characteristics of market (demand)	Dedicated market	Experimental procurement	Adapted procurement
	Generic market	Technological procurement	Efficient procurement

Figure 5. Types of public procurement with features of market and production process (source: Uyarra & Flanagan, 2010)

Edler et al. (2005) classified PPI into three types according to the type of end user. First, in the case of direct PPI, public institutions purchase products or services for their own use and can add special specifications or technologies in the contract process for generating innovation. In cooperative PPI, end users can be public institutions and private consumers, and the demand of public institutions plays the role of forming a market and stimulating private demand. Finally, catalytic PPI has a characteristic that private consumers are the end users, and public institutions only make purchases, but actual use is made in the private sector. From these classifications, Hommen & Rolfstam (2008) described the process of interaction between the user and the supplier according to each PPI type. It addressed three main interaction process including interactive learning, demand structure, and characteristics of needs. It was also noted that these types of interactions may vary depending on the technology and market level. This taxonomy is characterized by focusing on the diffusion of innovation results, which is one of the purposes of the PPI, and considering the interaction between actors in the innovation system. However, the impact path for each PPI type was not specifically presented for various economic and innovation-related variables, which has a limitation in that it is unclear what the final impact of each type of PPI would generate.

These studies attempted to classify public procurement or PPI from various perspectives. However, there is a limitation in that the taxonomy was constructed focusing on some factors since various innovation influences of PPI were not identified in the classification. Accordingly, in this study, taxonomy for PPI is constructed according to the characteristics of the market and technology, and the characteristics of demand pointed out by Uyarra & Flanagan (2010) are considered in connection with the utilization of PPI for tackling social problem which has recently drawn much attention in policy making process. In addition, this study tries to identify the impact paths for individual types and present the paths of the PPI that synthesized them from the perspective of the innovation system.

3.2.3 PPI-induced impact channels within innovation system from systemic viewpoints

Private suppliers experience various obstacles when they launch, develop, and finally commercialize the innovations. One of the main challenges is associated with the market uncertainty associated with expected demand for potential innovation outcomes. If the expected demand for innovative goods is low, the potential profits and returns from the investments associated with the development and commercialization of new products and processes are low. Therefore, it is difficult for private firms to decide whether to invest in basic research and R&D activities that will eventually be incorporated into the innovative goods (Uyarra et al., 2014; Gallup, 2011). However, the public sector with the purchasing power under the PPI scheme can reduce uncertainty by guaranteeing and enlarging the size of future demand for the innovative solutions.

Reduced market uncertainty with enlarged public demand in the early stage can partly eliminate barriers for suppliers with a stronger commitment to R&D and product innovation, as the public sector as a lead user of the innovation ensures certain returns of investments associated with new products/services (Uyarra et al., 2014; Dalpé et al., 1992). Accordingly, the reduced market uncertainty leads to increase the spending of private suppliers on R&D investments and production facility investments. Edler & Georghiou (2007) point out that the PPI contracted firms tend to increase investment for finalizing commercialization in order to meet the demand specifications. Geroski (1990), Edquist & Zabala-Iturriagagoitia (2012), and Hommen & Rolfstam (2008) also state that the guarantee of purchase before commercialization helps the suppliers to increase R&D investments and leads to faster and more successful development of new products.

Another type of uncertainty which the firms suffer from is associated with the technological uncertainty. Technological uncertainty is even much higher when the private supplier tries to develop innovative technology which is not realized yet since the probability for success of the innovation is relatively low but the riskiness of the technology itself is higher. The public sector with specification and signaling of needs and standards through tendering procedures can raise the initial recognitions of the procuring technologies or products and direction of the innovation (Uyarra & Flanagan, 2010; OFT, 2002). Although technological uncertainty is related to the supplier side, it can be included in direct demand-pull path since the agents which stimulate the change of the uncertainty is public institution which procures the product or technology. The reduction of technological uncertainty faced by the private supplier is driven by the interaction between suppliers and public consumers in contract and product delivery process, which can be interpreted that this impact channel is directly generated from the demand of public institutions. In other words, the specified market demand from the public sector under the PPI scheme can help the private suppliers face the reduced technological uncertainty as functional specifications noted in terms of outcomes or performances can provide guidance for private (potential) suppliers to propose innovative solutions.

Furthermore, public demand can play a key role as a testing ground of the innovation results, and feedbacks from the lead users of the innovation (i.e., public sector) can help suppliers finalize the modification and refinement processes of the innovations. Like this, PPI can also help offset systemic failures by enabling active interaction between suppliers and users, and by articulating and signaling unmet needs to the market (Uyarra et al., 2014). Interactions between suppliers and users under the PPI scheme can create an environment of trust and reduce transaction costs among actors through eliminating information asymmetries (Erridge & Nondi, 1994). Edquist (1996) also mentions that potential suppliers can collect the information and feedbacks about their innovation results for potential markets, which helps them to finalize commercialization process efficiently. Westling (2000) presents several examples which innovative products were successfully diffused in the market with the aid of early public demand (such as, copy machines, energy-efficient light bulbs, and energy-saving TVs).

As discussed above, the procurement policies can bring about direct demand-pull impacts on potential suppliers in undertaking R&D, product innovation, and launching relevant investments. Procurement policies can also induce indirect demand-pull impacts towards other actors in the innovation system through various channels. For example, the specified demand triggered by the public sector can indirectly affect the private consumers. For private consumers, their purchase behaviors are largely based on their own habits, preferences or routines of consumption patterns. Especially, private consumers are reluctant to purchase innovative products or services, due to the risks and technological fears especially when the newly introduced products are highly innovative. In other words, the introduction and diffusion of innovative products into markets are usually accompanied with certain degrees of resistance on the part of consumers (Hawkins et al., 2019). It constrains the rapid market penetration of innovative solutions.

Under this situation, government can act as a lead user for certain innovative solutions, products, and services (Edquist et al., 2015). The government with large purchasing power can create signaling effects as a lead user by promoting the diffusion process of innovative solutions more broadly. The public interventions in the form of PPI as one of innovation policy instruments would demonstrate the public sector's commitment to certain technologies and products with functional specifications. These actions work as an awareness-raising tool and encourage 'domino-effects' on purchasing practices of private consumers (Morrison et al., 2000; Urban & Von Hippel, 1988). When private consumers notice that certain goods are publicly procured under the PPI scheme, they start to think those products are guaranteed by the government and tend to change their purchase choices into more innovative products (i.e., procured goods). Payne et al. (2013) and Bauer et al. (2010) point out that the products which are subject to the PPI contracts draw more attentions, and it can attract much more private consumers compared to other products. They also suggest that in some countries (such as, United States, Japan, and some EU member state countries) most of the eco-friendly products have achieved successful market penetration with the leadership of the public sector after the introduction of PPI.

The PPI's effects are not limited to creating markets for new products/services by accelerating the pace of innovation and commercialization process through lowering market and technological uncertainty. Even after the innovative products and services are successfully developed and introduced into the market (with "direct demand-pull effects"), the private suppliers can obtain benefits from the PPI scheme through the expansion of their production volumes. As stated before, procured products under the PPI scheme are ensured with enlarging market demand not only from the public sector, but also from private consumers. In this regard, it is highly possible that the procured products under the PPI scheme would gain larger market shares with the changes of private consumers' purchasing behaviors affected by the first user of the innovation (with "indirect demand-pull effects"). Increases in demand for procured products make the private suppliers to increase their production volumes to meet demand conditions. The major benefits from the expansion of production volumes are associated with the economies of scale and learning effects. Greater volumes of demand formed by the PPI are to generate economics of scale, which promotes suppliers to achieve the reduction of the long-run production costs (Albano & Nicholas, 2016).

Cost reductions for procured products are also assumed to be achieved as a result of higher deployment of those solutions (i.e., learning by doing) and increased R&D activities (i.e., learning by searching). Learning effects represent technological progress as a function of some cumulative experience indicator. For example, learning by doing effects refer to increases in productivity gains with increases in cumulative capital intensity of production, or production volumes of suppliers (Stiglitz, 1987; Arrow, 1971). This learning by doing mechanism can be extended to the learning by searching mechanism with considerations of accumulated knowledge stocks. In this regard, learning by searching refers to the productivity gains obtained with a positive function of accumulated knowledge stocks (Nemet, 2009; Kouvaritakis et al., 2000). Productivity gains from the economies of scale and learning mechanisms drive the unit costs of production and the prices of procured products lower, which boosts the competitiveness of procured products (Korkmaz et al., 2012; Qiu & Anadon, 2012). These economies of scale and learning effects induce additional R&D and facility investment incentives for the private sector. That is, the policy impact of PPI to stimulate private innovation activity occurs not only through the direct demand-pull but also through the indirect technology-push channel.

Competitiveness of procured products would expand relevant markets that have come into existence, and may facilitate the market escalation. This market escalation process is accompanied by this "indirect technology-push effects" (through learning effects and economies of scale) and indirect demand-pull effects (through changing the private consumers' behaviors with cost competitiveness of procured products). Marron (2004) points out that the firms under the PPI contracts are found to have expanded production capacities much faster, and obtained higher benefits from economies of scale and learning effects. Empirically, examples of energy-saving technologies utilized in the construction of public buildings in Italy under the PPI scheme suggest that those technologies have experienced approximately 27% cost reduction during the PPI contract period (European Commission, 2012).

The competitiveness and cost advantages of the innovative solutions in PPI-targeted industries result in knock-on effects on other sectors through inter-industrial linkages. Inter-industry effects are realized by the other suppliers working in different vertically related sectors, mainly dependent on the existence of forward and backward linkages

(Blalock & Gertler, 2008; Crespo & Fontoura, 2007; Javorcik, 2004). The higher demand for certain products induced by the PPI leads to increases in demand for required intermediate inputs from other sectors. In this way, the dependences among industries shape the extent to which direct and indirect spillover effects driven by the PPI-relevant policies are generated within the innovation system. It implies that PPI can bring positive spillover effects, and stimulate technology progress and innovation-related activities within the innovation system (Brannlund et al., 2009). These impacts triggered by the PPI can be described as another type of "indirect technology-push effects".

Furthermore, it is required to understand the PPI's impacts on the innovation system from the dynamic views. With the procurement policies, the public sector can incentivize private suppliers to enter into the emerging sector, and shape the market structure in the long-run (OECD, 2011). As Cabral et al. (2006) points out; procurement policies are likely to have innovation impacts via intermediate outcomes such as, competition, industrial structure and network effects. In this regard, PPI can have effects on the intensity of competition among existing suppliers in short-run, while it can bring about long-term effects on the market structure, and competition conditions among future tenders (OFT, 2004). The public sector with considerable purchasing power may sustain a competitive market in the long term, or even help new potential suppliers overcome entry barriers. Promoting more intense competition among suppliers can result in lower prices and better quality of innovative solutions (IISD, 2012; Marron, 2004; van Calster, 2002; Rothwell, 1994). I refer this changes in market structure and promotion of competitive conditions as “indirect demand-pull effects” triggered by PPI.

As noted above, PPI-induced impacts on the innovation system include direct/indirect demand-pull, and indirect technology-push impacts in dynamic process. Those impact channels are summarized in Table 11. It provides us information on stylized facts for PPI-induced changes, and impact channels of PPI. Furthermore, I try to summarize and piece together those impact channels induced by PPI policies into the systemic perspective as depicted by Figure 4. From the innovation system perspective, it is important to specify the variables associated with each actor’s activities (or, decision-making process), and describe the relationships among those variables. Those causal relationships among variables would portray direct and indirect links among the economic (or, innovation-related) variables, and illustrate feedback loops. Furthermore, I mainly utilize two types of variables including stock and flow variables to illustrate the PPI-induced changes from a systemic perspective in the form of the casual loop diagram.

Applying this systemic approach to account for the PPI-induced changes, it is expected to provide generalized and conceptual frameworks to understand the system-wide impacts of PPI, which can be utilized to conduct more systematic assessments of the PPI policies. It can further inform the design and implementation process of future PPI policies with descriptions of the drivers of PPI-induced changes, as well as the dynamics of complex social, technological, and environmental conditions associated with the PPI applications. With this conceptual framework as depicted in Figure 6, policymakers can identify challenges/bottlenecks of system transitions, and implement tailored policy interventions to overcome system failures when they design and evaluate PPI policies in practice.

Table 11. PPI-induced impact channels within an innovation system

Impact channels	Impact mechanisms	Interactions
Direct demand-pull	Undertaking R&D and product innovation, and launching relevant investments	Public users → Private suppliers
Indirect demand-pull	Providing a leadership, an awareness-raising tool, and signaling effects as lead user	Public users → Private users
	Ensuring larger market shares of innovative solutions with the changes of private consumers' purchasing behaviors	Public/private users → Private suppliers
	Shaping the market structure, and affecting the incentives of private suppliers to compete intensively in the long run	Public users → Private suppliers
Indirect technology-push	Delivering products/services with lower prices and better quality through learning effects and economies of scale	Private suppliers → Public/private users
	Promoting knock-on effects/spillover effects on other sectors through inter-industrial linkages	Private suppliers → Other suppliers

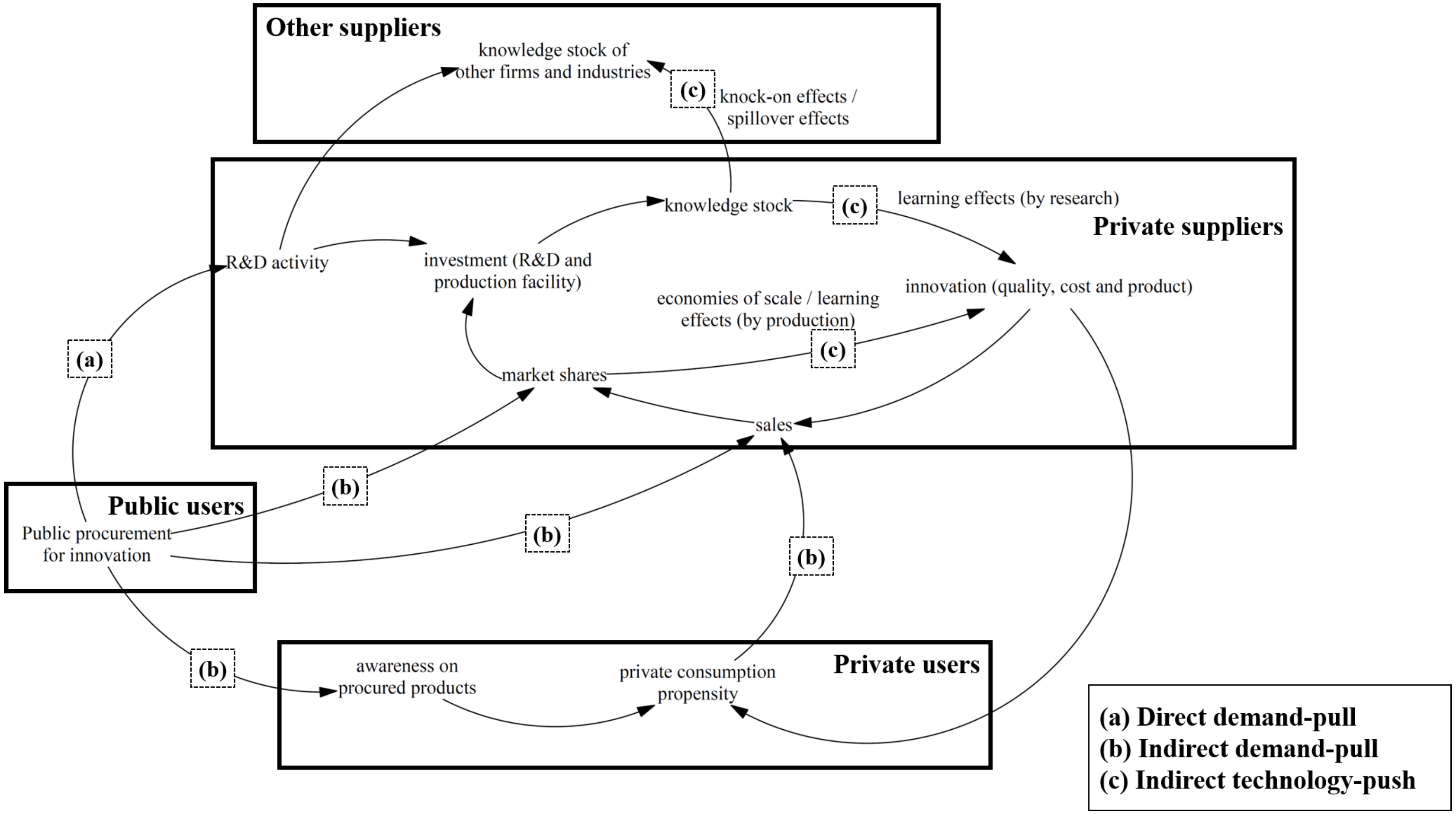

Figure 6. Causal loop diagram of PPI-induced impact channels

3.3 New taxonomies on types of PPI from systemic perspectives

Adopting a systemic perspective to understand the PPI-induced changes in innovation system, in this chapter I am to suggest new taxonomies for types of public procurement for innovation. In developing taxonomies on types of PPI, I assume that PPI-induced changes and impact channels as presented in Figure 6 can be different among industries and countries, in accordance of market and technology development stages relevant to procured products/services. Objectives of the introduction of the PPI can vary depending on the conditions of market formulation, and technological development. As depicted in Figure 6, market formulation stage consists of subsequent stages as follows: initial demand, market creation, market escalation, and market consolidation stages. On the other hand, innovation process in innovation system consists of basic research, R&D, scale-up, and commercialization stages, as illustrated in Figure 6. Based on these conditions in terms of market and technological developments, policymakers can design the PPI policies as an innovation policy instrument to achieve their policy objectives. They can include economic, and social terms, which determine the social factors in the innovation system. These social factors in the innovation system can also affect the impact channels induced by the introduction of PPI.

Accordingly, those factors including market, technological conditions, policy objectives, and social factors shape the interactions among actors in innovation system, which could generate different impact channels induced by PPI. Assuming that those factors can form different types of procurement policies, and different types of PPI can induce different aspects of impact channels, I try to develop new taxonomies on types of PPI. Firstly, a pre-commercial PPI can be defined as the policy interventions to guarantee the initial demand when the product development is not reached the commercialization stage yet. Secondly, a commercializing PPI aims to create and expand the market when there is insufficient private demand, even though the private suppliers have completed the commercialization stage and eventually launched the innovative solutions. Thirdly, a societal PPI refers to the procurement policy which aims to induce the supply and diffusion of innovative products aimed at solving social problems in case where the market has not been developed yet. Competitive PPI is defined as an action to induce incremental innovation through creating a competitive environment in a mature market and technology level. These four types are summarized in Table 12 and following four subsections will provide explanations on those newly defined taxonomies in detail with case examples.

Table 12. Proposed taxonomies on types of PPI

Type	Market formation (Demand articulation)	Technological development (Innovation process)	Degree of inclusion of social purpose
Pre-commercial PPI	Initial demand	Basic research or R&D	No or little
Commercializing PPI	Escalation	Scale-up and commercialization	No or little
Societal PPI	Initial demand/ Market creation	Diffusion and technology standardization	Included
Competitive PPI	Consolidation	Diffusion and technology standardization	Little

3.3.1 Pre-commercial PPI

Pre-commercial PPI can be understood as a policy action that guarantees the initial demand through pre-purchase contracts for technologies, products, or services which have not yet reached the commercialization stage. The policy impact channels of pre-commercial PPI can be categorized into direct demand-pull and indirect demand-pull paths. First, the direct effect of the expansion of the public demand driven by the PPI is to increase investments undertaken by suppliers through reduction of uncertainty. To be specific, technological uncertainty can be resolved through specification of technical characteristics and demand uncertainty is also reduced by the guaranteed initial demand.

Those reduced uncertainties associated with technological and market conditions make the private suppliers to increase both R&D and production facility investments, leading to higher probability of successful product development and increased volumes of products/services provided to the public sector. These impact paths reinforce the direct demand-pull effects of pre-commercial PPI with R1 feedback loop as shown in Figure 7.

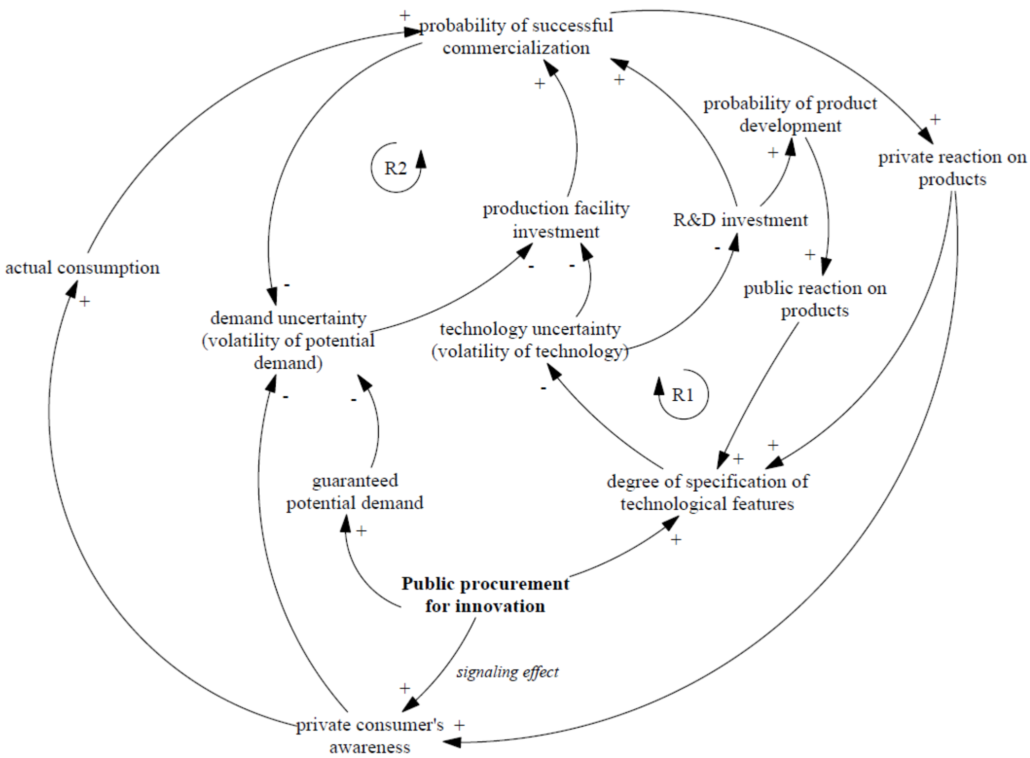

Figure 7. Causal loop diagram for pre-commercial PPI's policy impact channels

On the other hand, the indirect demand-pull effects can be mediated through private consumption. Public proactive purchase on products or services that do not yet exist in the market creates signaling effects on the private consumers. In other words, private consumers can gain awareness of products based on the specification of the public demand, leading to the formation of private demand on the innovative solutions (i.e., products or services). With the formation of the private consumption, gradual improvements on product developments can be made through interaction between suppliers and consumers, which generates reinforced feedback loop (R2 in Figure 7) of indirect demand-pull effects.

One of the renowned examples of pre-commercial PPI is procurement by the TEKES (Teknologian kehittämiskeskus) in Finland. TEKES is specially established institution by Finland government dedicated to procurement for early-staged technology and products. It has implemented dual approaches in promoting emergence of innovative products or solutions; one is direct R&D supports for private suppliers in the early stage of R&D activities, and another is to ensure public demand for products or services produced by firms who are provided with R&D supports. Likewise, TEKES guarantees the initial demand for the products which stems from its R&D supports. Moreover, it attempts to arrange the private consumers to purchase the targeted products preferentially when the private market is formed (Stern et al., 2011). In this regard, it can be understood that those efforts link the existing supply-side innovation policy (R&D support policy) and new demand-side innovation policy (i.e., PPI) in order to foster both technology and product developments and diffusion of innovation results.

3.3.2 Commercializing PPI

Commercializing PPI can be understood as purchasing innovative products or services that have succeeded in product development, but are still struggling to expand the market size due to the insufficient demand. Different from pre-commercial PPI, indirect technology-push effects are centered on the implementation of the commercializing PPI, while the indirect demand-pull effects are also addressed. First, as in the case of the pre-commercial PPI, the public demand in the commercializing PPI also has signaling effects on the private demand. The reduction of demand uncertainty and associated effects of R&D and production facility investments from the expansion of private demand are shown in Figure 8 as a feedback loop reinforced by R1 and R2.

In addition, commercializing PPI has indirect technology-push impact paths through learning effects and economies of scale. As mentioned earlier, the increase in private demand for both public and public demand leads to an increase in investments on production facilities and R&D activities. Among them, the increase in R&D investments increase the intra-firm knowledge stock, leading to expansion of innovation activities with learning by searching effects. Increased knowledge stocks also induce cost reduction and productivity improvement effects through learning by doing mechanisms. Finally, the increase in investments in production facilities leads to the expansion of production volumes, which results in economies of scale with the accumulated production volumes. This productivity enhancement and incremental innovation can create indirect effects on the continuous demand expansion, which is shown in the R3 and R4 feedback loops in Figure 8.

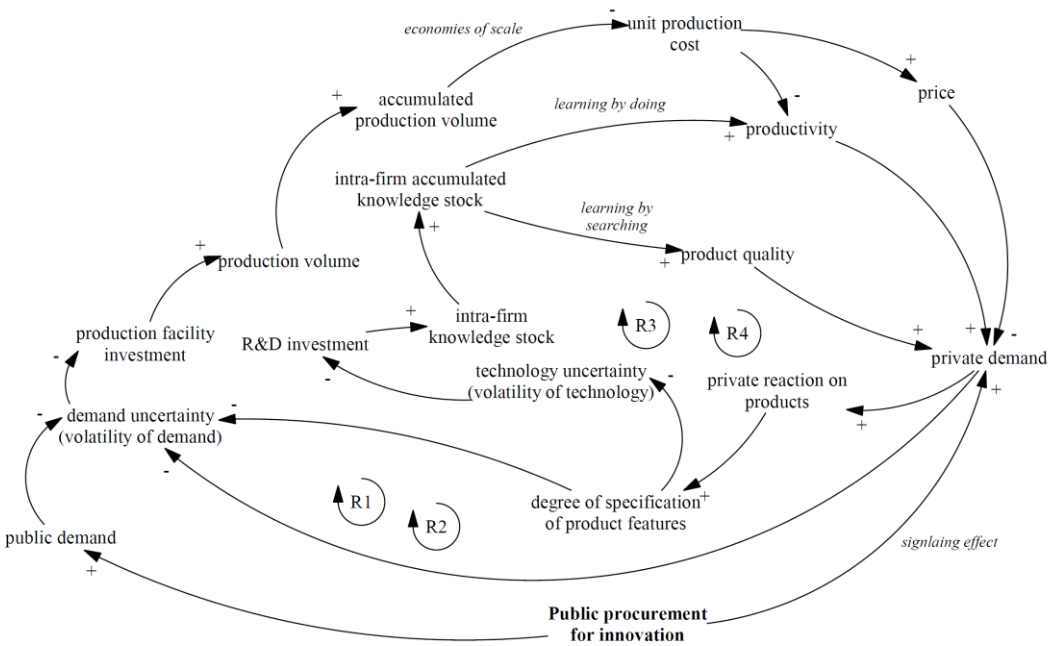

Figure 8. Causal loop diagram of commercializing PPI's policy impact channels

For example, Edquist & Zabala-Iturriagagoitia (2012) have introduced a successful commercializing PPI case of Swedish government in energy-efficient refrigerator. Sweden government has set a policy goal to develop and diffuse energy-efficient refrigerator with low emissions of Freon gas. It made the PPI contracts with private refrigerator manufacturers with the technological specifications. At the time of PPI contract, some Swedish manufacturers have already developed the technology of energy-efficient refrigerator, but did not take action to commercialize it because of the financial burdens. However, PPI contracts made them to put additional investments on commercializing the technology and Swedish government can get energy-efficient refrigerator in short period by them. In the perspective of new framework, this case can be understood as a case of the commercializing PPI.

3.3.3 Societal PPI

Societal PPI refers procurement practices aimed at addressing social problems through the diffusion of innovative products. This form of policy implementation aims to promote diffusion of innovative solutions within the society when it is difficult to expect natural increase of private demand due to the slowdowns in market escalation with fewer consumers who are associated with specific social problems. In this regard, the main rationale of social PPI is to promote the indirect demand-pull effects within the innovation system. In other words, this form of policy intervention should be oriented towards securing the critical mass necessary for market formation and market escalation of innovative products through the increase of awareness of private demand with signaling effects induced by proactive public demand. Although societal PPI generally does not explicitly aim at economic effects, it may have additional economic benefits, such as expanding markets and increasing innovation investment in the process of diffusion of innovative products. The relevant policy impact channels of the societal PPI can be depicted as shown in Figure 9.

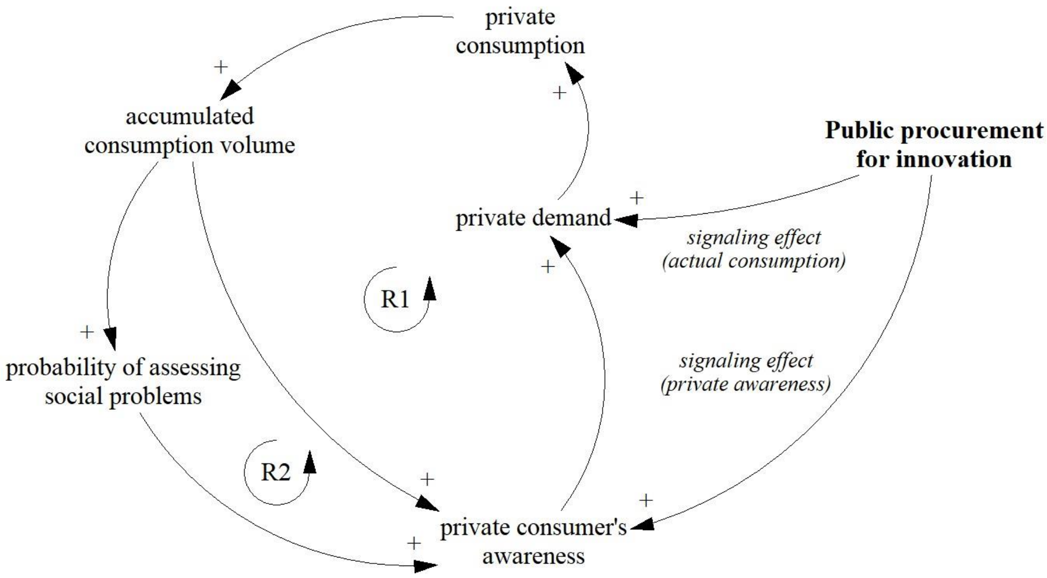

Figure 9. Causal loop diagram of societal PPI's policy impact channels

One of the key areas in which public authority utilizes societal PPI is environment sector. There has been long history of environmental-friendly or sustainable innovation and many products with both innovative and green features have been supported by the government. For example, Korean government has realized the importance of energy-efficient products earlier, because Korea has been heavily relying on imports in obtaining fossil fuel resources. For this reason, Korean government has much interests in the lights with Light-emitting Diode (LED) and set the plan to replace the lights in public road and parking lot from ordinary fluorescent light into LED light. In order to achieve the goal, Korean government utilizes PPI with the technological specification of energy-efficiency in LED suppliers. As a plan, it is targeted to replace all the lights in public road and parking lot into LED light by 2020 (Moon & Jang, 2011). This kind of mandatory procurement for energy-efficient lighting system is also seen in European countries, which they utilize societal PPI to diffuse innovative light into private sector (Valentova et al. 2012). European countries, moreover, have many societal PPI projects to deal with social issue not only related to energy or environment sector but also to aging society, birth and population issue, and the issue for the disabled. For example, the introduction of non-step and bendy bus in public bus transportation system was done for change the movement environment of disabled people into freer way. The technology to lower the bus deck or link the buses is not totally new, but the development and diffusion of technology is thanks to the public demand in public transportation system.

3.3.4 Competitive PPI

Competitive PPI aims to promote competition among product suppliers through contracts of public procurement. This is based on the logic that competition generates the economic benefits induced by the investment activation and product quality improvements within the innovation and economic system. Therefore, unlike the above three types of PPI, competitive PPI can potentially affect multiple suppliers and their relationships, so it is necessary to analyze the policy impact channels from the perspective of the innovation system. The policy impact paths of the competitive PPI can be divided into two categories: 1) intra-industry market (competition) and 2) inter-industry system. Figure 10 describes the causal loop diagram of competitive PPI's policy impact channels in terms of intra-industry competition. Figure 10 consists of three parts, incumbents, newcomers and intra-industry competition. Following the creation of a competitive environment, incumbents which were monopolizing the market through public procurement can experience a sudden drop in market share, which can lead to a temporary decline in investment. On the other hand, competitive PPI has positive policy impacts through indirect technology-push effects. From a longer-term perspective, the implementation of competitive PPI can make the market environment more competitive, resulting in higher R&D and production facility investments to gain higher market share. Increases in investments of R&D and production facilities contribute to productivity enhancements and product quality improvements through promoting economies of scale and learning effects, as I have seen in the case of commercializing PPI. Ultimately, the expansion of the entire market would be achieved with the promotion of competitive conditions within the market, and associated indirect technology-push effects.

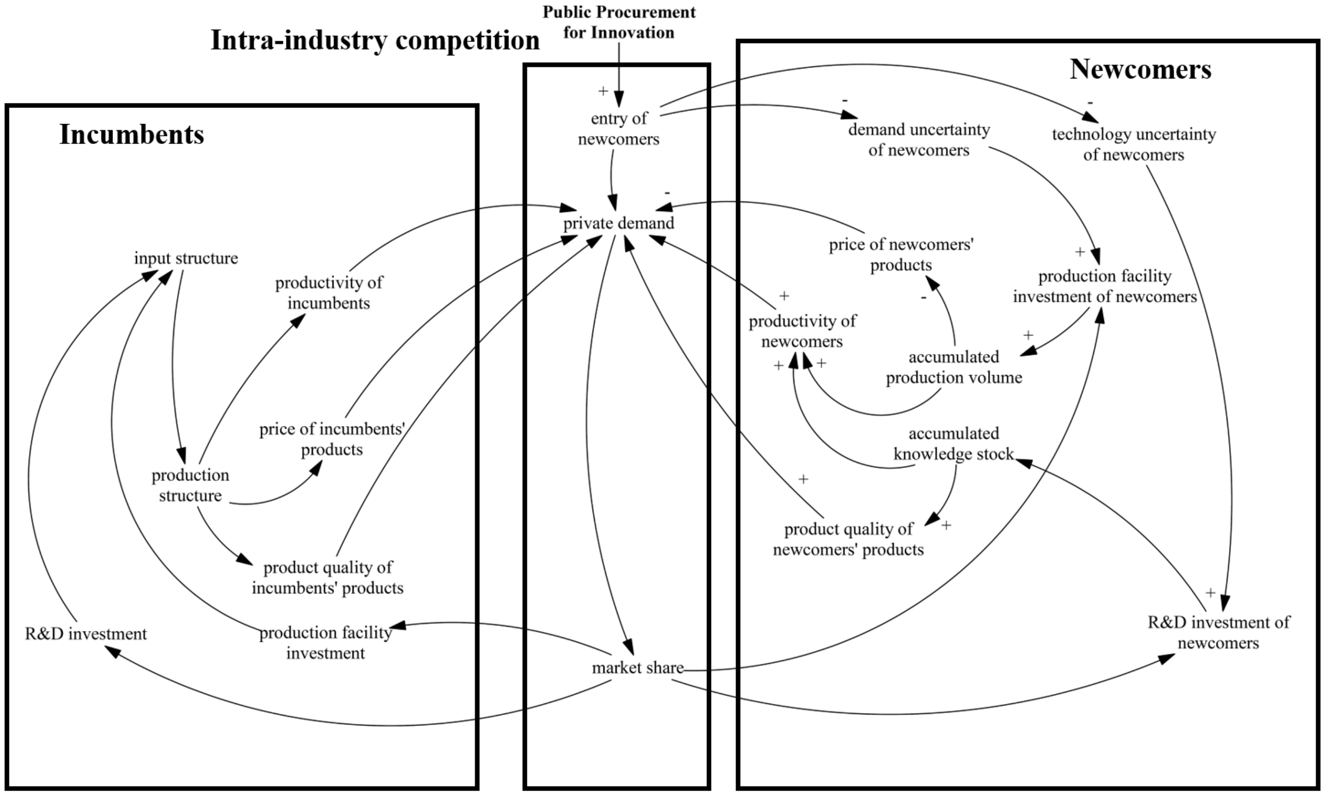

Figure 10. Causal loop diagram of competitive PPI's policy impact channels (intra-industry market)

On the other hand, Figure 11 describes other impact channels of competitive PPI in terms of the inter-industrial relations. First, expansion of investments in R&D and production facilities induce changes in the production structure of each company (i.e., supplier). From a systemic perspective, rather than an individual firm, this change in production structure creates a ripple effects through inter-industrial linkages. In other words, industries that are not subject to the PPI scheme can also experience changes in investment and production activities. This feedback process is depicted in Figure 11 as A1. Moreover, the firms with PPI contract experience spillover effects from knowledge stocks of other firms and industries, which can lead to further innovation. That is, PPI influences on the innovation system of entire economy. R1 feedback loop expresses this reinforcing feedback.

One of the famous examples of competitive PPI was done by US government when it procured new air traffic control system. Federal Aviation Administration (FAA) tried to switch its air traffic control system from radar-based system to satellite-based system and procured the core technology in new satellite-based system, which is Automatic Dependent Surveillance-Broadcast (ADS-B) program. In procuring the technology, US government made the PPI contract with plural number of private developers by performance-based procuring system. This competitive environment helped US government to experience low cost in entire system's life cycle. Moreover, the developers tried to draw final contract of procurement with continuous R&D effort, the technological level of the system got much higher than the first PPI contract's specification (Vonortas, 2015).

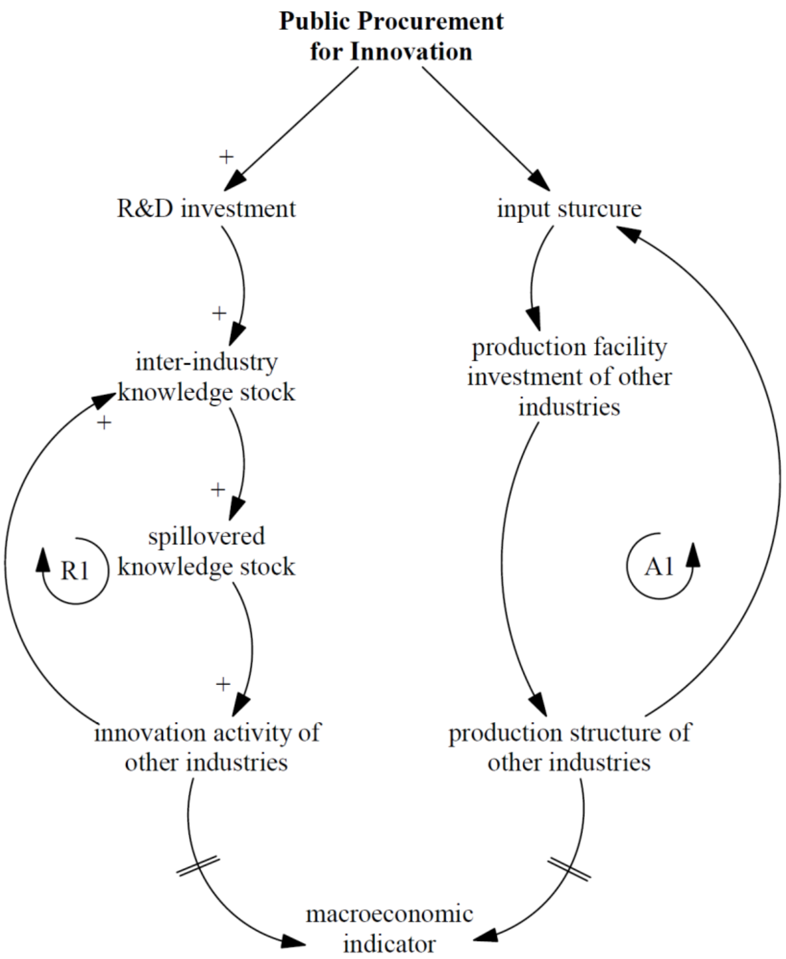

Figure 11. Causal loop diagram of competitive PPI's policy impact channels

(inter-industry system)

3.4 PPI case description: Korean electric vehicle sector

In system perspectives, I drew four different types of PPI and their impact channels related to the agents and variables in the socio-economic innovation system, respectively. It is worthwhile to depict the impact channels and feedback of each PPI type since the diagram suggests not only direct effect of PPI in innovation or diffusion of targeted products or technologies, but also indirect effect related to producers, consumers, social factors, and other economy- and innovation-related variables. This section suggests more detailed narration of policy impact with specific PPI case; Korean EV sector under the taxonomy which I suggested in previous chapter. This case description helps to understand four different PPI types and apply the real policy case to the taxonomy.

As concerns about environment problems increases, recent interest of global economy is green or sustainable development. Sustainable development has a goal to achieve economic and social development in environment-friendly way (Hopwood et al., 2005). From this movement, EV starts to commercialize and diffuse in some countries because it generates much less CO_2 emission than conventional vehicle with fossil fuels. In other words, the environmental effect of using EV is to reduce the air pollution and global warming due to the greenhouse gases. However, each government fosters EV not only for environmental reason. In macro-economy perspective, vehicle or transportation equipment industry has great influences on other industries such as forward and backward industries. Forward industries of EV include electric product manufacturing, metal product manufacturing, and electricity generation services. On the other hand, backward industries such as construction and distribution services are categorized as backward industries of EV. Therefore, development and diffusion of EV has also great production inducement effect to other industries. For these reasons, many countries, especially developed countries, have implemented various policy to develop and enhance EVs and penetrate them into the market. Because PPI can induce both technology development in R&D sector and demand expansion in market, each government tries to utilize PPI into EV development and market escalation.

In this study, policy implementation of PPI for EV in Korea is analyzed in the context of the proposed taxonomy. In other words, EV PPI in Korea can be categorized one of the four different PPI types. In Korean EV sector, there are several car manufacturers which try to develop EV in Korea, but technological level of their flagship model is far behind from the globally renowned models.[3] 2 In other words, technologically, Korean EV industry is not in the stage of commercialization or standardization relative to other global EV makers. For market factor also, enough market demand could not be formulated since technologically competitive products were not introduced in the market.[4] From these points, Korean EV PPI belongs to pre-commercial PPI. Figure 12 depicts the policy impact paths of Korean EV PPI, which reflects the similar impact

[3] For example, Hyundai IONIQ Electric from Hyundai Motors has 124 miles of driving range on a single charge and 28 kWh of battery storage. In contrast, Tesla Model S (P100DL) from Tesla Motors has 315 miles of driving range on a single charge and 100 kWh of battery storage. The driving range of Hyundai IONIQ Electric is not as long as half of that of Tesla Model S (P100DL), and the battery storage is even about quarter.

[4] Korean EV market share was 0.2% in 2016 and the total EV supplying equipment (charging station) stock was 113 per 1 million habitants in 2016.

channels of pre-commercial PPI in Figure 7.

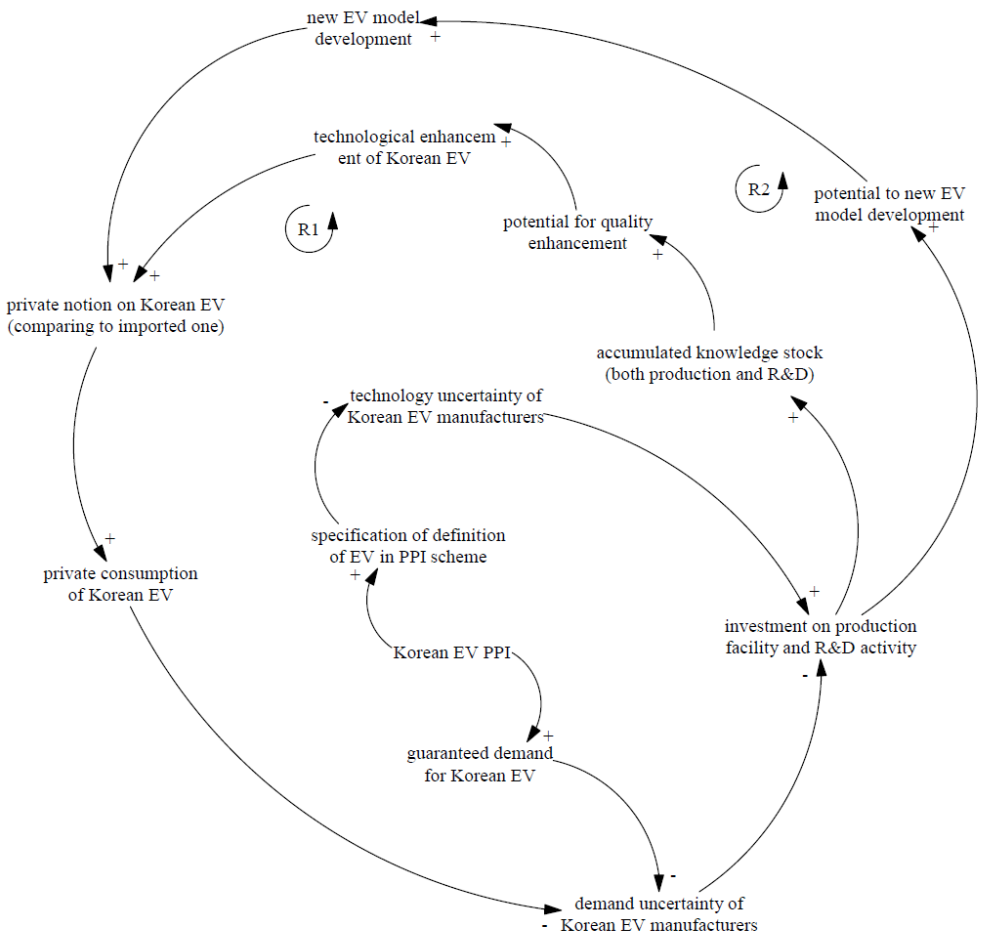

Figure 12. Causal loop diagram of the impact channels of Korean EV PPI

Korean government guides the public institutions to implement PPI of EV by law. Although the legislation involving mandatory EV PPI regulation for the public institutions was amended in 2016, the concept and support program for EV PPI were designated in 2011 (Act on the Promotion of Development and Distribution of

Environment-Friendly Automobiles, 2016). Individual public institutions began to purchase EV in the form of PPI from 2012, and PPS built an integrated EV PPI contract platform in 2016.

The legislation defines an EV as a vehicle whose power source is electric energy from electric source accredited by the government agency. This technological specification by the government has reduced technological uncertainty of Korean EV manufacturers and induced additional investment on innovation and production activities of EV. In 2013, the growth rate of R&D volume of Hyundai Motors from 2012 to 2016 was 70.5%, while that of Volkswagen was 16.4% and that of BMW was 7.8% during the same period (European Commission, 2014; 2017). Compare to the other car manufacturers, it is shown that R&D volume of Hyundai motors was dramatically increased. Not only R&D investment but also production facility investment was also generated by EV PPI in Korea. From 2011 to 2014, the private investment of Korean car manufacturing sector increased about 14.7% comparing to other industries such as semiconductor manufacturing, ship manufacturing, and communication and broadcasting equipment manufacturing which all experienced decreased investment.

This investment expansion leads two positive feedback in Korean EV sector, which depicts in Figure 12 as R1 and R2. R1 positive feedback loops include variables related to technological level of existing Korean EV model. Increased investment made significant improvement of technological specification of Korean EV. The first EV model from Korean car manufacturers, Kia Ray EV from Kia Motors, had only 56 mile of driving range with full single charge and 16.4kWh of battery storage, and its battery did not support full charge from fast-charging station. However, after 5 years, several EV models from Korean manufacturers have longer driving range and larger battery storage with shorter charging time.

On the other hand, R2 positive feedback loops consist of the variables related to new EV model generation. The firms invest on R&D and production facility in order to make new products and commercialize it, ultimately. In 2012, when the PPI for EV was launched in Korea, there was only one model, Kia Ray EV, in the Korean high-speed EV market. However, currently, there are three high-speed EV from the Korean car manufacturers and five EV including plug-in in the market.

There are two main impact channels of pre-commercial PPI, direct demand-pull effect from public purchase and indirect demand-pull effect by stimulating private consumption, as we depicted in section 4.1. Both feedback loops in Figure 12 are manifested by private consumption expansion, ultimately. From the continuous effort on innovation and commercialization of Korean EV manufacturers, the private notion on EV has changed, and, consequently, the private consumption has been increased after EV PPI implemented. In 2011, only 338 new EVs were introduced in the private sector, but 5914 new EVs were supplied in 2016.

In sum, there has been both direct and indirect demand-pull effect from Korean EV PPI since 2011. These two effects show the impact channels of pre-commercial PPI, and they are described in Figure 12 as causal loop diagram. Korean EV manufacturers successfully developed new EV model and enhanced EV technology. From these improvement, private consumption on EV in Korea has been expanded. As described in Figure 12, the relationship between the variables further reinforces their change through the feedback loops. It means that further innovation on new product development and quality improvement for EV is also expected. As the private market expands and the technological level enhances, the effect of EV PPI of Korean public sector can induce the innovation differently, as PPI changes its type into commercializing PPI.

3.5 Sub-conclusion

As growing strength on innovation for economic growth, the role of policy intervention to stimulate private sector innovation becomes much more significant. Although there have been various innovation policy tools implemented over decades, demand-side innovation policy, especially public procurement for innovation, pays significant attention for influencing both technology development and diffusion of innovation simultaneously. However, the studies which tried to investigate policy impact of PPI did not provide the fruitful policy implication because they analyzed the effect of PPI in specific case and context. In other words, they have a limitation for PPI's policy impact assessment in entire economy.

For this reason, this study attempted to analyze the policy effect of PPI from the systemic perspective. Specifically, we confirmed the policy impact paths of PPI through the adaptation of innovation system that covers all economic and social agents related to innovation activities. This study divided the PPI's innovation and economic impact, which has been sporadically addressed in previous literature, into paths of direct demand-pull, indirect demand-pull, and indirect technology-push. Based on the identification of these paths, we could draw the stock-flow diagram to illustrate the PPI's policy impact in schematized way. From this work, this study proposed new taxonomies of types of PPI: pre-commercial PPI, commercializing PPI, societal PPI, and competitive PPI. Each type was categorized based on the degree of market formation, technology maturity, and social purpose inclusion. This study addressed the different policy impact of these four types of PPI through causal loop diagrams. Through causal loop diagrams, it is shown that policy impact paths are different according to different types of PPI classified according to policy environment and purpose. In particular, different feedback loops for each type of PPI have been shown, indicating a difference in the degree of direct demand-pull, indirect demand-pull, and indirect technology-push effects presented earlier part of the study. Finally, this study deeply investigated the PPI case of Korean electric vehicle sector, which can be categorized as pre-commercializing PPI. In case study, it is found that PPI helped Korean EV sector to open the private market and experience technological advances.

This study provided new framework and taxonomy for PPI policy impact evaluation and assessment. Since each PPI policy scheme has multiple policy goals, it is required to understand the policy impact of PPI in system perspective, especially in innovation system perspective. Scattered facts and evidences on PPI's policy impact were interpreted and organized in innovation system framework. This helps to investigate not only ex-post evaluation of PPI cases but also ex-ante impact assessment from micro-level of each economic agents to macro-level of nation-wide economy. Moreover, in policy design and decision-making process, four different PPI types this study suggested provides the guide line for policy goal setting and prediction of potential additional effect on economy and society. This anticipation helps decision-maker, government, to manage the policy implementation process and deal with the change of economy and social environment.

Although these contributions both on PPI research and policy implementation, this study remains some points for future study related to case study. This study selected PPI for electric vehicle in Korea as case for analysis, but it was difficult to reveal the potential policy impact path of EV PPI into economy-wide variables such as GDP, export of Korean EV, and interindustry relations. It was because PPI for EV in Korea has been in the stage of pre-commercial PPI. In future study, as PPI for EV continues, more obvious and direct impact paths to economy-wide variables can be drawn. In addition, there were some paths which do not have specific direction, negative or positive. Although it is also worthwhile to investigate the causal relationship itself between economic acts or indicators, the exact direction can help the decision-makers to forecast the economy-wide impact of PPI much precisely. These points may be dealt with future studies of PPI's economy-wide policy impact assessment.

Chapter 4. Impact of Public Procurement for Innovation on Firm and Sectoral Productivity

4.1 Introduction

Interest has increased in public procurement and in managing and utilizing it in innovation policy framework (Crespi & Guarascio, 2019; Uyarra et al. 2020). This new policy concept is called the PPI, an application of the concept of demand-pull innovation (Piva & Vivarelli, 2009; Schmookler, 1966), in which consumers demand innovation from the public sector. There are two primary reasons for the rise of demand-side innovation policy, especially PPI. First, many scholars and policy makers have raised limitations of supply-side innovation policy, including R&D tax grant and subsidy (Edler & Georghiou, 2007). This is linked to the crowding-out effect of R&D subsidy, as pointed out by many studies including David et al. (2000) and Bong et al. (2020). Second, the efficient use of the government budget (Kundu et al., 2020) is increasingly emphasized. This is because demand-side innovation policy is more effective in promotion and diffusion of innovation, than supply-side policy (Borrás & Edquist, 2013).

Various studies have clarified the impact path of PPI. First, PPI induces investment in R&D and production facility by reducing technology and market uncertainty by guaranteeing potential demand (Edquist & Zabala-Iturriagagoitia, 2012). Additionally, as

PPI involves a large volume of demand, productivity gains can be achieved through economies of scale and learning effects in production (Albano & Nicholas, 2016). Finally, PPI raises awareness of innovative products and stimulates private demand in an innovative way (Bauer et al., 2010; Morrison et al., 2000).

However, empirical research on policy impact of PPI is lacking (Aschhoff & Sofka, 2009; Ghisetti, 2017; Raiteri, 2018), even when broadening to demand-side policy (Costantini et al., 2015; Lee, Shin, and Lee, 2020). Particularly, few studies have attempted to confirm the impact of PPI on productivity enhancement, one of the main policy targets of innovation policy. Chang (2017) was the only one to investigate the relationship between public procurement and productivity, but it was focused on general procurement activity, not PPI.

Innovation policies are linked to overall industrial development and national economic growth. However, before examining these economy-wide impact of innovation policy, it is necessary to analyze its influence on the micro-factors leading to industrial and economic changes. Productivity is an important economic variable that is linked to the behaviors and interactions of actors in the innovation system, such as economies of scale, learning effects, and knowledge spillover. It implies that productivity is an appropriate factor for impact assessment of innovation policy in mirco-level. From the perspective of the innovation system, learning effects and economies of scale are factors that enable the overcoming of system failure, which in turn promotes innovation activities in the private sector (Negro et al., 2012; van Rijnsoever et al., 2015). In particular, in the case of PPI, since it is directly related to the production activity of a product, it is expected that effects such as a decrease in unit cost and improvement of product quality from an increase in production are expected. As discussed earlier in Chapter 3, these impact channels of PPI are significant to investigate the change of the private sector's behavior including production, R&D activity, and even consumption.

Therefore, this study analyzes PPI's policy impact within the innovation policy framework and empirically investigates the impact of PPI on firms' productivity. We use Korean data and distinguish between general public procurement and PPI to identify the impact on total factor productivity (TFP) of PPI, compared to general procurement. Propensity score matching (PSM) methodology using the outcome variables as differentiated ones is employed, which is frequently used for impact assessment of innovation policy to compare and link existing studies. Through empirical analysis on productivity effect of PPI, it is possible to broaden the understanding of the impact paths of PPI in market formation and escalation.

In addition, this study conducts the impact evaluation of PPI on sectoral productivity. It is expected that the ratio of the firm with PPI contract is positively correlated with the overall level of sectoral productivity if PPI has a positive impact on the firm productivity of the beneficiary. Including the confirming the impact paths of PPI related to learning and economies of scale in intra-firm level, it is possible to find inter-firm or inter-industry productivity spillover effect of PPI with the investigation of PPI's impact on sectoral productivity. Moreover, the quantitative results from this analysis can be utilized in the next chapter which may contain the impact of PPI on productivity at the industry level as one of the equations of the CGE model.

4.2 Data and methodology

4.2.1 Procurement of excellent products in Korea

Although the concept of PPI is paid attention from the policy and academic fields recently, many governments have set diffusion and stimulation of innovation as one of the policy purposes of public procurement. Korean government have also implemented procurement of excellent products from 1996, which Public Procurement Service (PPS) designated the products and software with excellent quality and performance or innovative technology (Lee & Jung, 2018). There are several conditions for the designations of excellent products including the certificates, application of patent or utility model, and commercialized ones from national-funded R&D projects (Cho & Lee, 2014). Figure 13 depicts the trend of procurement of excellent products by PPS from 2010 to 2020. It shows that the procurement volume for excellent products has increased steadily.

In light of the four types of PPI classification in Chapter 3, it can be said that the PPI used in this analysis is similar to the type of commercializing PPI. This is because, in the case of procurement of excellent products, the procuring firms should develop the product or service development beyond the prototype in order to get certification of innovative products to be transacted in public procurement market. Products procured in this way generally do not have enough private market due to the incorporation of new technologies, or lack of awareness of the private consumption sector for the product. On the other hand, there are some cases of industries and products are selected as excellent procurement target products with incremental technology improvement, and it can also be similar to competitive PPI. Both commercializing PPI and competitive PPI have an impact paths of enhancing productivity through intra-firm economy of scale and learning effect.

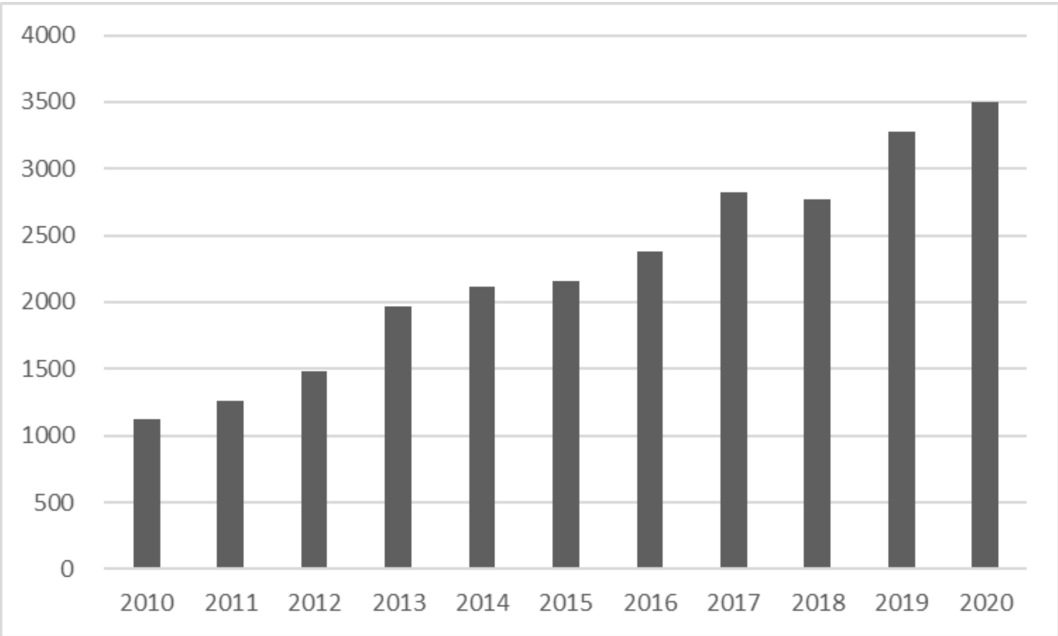

Figure 13. Trend of procurement of excellent products by PPS (unit: billion KRW)

Figure 14 illustrates the impact paths of Korean PPI which this chapter will analyze based on the several causal loops of impact channels descripted in Chapter 3. Both indirect demand-pull and indirect technology-push effects are in center of the causal loop. In order to capture the indirect demand-pull effect of PPI via securing private awareness of the innovative products, the change of managerial performance including revenue or value-added can be analyzed. Moreover, for validating indirect technology-push channels which are generated by economies of scale and learning effect in intra-firm context, it is necessary to analyze whether PPI has an influence on the change of productivity of the beneficiary firms.

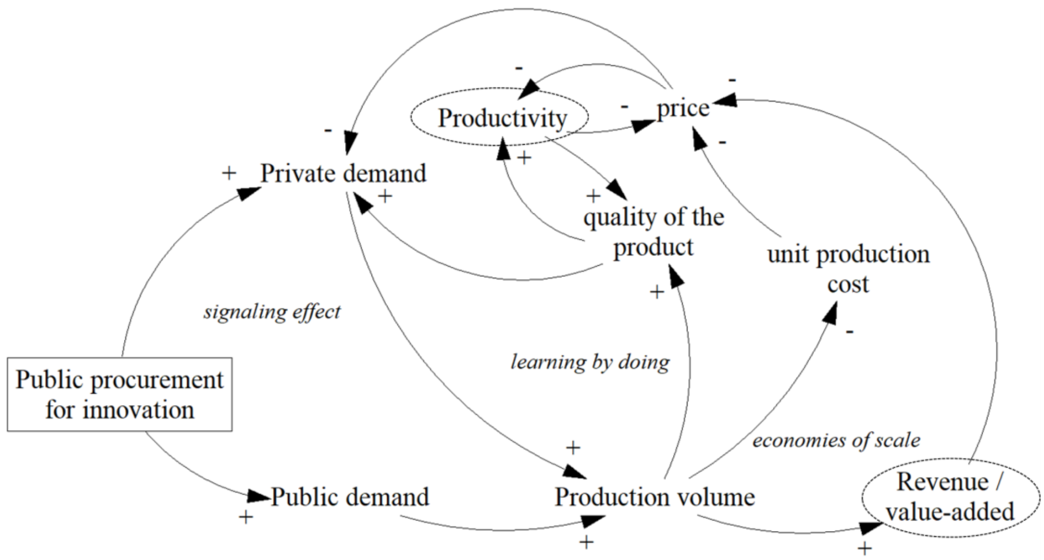

Figure 14. Causal loop diagram for impact channels of PPI in firm-level analysis

In addition to the firm-level analysis of PPI's policy impact on firm productivity, this chapter has another quantitative regression to find out the relationship between the level of PPI participation in a certain industry and sectoral productivity. This regression reflects the possibility of spillover effect and production process alteration from inter-firm and inter-industry relationship. Figure 15 suggests the causal loop diagram for sectoral level analysis of PPI's policy impact on productivity.

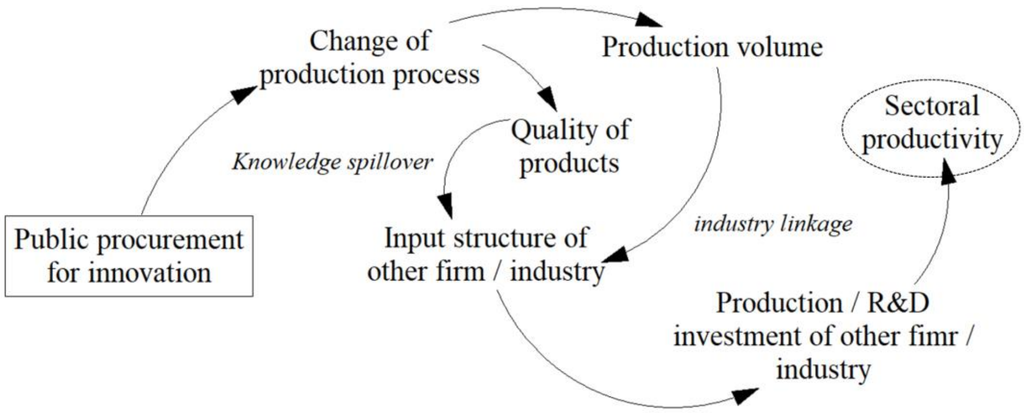

Figure 15. Causal loop diagram for impact channels of PPI in sectoral level analysis

4.2.2 Data

Two main sources of data are used in this study. First, KIS-Value database was used to obtain financial information of Korean firms (Kang et al., 2017). Second, the database from the Public Procurement Service (PPS), a government agency of Korea dealing with public procurement, was employed to check contract information on public procurement. By merging the two datasets, a unique database with the manufacturing firms which did at least one contract of public procurement from 2013 to 2017 was constructed. In public procurement system of Korea, there is a system of procurement of excellent products, which is separately operated from general public procurement; this study considered the former as PPI. Through this setting, it is possible to identify the impact of PPI, differently from general procurement. Figure 16 shows the change of the number of firms with public procurement, including PPI, from 2013 to 2017. Approximately 10% of the firms which procure their products into public institutions are participating in the program of procurement of excellent products.

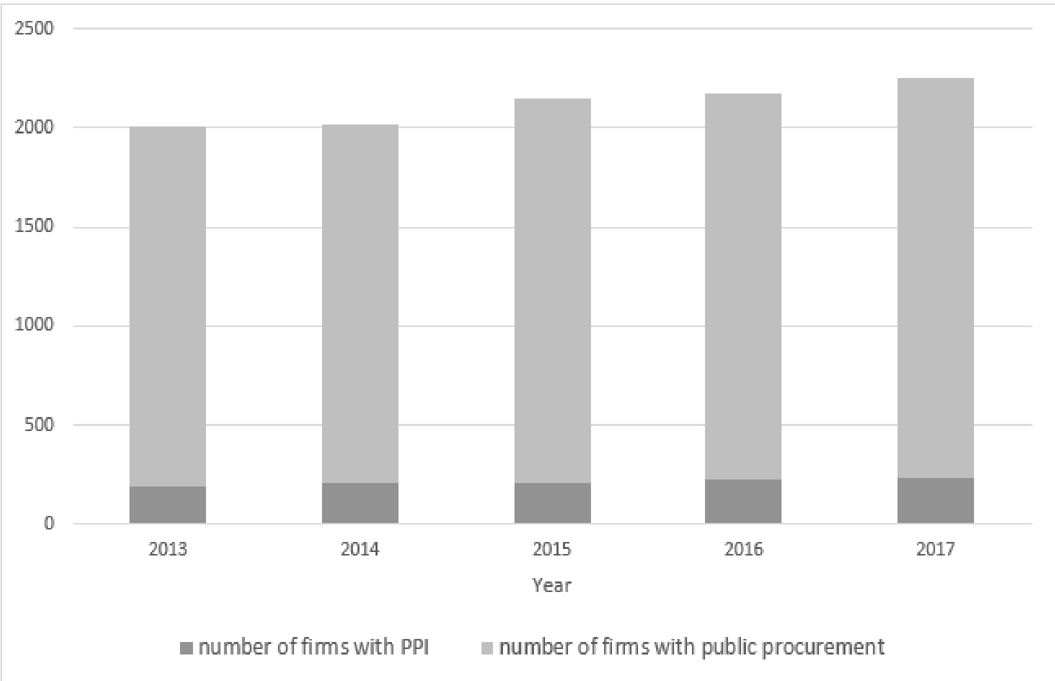

Figure 16. Number of firms with public procurement including PPI

4.2.3 Calculating TFP in firm level

Productivity is the ratio representing the relationship between inputs and outputs used in the production process of a product or service (Baek et al., 2014; Cosmetatos & Eilon, 1983). Input factors may include labor, capital, intermediate goods, and raw materials. Productivity can be largely divided into partial productivity or single factor productivity, which measures productivity by individual inputs, and TFP, which measures productivity by combining inputs (Grossman, 1984). In the case of partial productivity, the concept of average productivity based on the assumption that output is obtained by inputting only one production factor is used, but there is a limitation that it does not reflect the overall efficiency improvement from the interaction between input factors occurring in the production process. (Windle & Dresner, 1992). Therefore, this study analyzes the productivity effect centering on TFP, which can comprehensively check various changes in the production process caused by policy input called PPI.

In economics, TFP is described as a residual between the change in output and the contribution of inputs and is used to account for the impact of technology development in the production process (Felipe, 1999). At the national and industrial level, TFP is generally measured through growth accounting, and related methodologies have been developed through various studies including Aghion & Howitt (2007), Denison (1972; 1993), Griliches (1973) and Klenow & Li (2021). On the other hand, since the calculation of TFP in the national or industry level does not take into account changes in productivity of individual companies (Baek, 2015), in this study, TFP at the firm level is calculated in the following manner.

TFP in the firm level was calculated by merging various financial information. To compare TFP between the firms well, this study utilizes the method of Good et al. (1997) and Aw et al. (2001) which calculated TFP compared to the hypothetical firms which indicates industry average of reference year. The method called chained multilateral index number approach and the graphical logic follows as Figure 17.

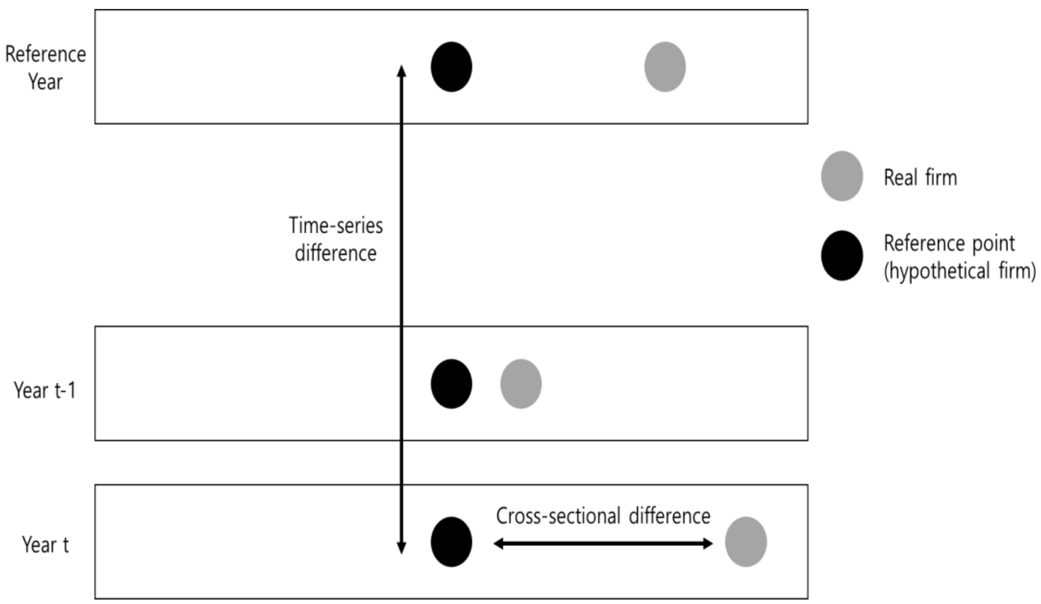

Figure 17. Graphical explanation of chained multilateral index number approach (source: Baek et al., 2014)

Equation (4-1) shows the calculation process of TFP at the firm level. $Y_{i,t}$ is total output of firm i at time t ; $X_{f,i,t}$ is expenditure on production factor f of firm i at time t; and $S_{f,i,t}$ is a share of expenditure on production factor f to total revenue of firm i at time t. Variables with upper bar indicated the industry average. All variables are used as logarithms.

$$\ln TFP_{i,t} = (\ln Y_{i,t} - \overline{\ln Y_t}) - 1/2(\sum_f (S_{f,i,t} + \overline{S}_{f,t})(\ln X_{f,i,t} - \overline{\ln X}_{f,t}) + \sum_s(\overline{\ln Y}_s - \overline{\ln Y}_{s-1}) - \sum_s\sum_f 1/2(\overline{S}_{f,s}+\overline{S}_{f,s-1})(\overline{\ln X}_{i,s} - \overline{\ln X}_{i,s-1}) \quad \text{Eq. (4-1)}$$

The firm-level accounting data is from KIS-Value. Total output of the firm is utilized the data of total revenue. For production factor, this study includes capital, labor, and intermediate goods. Capital input is calculated by the amount of fixed capital minus the amount of land, building, and constructed things. Labor input accounts all expenses to the employees including salary, incentives, and employee benefits. The expenditure for intermediate goods calculated by the sum of sales cost and selling and administrative expenses minus the expenditure on labor, capital depreciation, and R&D. The industry-level data is utilized the results of Financial Statement Analysis conducted by Bank of Korea. The reference year was set as 2011.

4.2.4 Methodology

Dependent variables include the financial and productivity aspects of the firm, which can be found in the Cobb-Douglas production function. Thus, four dependent variables were analysed: value-added, TFP, labour input, and capital input. We examined the impact of PPI on TFP. Labour input was analysed as the logarithm of the number of employees and capital input as the logarithm of the amount of fixed asset.

In this study, the 'treated' firm refers to it having been contracted for PPI. In order to compare the impact of PPI on the firm's productivity and innovation activity with that with general public procurement, this study set the control group as the firms which contracted at least one contract of general public procurement. This means that the firms without any kinds of public procurement contract are excluded from the analysis. In addition, only the small or medium size enterprises (SMEs) in manufacturing are included in the data set. The total number of available observations is 8,879 from 2013 to 2017.

This study utilizes PSM to assess the impact of PPI on productivity and innovation activity of the beneficiary firms. PSM is widely used for innovation impact assessment by comparing the outcome of the firms with policy, or treated firms, and that of the firms without policy, or control firms (David et al., 2000; Kim et al., 2015). In order to investigate the policy impact by PSM, it is vital to have following assumptions. First one is conditional independence assumption (CIA), which is participation of the policy and the outcome is independent conditional on observable characteristics (Lechner, 1999; Caliendo & Tübbicke, 2020). From CIA, we can interpret counterfactual results of the treated firms when they did not participate in the policy as the actual results of the control firms. Another assumption is common support condition which is the firms with same observable characteristics have a positive probability of benefiting policy or not (Heckman et al., 1999; Wu et al., 2010). By this assumption, the matching quality between the treated firms and control firms gets higher and the validity of the impact assessment results is secured.

In PSM methodology, propensity score represents the conditional probability of being treated and reflects the characteristics of each firm (Rosenbaum & Rubin, 1983). This study sets the factors which affect whether the firm contracted PPI or not and calculates the score through probit regression. Specifically, the factors include total asset, R&D investment, total capital, education and job training expenses, TFP, number of employees, fixed asset, and dummy variables to control year and industry. This study employs the one-period lagged values for the covariates. Specifically, lagged variable of TFP is included to eliminate the selection bias of the policy. Table 13 describes the result of probit regression to calculate propensity score.

We applied kernel matching method for linking treated and untreated groups (Dalgıç & Fazlıoğlu, 2020). To check the matching quality, the kernel density distribution of the treated and untreated group was compared. As described in Figure 18, the inequality in the means of covariates between two groups decreased after matching. Table 14 which depicts the characteristics of the treated and untreated group before and after matching also reveals it.

Table 13. Probit estimation for propensity score calculation

	dy/dx	
	coefficient	Standard deviation
ln(total asset)	-0.056	0.074
ln(R&D investment)	0.021***	0.002
ln(total capital)	0.135***	0.039
ln(education and job training expenses)	0.023***	0.005
ln(TFP)	0.003	0.040
ln(number of employees)	-0.160***	0.042
ln(fixed asset)	0.033*	0.018
Overall model significance	LR $chi^2(12) = 371.60$***	
Wald test – year dummy	$chi^2(4) = 1.89$	
Wald test – industry dummy	$chi^2(3) = 210,48$***	
Number of observations	5,697	

Note: * indicates significant level 10%. ** indicates significant level 5%. *** indicates significant level 1%.

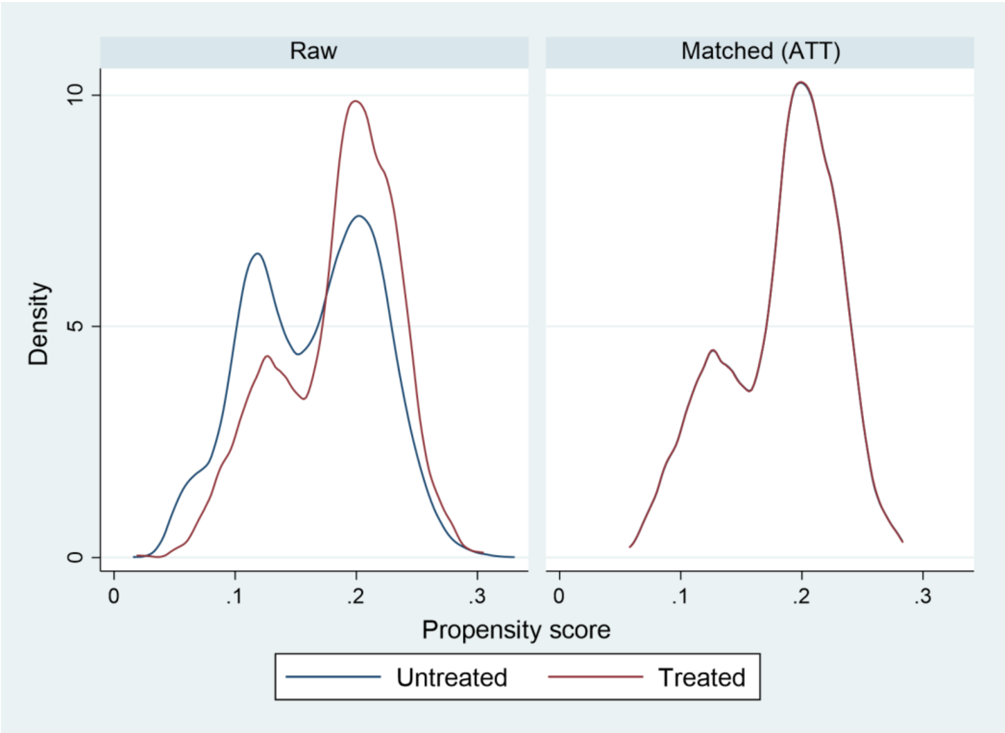

Figure 18. Kernel density distribution of treated and untreated groups before and after matching

In order to consider the selection bias and the influence of unobservable characteristics, this study employs the outcome variables as differentiated ones. The estimator for average treatment effect for the treated (ATT) is as equation (4-2). ATT is statistically tested by t-test, which compares the average outcome variable between treated groups and control groups of only matched samples.

$$\Delta ATT = E[Y_{i,t+k}(1) - Y_{i,t}(0) \mid D_{i,t} = 1] - E[Y_{i,t+k}(1) - Y_{i,t}(0) \mid D_{i,t} = 0] \ (k = 1,2,3) \quad \cdots\cdots \text{Eq. (4-2)}$$

Table 14. Comparison of treated and untreated group before and after matching

	Before matching			After matching		
	Mean of the treated group	Mean of the untreated group	t-statistics for the mean differences	Mean of the treated group	Mean of the untreated group	t-statistics for the mean differences
ln(total asset)	22.682	23.323	4.179	23.684	23.694	-0.260
ln(R&D investment)	15.660	11.382	13.423	15.253	14.247	2.608
ln(total capital)	22.865	22.462	4.615	22.842	22.824	0.377
ln(education and job training expenses)	13.851	12.662	6.550	13.884	13.607	1.456
ln(TFP)	0.369	0.271	0.535	0.040	0.057	-0.550
ln(number of employees)	3.738	3.502	4.576	3.760	3.740	0.343
ln(fixed asset)	22.802	22.334	5.298	22.826	22.881	1.238
Number of observations	1,043	7,836		706	2,108	

For the analysis of the impact of PPI on sectoral productivity, this study used generalized least squares (GLS) regression. The dependent variable is the average TFP level of the firm in a certain industry with the weight of revenue of each firm (TFP). In order to capture the impact of PPI, only the firms contracted either general public procurement or PPI are included for the calculation of the average TFP level. The independent variable is the ratio of the number of the firms with PPI contract to that with public procurement contract with the weight of revenue of each firm (RPPI). The regression equation is as equation (4-3). i denotes the industry and t denotes the year which is from 2013 to 2018. In order to reflect potential time lag between PPI contract and productivity, this study used 1 year lagged variable for the ratio of PPI firms.

$$\ln(TFP_{i,t}) = \beta_0 + \beta_1 RPPI_{i,t-1} + \varepsilon_{i,t} \quad \cdots\cdots\cdots \text{Eq. (4-3)}$$

4.3 Empirical results

4.3.1 Impact of PPI on firm productivity

Table 15 shows the results of analysing the impact of PPI on value-added, productivity, labour input, and capital input using PSM methodology. By considering the change of the outcome variables up to three years after the firms did PPI or general procurement, this study tries to check the dynamic change of policy impact with signalling and economics of scale effect of PPI. Kernel matching method was used to automatically calculate bandwidth following the methodology similar with Huber et al. (2013; 2015).[5] Additionally, 1:5 nearest neighbour matching (NNM) with 0.01 caliper was performed as robustness check.

As Table 15 suggests, firms with PPI show a higher growth rate of value-added by approximately 7.6% compared to the general procurement firms after 1 year of procurement contract. When dividing this into TFP, labour input, and capital input, PPI does not lead to significant changes in labour and capital input; however, a significant positive relationship was found between PPI and TFP. Specifically, the firms with PPI experiences approximately 4.5% higher TFP change rate than those with general procurement after 2 years of the contract. The estimated value for increase of TFP and value-added is statistically significant at 10% level. In sum, the firms which did a PPI contract has a higher value-added increase first and generated larger TFP enhancement later, compared to those without PPI. Table 15 also shows that the trend of the results is maintained even in the NNM method.

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[5] This study uses kmatch command in STATA and the command uses an algorithm of pair-matching similar with Huber et al. (2013; 2015) by setting the bandwidth to 1.5 times the 90% quantile of the distribution in pair matching with replacement.

Table 15. The policy impact of PPI on the firms' value-added, productivity, and factor inputs

	ΔlnY			ΔlnA			ΔlnL			ΔlnK		
	t+1 - t	t+2 - t	t+3 - t	t+1 - t	t+2 - t	t+3 - t	t+1 - t	t+2 - t	t+3 - t	t+1 - t	t+2 - t	t+3 - t
Kernel matching												
Average treatment effect of the treated	0.076*	0.069	-0.029	0.104	0.045*	0.008	0.034	-0.029	0.007	-0.014	0.049	0.041
Standard deviation	0.045	0.069	0.071	0.085	0.024	0.020	0.056	0.064	0.077	0.033	0.050	0.107
Nearest neighbor matching (1:5)												
Average treatment effect of the treated	0.079*	0.062	0.048	0.037*	0.028*	0.004	0.016	-0.069	-0.002	-0.006	0.018	0.027
Standard deviation	0.045	0.055	0.056	0.020	0.015	0.018	0.052	0.061	0.074	0.036	0.035	0.103

Note: * indicates significant level 10%. ** indicates significant level 5%. *** indicates significant level 1%.

The productivity of the firms with PPI can be enhanced by economies of scale and learning effect which were mentioned in Chapter 3. Specifically, in order to meet the demand from public sector, the firms with PPI should increase their production. Through expansion of production volume, they can reduce the unit cost of production, which is economies of scale. Additionally, the firms can accumulate production experience in doing PPI and, ultimately, improve quality of the product by learning effect.

The empirical results validate these impact paths between PPI and productivity. The firms with PPI first experience the increase of value-added which is closely related to the production volume and managerial performance. After that, their level of productivity enhances due to economies of scale and learning effect.

4.3.2 Impact of PPI on sectoral productivity

Next, this study estimates the impact of PPI on sectoral productivity. Before the regression, Breusch-Pagan test is conducted to find out the appropriability of panel model. The result shows panel regression is applicable for this econometric setting.

The regression result is in Table 16. The regression was done only for the industry which have at least 1 firm with PPI contract at the certain year. The result shows that there is a positive relationship between the ratio of the number of firms with PPI to that with total public procurement and sectoral productivity calculated by the average TFP of the firms with public procurement. Specifically, 1% increase of the ratio of the number of firms with PPI leads 0.34% of increase of sectoral productivity. This estimation confirms the above results which PPI generates the higher growth rate of TFP in the firm level.

The result implies that the overall productivity of the industry can be enhanced when the number of the firms participating in PPI program is increased in the industry. It can be inferred from the result that PPI can generate productivity enhancement not only from the learning and economies of scale in the firm but also from productivity spillover taking place in inter-firm or inter-industry level.

Table 16. The policy impact of PPI on sectoral productivity

	Coefficient	Standard deviation	P-value
RPPI	0.340	0.192	0.077
Constant	-0.199	0.041	0.000
Log likelihood		-49.405	
Number of observations		109	

4.4 Sub-conclusion

As a demand-side innovation policy, PPI affects not only private innovation activities but also production activities necessary for the diffusion of innovation. This chapter focuses on this and analyzes the productivity improvement effect of PPI at the firm and industry level from the viewpoint of additional output. The results show that firms with PPI had a larger increase in productivity growth in the following year of PPI contract, than those with general procurement. This led to the difference in the change rate of value-added between them. Thus, it was empirically confirmed that the purchase activity of government for innovative products positively affects the improvement of productivity of the contracted firms. Analysis of the industry level also confirmed a positive and significant correlation between PPI and productivity improvement as above.

The results imply that PPI is a useful measure for the enhancement of productivity. Despite the significance of productivity in innovation policy goals, it is meaningful to address the effectiveness of PPI in productivity enhancement. This study also grasped the impact of PPI on productivity along with value-added and production factor inputs, to consider PPI's impact path on production process comprehensively. From the results, it is possible to check the sequential effect from value-added to TFP which includes economies of scale and learning effect thanks to PPI. PPI is expected to improve the firms' productivity and to broaden academic studies to evaluate the impact of PPI on productivity and production activity regarding the impact paths of economies of scale and learning effects. In addition, through the analysis of the industry level, it was confirmed that the change in production activity of the PPI performing firms have influences on the innovation and production activities of other companies and industries through the inter-firm and inter-industry relationship. Specifically, high TFP levels were observed in industries with a high proportion of PPI performing firms, suggesting that PPI has an effect on the generation of spillover effects at the industry level.

This study has the following implications. In academic perspective, this is the first attempt to empirically analyze the productivity enhancement effect of PPI. Until now, most of the empirical studies on the impact of public procurement have targeted general one, but this study quantitatively presented the effect of PPI which explicitly reflects the factor related to innovation in procuring conditions. Particularly, the fact that the impact of PPI is presented through comparison with general public procurement is also a major academic contribution. In addition, considering that there are few studies which tried to investigate the PPI's impact on productivity, the empirical analysis on the productivity effect of PPI can be said to be another academic improvement.

From a policy point of view, the results of this study provide quantitative evidence on the effectiveness of PPI and suggest that PPI should be implemented with deep consideration of the various policy goal including technological progress, employment expansion, and productivity enhancement. It was revealed that PPI had no statistically significant effect on employment expansion or increase of production facility investment. This suggests that PPI cannot be implemented in order to achieve various policy purposes in total, implies that various policy measures including R&D subsidies, tax grants, and regulations need to be implemented in the form of a policy mix together with PPI.

This reflects the need to analyze the policy impact of the innovation policy mix including PPI as a follow-up work. In particular, as mentioned above, as various factors in addition to technology development through R&D affect the improvement of the productivity, it can be said that investigating the input, output, and behavioral additionality of the beneficiary firms is important for impact assessment of innovation policy. In addition, analyzing the industrial development and macroeconomic impacts of the PPI could be another research topic. In this case, in the analysis of the economy-wide impact of PPI through the CGE model in Chapter 5, the quantitative results of this chapter are reflected in equations and scenarios to present.

Chapter 5. Economy-wide Impact Assessment of Public Procurement for Innovation: A Computable General Equilibrium Approach

5.1 Introduction

PPI is used in various countries as one of the main measures of demand-side innovation policy. In the case of the European Union (EU), through the Lead Market Initiative (LMI) from 2006, a policy emphasis on the use of public demand to promote innovation was started (Aho et al., 2006; Edler et al., 2009). It is included as an essential policy element in various EU policy initiatives related to innovation such as Horizon 2020 (Mwesiumo et al., 2021). United States has long history of utilizing public demand in innovation policy. Specifically, it has been leading the diffusion of innovative products or services from public demand, mainly in the defense field (Williams, 2012), and Small Business Innovation Research (SBIR) project which public authority guarantees the procurement of the results of R&D in multi-ministerial framework has motivated the private innovation activities in various fields including public health, energy, and transportation (Edler & Georghiou, 2007). Korea also has public R&D support program including content related to the demand of the results of projects, and from 2020, the “Innovation Market” has been operated to spread the public procurement of innovative products.

However, despite the increasing policy interest in PPI, few studies have attempted to examine the nation-wide economic impact of PPI. Most of the studies that investigated the PPI's policy impact have focused on the changes in innovation-related outcomes including R&D investment and product development at the firm-level. These studies have academic importance in that they examine the creation and diffusion of innovation in the private sector, which is the direct policy goal of innovation policy including PPI. On the other hand, they fail to look at the changes in economic activities such as consumption, investment, and transaction with other countries induced by the evolution of corporate activities since they take partial equilibrium perspective in their analysis.

Considering that the ultimate purpose of the innovation policy is the development of the national economy through the expansion of industrial activities, policy impact assessment of PPI in macro-economic or economy-wide perspective is important to draw policy and academic implication. Particularly, as discussed in Chapter 3, since PPI affects the interactions between various actors within the innovation system, simply analyzing the relationship between policy inputs and outcomes in partial equilibrium perspective can underestimate or overestimate the policy impact of PPI. Therefore, in this study, the economy-wide impact of PPI is analyzed by adopting the general equilibrium perspective to consider various impact paths of PPI.

This study investigates the economy-wide impact of PPI using the Computable General Equilibrium (CGE) model. The CGE model expresses various economic activities such as intermediate goods transaction, private and government consumption, investment, and transactions with other countries in the form of a system of equations, allowing the policy impact to be quantitatively assessed from the perspective of general equilibrium. As discussed in Chapter 2, the CGE model is used to investigate the impact of various policies, and several studies have been conducted on innovation policy impact assessment. Considering that PPI has various impact paths, it is expected that the economy-wide impact of PPI can be observed comprehensively by reflecting the effects of PPI in the CGE model as equations.

Specifically, this study considers the following two impact paths to examine the economy-wide impact of PPI. The influence path includes one positive path and one negative path, which can be expressed as a simplified description as shown in Figure 19. The first path (P1) expresses the effect of productivity improvement by PPI. Productivity is improved through learning effects from in-house R&D investments or spillover effects from external R&D investments, but on the other hand, economies of scale effect through expansion of production volume is also an important factor of productivity improvement. Various case studies have shown that PPI guarantees production volume above a certain level through the reduction of demand uncertainty faced by private firms, which leads to productivity enhancement (Cabral et al., 2006; Flolio et al., 2018; Hollanders & Arundel, 2007). In the empirical analysis in Chapter 4, it was confirmed that productivity improvement was experienced when the firms received PPI contract. Moreover, the productivity enhancement effect of PPI was revealed also in industry-level econometric analysis. This productivity improvement leads to additional production and a positive feedback loop is formed between them.

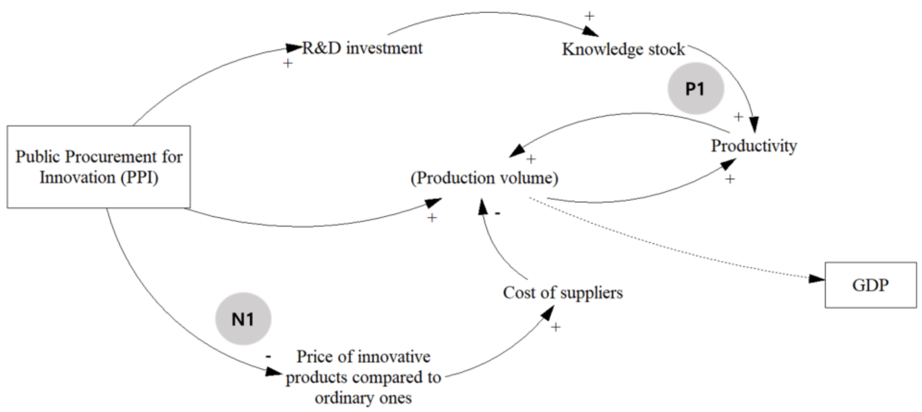

Figure 19. Simplified impact paths of PPI in CGE model

In the meantime, most of the empirical and qualitative studies have been concentrated to analyze the positive impact of PPI to confirm its potential as an innovation policy. However, as every policy has its advantages and drawbacks, it is necessary to take into account potential negative impact of PPI when its economy-wide impact is assessed in addition to the positive influence.

The negative impact of PPI is related to the price of procured products and production cost of private suppliers. In general, innovative products have a higher initial price than ordinary products with similar characteristics and objectives (Chen et al., 2007; Frattini et al., 2014). This implies that PPI is more likely to pay a higher price compared to general products which can be used for achieving same purpose and government might pay different price between PPI and ordinary procurement (Czarnitzki et al., 2018; Gokhberg

& Kuznetsova, 2011; OECD, 2017b). However, it is difficult to pay a different price between them when public institutions try to implement PPI in the policy field in practice. This is because not only price discrimination would hurt one of the important principles of public procurement, efficiency (Potts, 2009) but also public authority feel difficulties in setting an appropriate price for innovative products. Therefore, government generally follows the pricing strategy and procedure for PPI contract similar with the ordinary procurement. This means that the public sector would fail to properly evaluate the innovation of the private sector. As a result, it can be expected that this will hinder innovation motivation and hinder the commercialization process since private suppliers felt higher cost for production when they procure their products into PPI than the case of ordinary procurement. These negative effects are depicted in N1 of Figure 19.

This study is expected to provide academic and policy implications related to the economy-wide impact of PPI through reflecting positive and negative impact paths described above. In particular, by considering the negative effects of PPI that may exist, various policy considerations related to decision-making and implementation of PPI can be identified beyond the simple presentation of potential positive effects of PPI. With regard to innovation policy, securing policy evidence through ex ant policy evaluation is becoming increasingly important (Ahrweiler, 2017; Dosso et al., 2018; Ma et al., 2020), and the result of quantitative policy impact assessment from the perspective of general equilibrium can be contributed to the policy making process of the innovation policy including PPI.

5.2 Methodology: Computable general equilibrium modelling

5.2.1 Methodological background

Many studies have been done at the micro level to examine the effects of various economic policies. However, it is becoming more important to understand the economy-wide impact of the policies due to the expansion of interactions between actors and countries within a country and the increase in uncertainty in the domestic and international economic environment. Accordingly, various macroeconomic models have emerged to describe the real economy based on economic theory and efficiently analyze policy impact based on the theory for ex-ante policy evaluation (Meng & Siriwardana, 2017; Pollitt et al., 2019). These models can be broadly classified into a macroeconomic equilibrium model that focuses on economic fluctuations and a general equilibrium model that attempts an empirical model of Walras's general equilibrium theory. (Lee et al., 2007).

The macroeconomic equilibrium model aims to check the changes in policy variables on economic indicators including price and growth rate based on macroeconomic theory (Lee et al., 2007). The traditional model built in the early days is suitable for the analysis of short-term projections based on the correlation of time series data, but there are limitations which were lack of microeconomic basis and adaptive expectation assumptions (Moon et al., 2008). Since Lucas critique (Lucas, 1976) pointed out the validity of analysis based on a static model because the expectations of economic agents are changed by policy implementation, rapid improvement of the model has been made by supplementing the microeconomic basis, and recently, the dynamic stochastic general equilibrium (DSGE) model has been developed (Hurtado, 2014; Lee, 2013). DSGE model observes economic changes over time in response to external shocks, assuming the optimization process of rational economic agents and the simultaneous equilibrium of the market. The model has the advantage of considering uncertainty and business fluctuations and minimizing arbitrary variable setting. However, when the model is expanded, it is difficult to derive an optimal solution, which may limit the number of equations and variables of the model (Cooley, 1995). Accordingly, DSGE model mainly focuses on short-term economic changes and is widely used in the analysis of fiscal and monetary policies (Aursland et al., 2020; Bhattarai & Trzeciakiewicz, 2017; Hohberger et al., 2020; Rubio, 2020).

The general equilibrium model assumes the stability of the economic system based on the input coefficient, or technical coefficient, of the input-output table. Initially, it started with static analysis, but it has developed into industrial and macroeconomic models along with the empirical construction of Walras's general equilibrium theory (Lee et al., 2007). CGE model logically describes the behavior of economic agents and can quantitatively represent changes in macroeconomic variables by considering the inter-industry relationship, so it is being used for analysis through various policy scenario experiments (Bosetti et al., 2006; Burfisher, 2017; Dwyer et al., 2006). The CGE model has the advantage of allowing the interaction of the endogenous sector because it can model most of the economic activity (Stenberg & Siriwardana, 2005), but has the disadvantage that it is difficult to statistically verify the results (Cho & Lee, 2018).

Comparing the CGE model and the DSGE model, which have been widely used as macroeconomic models recently, although DSGE model confirms a relatively short-term policy effect based on economic fluctuations, CGE model can observe long-term policy impact under the condition of long-term economic stability (Shoven & Whalley, 1972; Kehoe et al., 1995). In addition, DSGE model may have large differences in results depending on the model design method such as parameter values and the structure of equations (Cogley & Yagihashi, 2010), but CGE model can secure the consistency of the results regardless of the parameter setting since it utilizes real economic data including input-output table, tax statistics, and national accounts (Park & Kwon, 2018).

This study uses CGE model suitable for long-term policy impact analysis to assess the impact of PPI, an innovative policy tool that can be used continuously. Chan & Anadon (2016) pointed out that the CGE model is a suitable model for related analysis when R&D is considered, and Hong et al. (2014) showed that the CGE model including R&D describes the Korean economy well. In addition, as can be seen from the policy effect path of PPI presented in Chapter 3, to investigate the policy impact of PPI more precisely, it is necessary to consider the relationship between companies and industries, and a CGE model was built to model it. This study utilizes TEMIP model which is constructed for the analysis of innovation policy by Hwang et al. (2020).

5.2.2 Construction of social accounting matrix

5.2.2.1 Concept of SAM and construction of knowledge-based SAM

For the simulation analysis through the CGE model, it is necessary to construct the Social Accounting Matrix (SAM), a dataset that represents the process of production, consumption, and capital accumulation in the national economy. Based on the input-output table, SAM is constructed with additional data expresses the interaction of economic actors (Pyatt & Round, 1985). In the SAM, income of each sector is displayed in rows and expenditures in columns similar to the input-output table, but the items on the horizontal axis and the vertical axis are composed as square matrix. In other words, it must be constructed so that the income and expenditure of each economic agents are equal. Through this, the SAM describes the equilibrium of the base year in the CGE model by satisfying the income and expenditure identities (Shim et al., 2019).

SAM can be constructed in various forms depending on the purpose of analysis, but it should include basic economic activities such as production activities, production factors, institutions, investments, taxes and foreign transactions. In this study, knowledge-based SAM was constructed that additionally reflected related factors for policy simulation related to knowledge and R&D. Various studies have attempted to construct SAM by adding a knowledge account (Lecca, 2009; Wing, 2003). In this study, knowledge-based SAM construction method suggested in Hwang et al. (2020) is used. The knowledge-based SAM constructed in this way defines knowledge as a production factor that is defined separately from labor and capital and recognizes knowledge capital as another capital that follows different accumulation process with physical capital.

The reference year of the SAM used in this study is 2015. Bank of Korea makes input-output table with actual measurement every five years, and the most recently constructed one is as of 2015. The input-output table in 2015 was divided into 33 industries based on the major classification, and in detail, it had 381 basic sectors. In this study, in order to construct knowledge-based SAM, classification of R&D industries and knowledge capital were done.

In 2008 SNA, the latest edition of Systems of National Accounts (SNA), R&D is defined as a systematic creation activity aimed at increasing the knowledge stock and an activity that devises a new method of operation using existing knowledge (Hong et al., 2014; OECD, 2017a). Under this definition, R&D investment is recommended to treat all R&D as capital formulation (Bank of Korea, 2019). Accordingly, this study also defined the R&D industries in the input-output table as an R&D asset production industry and assumed that the output of those industry was utilized as R&D investment. There are four R&D industries in basic classification. Among them, in the case of the sector of R&D (industry), it was regarded as a production activity that did not become knowledge capitalized as a for-profit R&D business (Shim et al., 2019; Lee et al., 2021). Therefore, remaining three sectors including R&D (public), R&D (non-profit), and intra-firm R&D were categorized into R&D industries and divided into public and private R&D industries. Table 17 shows the sector classification of the knowledge-based SAM.

Table 17. Sector classification

No.	Sector	No.	Sector
S01	Agriculture, forestry and fishery	S16	Electricity, gas, steam and water supply
S02	Mining and quarrying	S17	Construction
S03	Food, beverages and tobacco products	S18	Wholesale and retail trade
S04	Textile and apparel	S19	Transportation
S05	Wood and paper products, printing and reproduction of recorded media	S20	Accommodation and food services
S06	Petroleum and coal products	S21	Communications and broadcasting
S07	Chemicals, drugs and medicines	S22	Finance and insurance
S08	Non-metallic mineral products	S23	Real estate and business services
S09	Basic metal products	S24	Public administration and defense
S10	Fabricated metal products except machinery and furniture	S25	Education services
S11	General machinery and equipment	S26	Health and social work
S12	Electronic and electrical equipment	S27	Other services
S13	Precision instruments	S28	Private R&D
S14	Transportation equipment	S29	Public R&D
S15	Furniture and other manufacture products		

In this study, to analyze the economy-wide of PPI, SAM was constructed to explicitly reflect the account related to PPI. In the input-output table, public procurement is recorded in two different accounts, intermediate goods input of the public service sector and government consumption. Government consumption is classified according to the type of public sector finally used, so the value is not recorded for all industries. Therefore, in this study, PPI is regarded as final consumption in which some of the public use of intermediate goods in the public service sector are converted as one of the accounts in final demand. This is in line with Yang et al. (2012) which tried to capitalize some of R&D expenses recorded in intermediate input to final demand. A data system that can analyze related policies through the CGE model can be established by converting some of the public procurement that were reflected as intermediate consumption into final consumption.

5.2.2.2 Construction of SAM for PPI impact assessment

The data of annual public procurement by the types of institutions and procured objects was used for conversion of public procurement from intermediate inputs of public administration and defense sector to another final demand of government. Public Procurement Service (PPS) of Korea announced the amounts of public procurement in each year. The types of institutions are classified into 10 category and there are four types of the procured objects. Table 18 illustrates the detail of this categorization. Among them, this study accounts the public procurement done by national institutions and local government for products and general services. This study only considers the public procurement by general government which produces public services in the industry S24. In addition, public procurement of construction service is captured in fixed capital formation of the government not in the intermediate input of S24, and that of technical service is reflected in either public or private R&D sector which is S28 or S29. Figure 20 depicts the conversion method of public procurement briefly.

Table 18. Categorization of public procurement in Korea

Types of the institutions	Types of the procured objects
National institutions	Products
Local government	General services
Education administration institutions	Construction services
Public enterprise (national)	Technical services
Quasi-governmental institutions	
Other public institutions	
Public enterprise (local)	
Local medical center	
Government-funded research institute	
Special corporation	

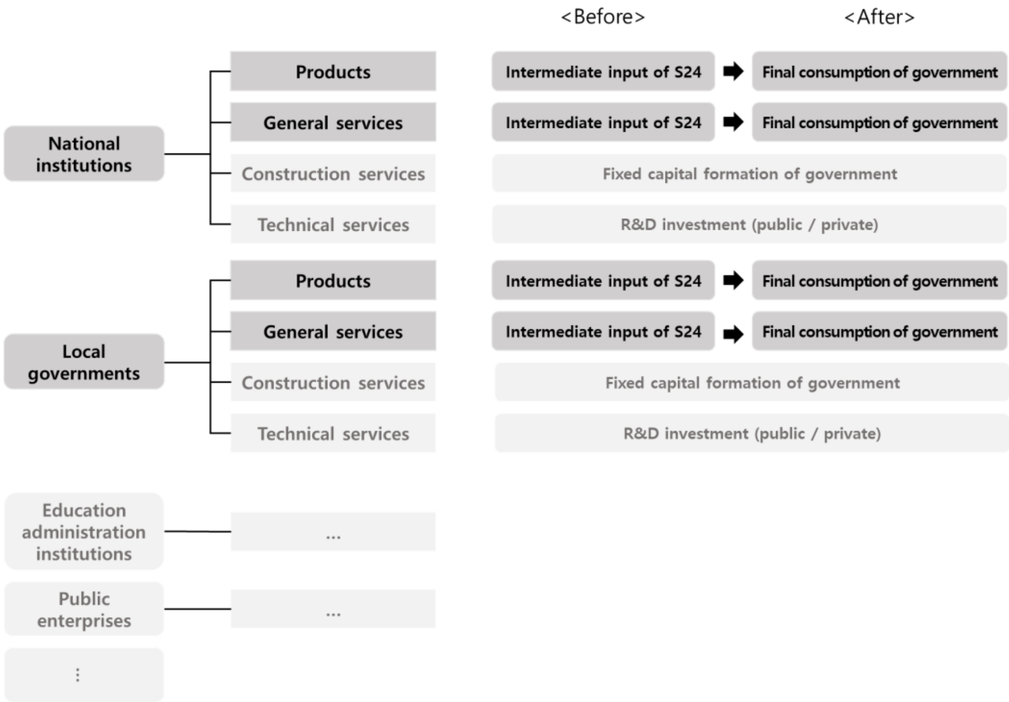

Figure 20. The conversion of public procurement to final demand in SAM

As of 2015, which is the base year of this simulation analysis, the amount of total public procurement in Korea was approximately 110.4 trillion Korean Won (KRW). Among them, the procurement amount of products and general services done by either national institutions or local governments was approximately 28.7 trillion KRW. As input-output table records the public procurement as the part of intermediate input consumption for public service production, the amount of procurement, 28.7 trillion KRW is reflected in the intermediate input of public administration and defense (S24) sector. Since the amount of total intermediate input of public administration and defense (S24) sector is approximately 31.2 trillion KRW, the proportion of public procurement is 91.8%. This study assumes that S24 sector has same ratio of public procurement to total intermediate input in all industry sectors and converts the part of intermediate input to final demand of government. Figure 21 describes the detailed steps of conversion of public procurement into final government consumption. Parameter rpp is the proportion of public procurement which is 91.8%. The other parameter rppi is the proportion of PPI to total public procurement and it is decided by the simulation scenario. Since Korean PPI policy scheme does not include the consumption of imported goods in PPI program, PPI for foreign goods set to be 0. In order to balancing the SAM, the total amount of ordinary public procurement and PPI is extracted from the general government consumption of S24 sector.

The production factors in this study are labor, capital, and knowledge, and the institution account is composed of household, firm, and government. In the case of the production sector, domestic goods and imported goods, including R&D and Public administration by PPI, are separately labeled, and taxes are classified into production tax, corporate tax, and income tax. The following is a summary of how to create major accounts based on the SAM structure in Figure 22.

<Before>

			Production activity	Final demand			
			Domestic goods	Private consumption	Government consumption		
					Non-procurement consumption	Procurement consumption	
			S24			Ordinary public procurement	Public procurement for innovation
Production activity	Domestic goods	S01	AD1		GC1		
		S02	AD2		GC2		
		⋮	⋮		⋮		
		S24	AD24 = 0		GC24		
		⋮	⋮		⋮		
		S29	AD29		GC29		
	Foreign goods	S01	AF1				
		S02	AF2				
		⋮	⋮				
		S24	AF24 = 0				
		⋮	⋮				
		S29	AF29				
Production factors							
Institution							
Investment							
Tax							
ROW							
Total							

<After>

			Production activity	Final demand			
			Domestic goods	Private consumption	Government consumption		
					Non-procurement consumption	Procurement consumption	
			S24			Ordinary public procurement	Public procurement for innovation
Production activity	Domestic goods	S01	AD1 – OPPD1 – PPID1		GC1	OPPD1 = rpp * (AD1 * (1-rppi))	PPID1 = rpp * (AD1 * rppi)
		S02	AD2 – OPPD2 – PPID2		GC2	OPPD2 = rpp * (AD2 * (1-rppi))	PPID2 = rpp * (AD2 * rppi)
		⋮	⋮		⋮		
		S24	AD24 = 0		GC24 – (OPPD1 + PPID1 + … + OPPD29 + PPID29)	0	0
		⋮	⋮		⋮	⋮	⋮
		S29	AD29 – OPPD29 – PPID29		GC29	OPPD29 = rpp * (AD29 * (1-rppi))	PPID29 = rpp * (AD29 * rppi)
	Foreign goods	S01	AF1 – OPPM1			OPPM1 = rpp * AF1	0
		S02	AF2 – OPPM2			OPPM2 = rpp * AF2	0
		⋮	⋮				
		S24	AF24 = 0				
		⋮	⋮			⋮	⋮
		S29	AF29 – OPPM29			OPPM29 = rpp * AF29	0
Production factors							
Institution							
Investment							
Tax							
ROW							
Total							

Figure 21. Detailed method for the conversion of public procurement into final consumption in SAM

			Production Activities		Production Factors			Institutions					Investment			Tax			ROW		Total
										Government				Knowledge Capital							
			Domestic	Imported	Labor	Capital	Knowledge	Household	Firm	Non-procurement consumption	Procurement consumption	PPI consumption	Physical Capital	Public	Private	Indirect Tax	Corporate Tax	Income Tax	Export	Import	
Production Activities	Domestic		Domestic intermediate goods					Private consumption (Domestic)		Non-procurement consumption (Domestic)	Procurement consumption (Domestic)	PPI consumption (Domestic)	Fixed capital formation (Domestic)	Knowledge capital formation (Domestic)	Knowledge capital formation (Domestic)				Export (Domestic)		S1
	Imported		Imported intermediate goods					Private consumption (Imported)		Non-procurement consumption (Imported)	Procurement consumption (Imported)		Fixed capital formation (Imported)	Knowledge capital formation (Imported)	Knowledge capital formation (Imported)				Export (Imported)		S2
Production Factors	Labor		Labor compensation																		S3
	Capital		Capital compensation																		S4
	Knowledge		Knowledge compensation																		S5
Institutions	Household				Labor income	Capital income															S6
	Firm					Capital income	Knowledge income														S7
	Government	Non-procurement							Government transfer				Government debt			Indirect tax	Corporate tax	Income tax			S8
		Procurement							Government transfer				Government debt								S9
		PPI							Government transfer				Government debt								S10
Investment	Physical Capital							Household saving	Firm saving	Government saving	Government saving	Government saving									S11
	Knowledge Capital	Public							Private knowledge investment	Public knowledge investment											S12
		Private							Private knowledge investment	Public knowledge investment											S13
Tax	Indirect Tax		Indirect tax																		S14
	Corporate Tax								Corporate tax												S15
	Income Tax							Income tax													S16
ROW	Export																			Export	S17
	Import			Net import									Trade balance								S18
Total			S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	

Figure 22. Structure of knowledge-based SAM

First, the intermediate goods accounts of production activities were separately entered into domestic and imported intermediate transactions of the input-output table. For labor compensation, the wage item of the input-output table was used, and the capital compensation was written by the sum of operating surplus, fixed capital consumption, and production tax except subsidy of the input-output table. However, since knowledge compensation is also included in those items, it is necessary to extract them from capital compensation.

For the proportion of knowledge compensation among related accounts in the input-output table, Survey of Research and Development in Korea conducted by Korea Institute of S&T Evaluation and Planning (KISTEP) and the World KLEMS database were used. Lee et al. (2021) also estimated the share of knowledge capital in a similar way, and the particular share by industry can be found in the Appendix 1. For the private and public R&D (S28, S29) sector, following the manner of Hong et al. (2014), it was assumed that knowledge compensation does not exist as it was regarded as a non-market producer. Indirect tax is a balance item of domestic production activity, reflecting the difference between row and column totals by industry. For production activities of imported goods, the net import item in input-output table was used as transpose matrix.

Among the production factors, labor income and labor compensation were set to be the same according to the principle of double-entry bookkeeping. Capital income is divided into household and firm, and data from “Income account by institutions” of National Accounts published by Bank of Korea were used. Specifically, household capital income was calculated using the sum of the operating surplus and property income of the "household and non-profit organization" of the National Accounts data, and the firm capital income was recorded as the value obtained by subtracting household capital income from capital compensation. In the case of knowledge income, the value is set as the sum of the previously classified knowledge compensation.

In the institutional sector, household consumption was divided into domestic goods and imported goods, respectively, and the values of the input-output table were used. Government consumption also entered relevant information in the input-output table. For household savings, total savings of "household and non-profit organization" were entered in the "Total savings and total investment" statistics of National Accounts. Firm savings and government savings also used the same statistics. The sum of total savings of 'non-financial firms' and 'financial institutions' becomes firm savings, and the value of total savings of 'general government' becomes government savings.

Subsequently, knowledge investment by institutional sector was classified. In the Survey of Research and Development in Korea, the sources of R&D investment and the actual users are classified and indicated, and based on this, public and private knowledge investments are indicated.

In the case of income tax, the balance is expressed as the sum of household accounts minus household consumption and savings. Corporate tax was used as a corporate tax item in the "Tax income by year and accounts" statistics in the Statistical Yearbook of National Tax published by National Tax Service. For government transfer, the sum of firm accounts minus firm savings (physical and knowledge capital) and corporate tax was entered as a balance item.

Investment in physical capital is expressed as the sum of private and public fixed capital formation, change of stock, and net acquisition of valuables in the input-output table, and domestic goods and imported goods are divided. Investment in knowledge capital is written only for R&D industry (S28 and S29). This value is the sum of private and fixed capital formation, change of stock, and net acquisition of valuables of the R&D sector in the input-output table. The items in export account is from input-output table and divided into domestic and imported goods. Trade balance is recorded as the difference between exports and imports. Lastly, government debt is the sum of physical capital accounts minus fixed capital formation and trade balance.

When SAM constructed in this way, some items may have a value less than 0, so this was adjusted to 0. In this case, the sum of rows and columns may not match, so a cross-entropy adjustment method was used for these accounts. The cross-entropy method is a methodology that adjusts the matrix by minimizing the reference function based on the entropy principle, and the method of Shin (1999) was applied. The SAM constructed in this way is a knowledge-based SAM that explicitly reflects knowledge production factors and knowledge capital formation and adds PPI-related sectors within the production activities to simulate the economy-wide impact of PPI.

5.2.3 Structure of TEMIP model

5.2.3.1 Overall structure of TEMIP model

Hwang et al. (2020) systemized the knowledge-based CGE model which has developed by various studies including Hong et al. (2014), Jung et al. (2017), Yeo & Lee (2020) as TEMIP model. As mentioned in Chapter 2, the TEMIP model attempted to endogenize the innovation-related elements in the CGE model by reflecting knowledge as an additional production factor and explicitly reflecting the investment of knowledge capital. In addition, the process of accumulating knowledge capital was described, and related elements were added within the production function of individual industry sectors to reflect the spillover effect of knowledge. Figure 23 and 24 show the overall structure of the TEMIP model used in this study.

Figure 23 is a schematic diagram of the TEMIP model used in this study divided into demand-side and supply-side. On the supply-side, domestic supply is produced by value-added composites and intermediate inputs. Value-added composites are formed by a combination of three production factors, which are labor, capital, and knowledge. On the demand-side, the domestic supply produced is consumed domestically or used for export. In this case, domestic goods are used for intermediate and final consumption along with imported goods. Intermediate consumption means intermediate input demand, and final consumption includes household and government consumption, physical capital and knowledge capital investment. This process is reflected in the form of equations in the

CGE model used in this study, and the behavior of various economic agents and their interactions are considered within the equation system. In the following section, we look at the structure of the detailed model through the form of a specific equation. For the indices, parameters, and variable described in the following section are summarized in Appendix 2.

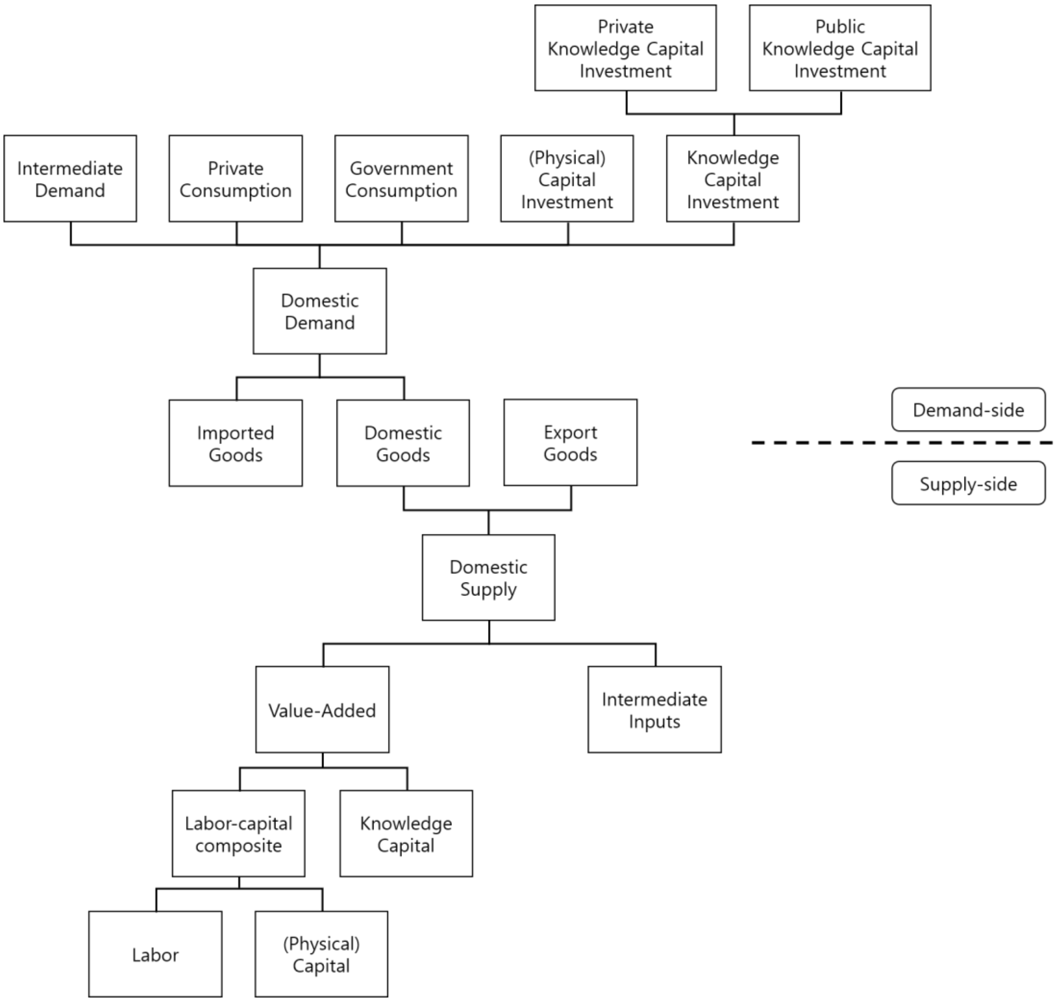

Figure 23. Structure of TEMIP model used in this study in supply- and demand-side

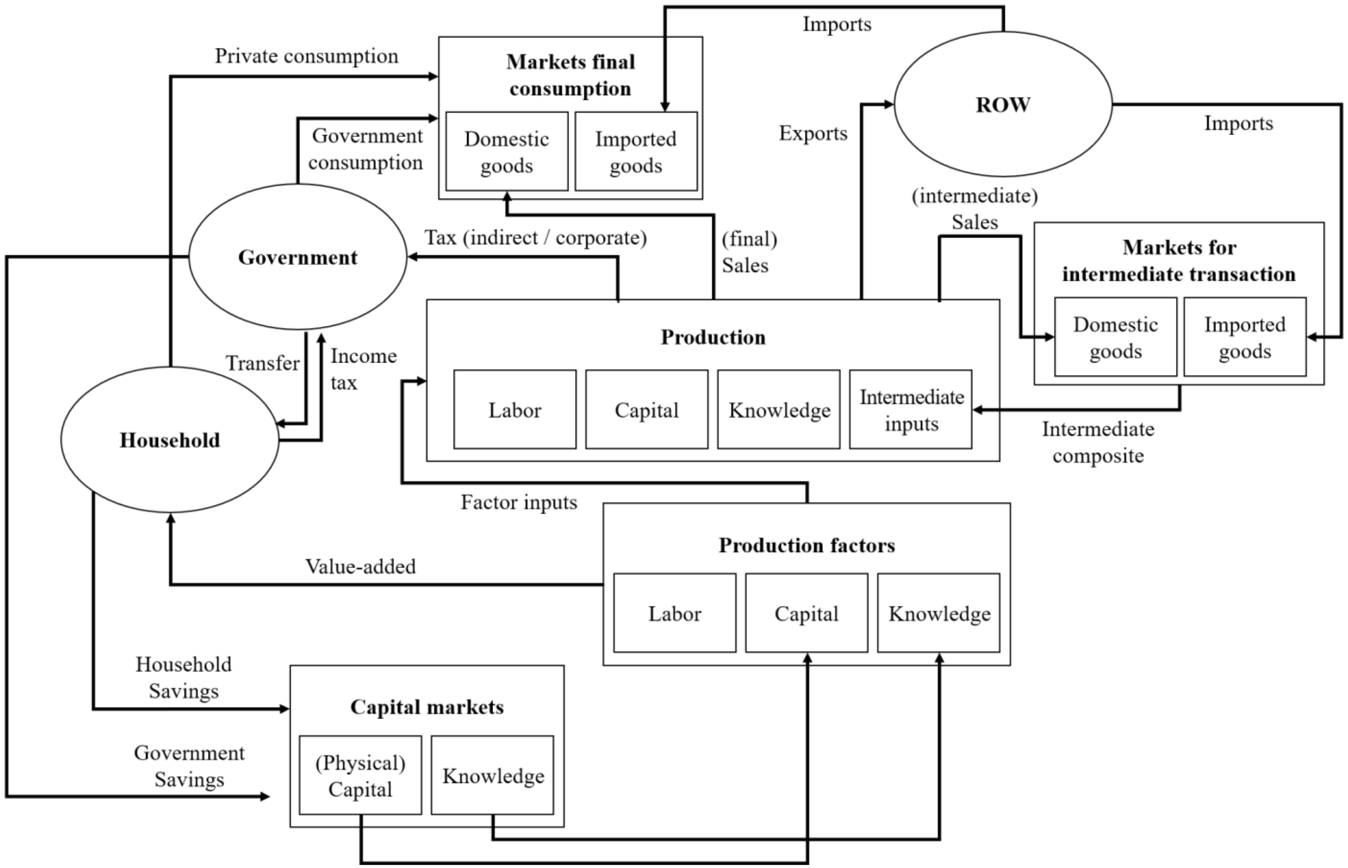

Figure 24. Overall structure of TEMIP model used in this study

5.2.3.2 Production structure of final goods

The production sector uses value-added composite (RVA) and intermediate input (YIM) to produce the final product (Y). Value-added composite is formed through two steps. First, a labor-capital composite (VA) is formed that combines labor (L) and capital (K), and then this and knowledge (R) are combined to form a value-added composite (RVA). Both final good and value-added composite are made as functions in the form of constant elasticity of substitution (CES) production function. In general, the CES production function is used when there are two input elements, but Sato (1967) pointed out that the CES function can be used even when there are three or more production elements.

Equation (5-1) to (5-3) expresses the production process of the final product. Equation (5-1) represents the CES production function of the final goods, and Equation (5-2) represents the unit cost function of the final goods production sector. At this time, γy and μy are calculated by the reference year SAM as scale parameter and share parameter, respectively. PY, PYIM, and PRVA indicates price of final goods, price of intermediate input, and price of value-added composite, respectively, and τy represents the indirect tax rate. The parameter τppi indicates the negative effect of PPI on the suppliers in cost side. The value is decided in dynamic process, with the previous volume of PPI in a certain sector.

$$Y_i = \gamma y_i \cdot (YIM_i^{\mu y_i} \cdot RVA_i^{(1-\mu y_i)}) \quad \cdots\text{Eq. (5-1)}$$

$$(1 - \tau y_i - \tau ppi_i) \cdot PY_i \cdot Y_i = PYIM_i \cdot YIM_i + RVA_i \cdot PRVA_i \quad \cdots\text{Eq. (5-2)}$$

$$YIM_i \cdot PYIM_i = \mu y_i \cdot Y_i \cdot (1 - \tau y_i - \tau ppi_i) \cdot PY_i \quad \cdots\text{Eq. (5-3)}$$

Equation (5-4) and (5-5) are equations for the determination of intermediate input. Intermediate input is determined by the input coefficient (aqm) derived from the reference year SAM. QIM is intermediate input transaction between the industry sectors.

$$QIM_{j,i} = aqm_{i,j} \cdot YIM_i \quad \cdots\text{Eq. (5-4)}$$

$$PYIM_i = \sum_{j=1}^{29} (aqm_{i,j} \cdot PQ_j) \quad \cdots\text{Eq. (5-5)}$$

Next, Equation (5-6) to (5-8) is equations related to value-added composite. First, Equation (5-6) is a CES function for the formation of RVA, and γrva and μrva are scale parameters and share parameters, respectively. In the case of TFP, it is determined as a function of the R&D stock in the dynamic process. For the formulation of value-added composite, in the case of R&D industry, there is no separate knowledge production factor, so the value of labor-capital composite (VA) is determined as RVA. Equation (5-7) and (5-8) are equations that determine the price of labor-capital composite and knowledge, respectively. In this case, PVA and PR represent price of labor-capital composite and price of knowledge, respectively.

$$RVA_i = TFP_i \cdot \gamma rva_i \cdot (VA_i^{\mu rva_i} \cdot R_i^{(1-\mu rva_i)}) \quad \cdots\text{Eq. (5-5)}$$

$$VA_i \cdot PVA_i = \mu rva_i \cdot RVA_i \cdot PRVA_i \quad \cdots\text{Eq. (5-6)}$$

$$R_i \cdot PR_i = (1 - \mu rva_i) \cdot RVA_i \cdot PRVA_i \quad \cdots\cdots \text{Eq. (5-7)}$$

Equation (5-9) to (5-11) shows the composition of a labor-capital composite. γva and μva are scale parameter and share parameter, respectively, and PL and PK are labor price and capital price, respectively. In this study, it is assumed that labor price and capital price have common values for all industries.

$$VA_i = \gamma va_i \cdot (K_i^{\mu va_i} \cdot L_i^{(1-\mu va_i)}) \quad \cdots\cdots \text{Eq. (5-9)}$$
$$K_i \cdot PK = \mu va_i \cdot VA_i \cdot PVA_i \quad \cdots\cdots \text{Eq. (5-10)}$$
$$L_i \cdot PL = (1 - \mu va_i) \cdot VA_i \cdot PVA_i \quad \cdots\cdots \text{Eq. (5-11)}$$

5.2.3.3 Household

Households earn income by providing production factors including labor, capital, and knowledge. Some portion of the income is paid to the government as corporate and income taxes, while government transfer can be added to household disposable income. The use of disposable income can be broadly divided into consumption and saving.

The equation (5-12) to (5-14) represents factor income. HIL, HIK, and HIR stand for labor income, capital income, and knowledge income, respectively. Equation (5-15) represents the composition of disposable income (HI), and tl and tk represent the income tax rate and corporate tax rate, respectively. GT is the government transfer. Equation (5-16) to (5-18) represents household consumption. muh and γh are scale parameters and share parameters for each sector of the consumption function, respectively, and their values are determined from the data of the reference year SAM. The relationship between sectoral consumption (QH) and total consumption (HC) is presented in Equations (5-16) and (5-17). Parameter ahs in Equation (5-18) is determined from the base year SAM as the propensity to consumption, and PHC is the consumption price. In the CGE model, all price is expressed as a relative price, and for this, a numeraire setting that sets a specific price to 1 is required. In this study, the PHC is set to be a numeraire. Equation (5-19) indicates the relationship between household saving (HS) and household income.

$$HIL = \sum_{i=1}^{29} (PL \cdot L_i) \quad \text{Eq. (5-12)}$$

$$HIK = \sum_{i=1}^{29} (PL \cdot K_i) \quad \text{Eq. (5-13)}$$

$$HIR = \sum_{i=1}^{27} (PR_i \cdot R_i) \quad \text{Eq. (5-14)}$$

$$HI = (1 - tl) \cdot HIL + (1 - tk) \cdot HIK + HIR + GT \quad \text{Eq. (5-15)}$$

$$QH_i = muh_i \cdot HC \quad \text{Eq. (5-16)}$$

$$HC = \gamma h \cdot \prod_{i=1}^{29} QH_i^{muh_i} \quad \text{Eq. (5-17)}$$

$$HC \cdot PHC = (1 - ahs) \cdot HI \quad \text{Eq. (5-18)}$$

$$HS = ahs \cdot HI \quad \text{Eq. (5-19)}$$

5.2.3.4 Government

Government gets their income through various taxes including indirect tax, corporate tax, and income tax. Government spending is divided into government transfer, consumption including pubic procurement, and saving. Within the CGE model, the government generally establishes a fiscal balance between income and expenditure in every period, so the difference between them is expressed as government debt (GD).

Equation (5-20) represents the composition of government income (GI). Equation (5-21) represents the decision formula of government transfer (GT), which reflects the additional revenue of the government caused by the cost inefficiency that the private suppliers experience. This additional revenue does not include into government revenue and transferred to the household without using it in production activity. Parameter agt is the share of government transfers to government revenue and is determined by the SAM in the base year. Equation (5-22) to (5-24) is an equation related to non-procurement government consumption. Government consumption (GC) is income minus savings (GS) and transfer, which is linked to sectoral government consumption (QG). Parameter rgc in equation (5-22) indicates the proportion of non-procurement government consumption to total government consumption including public procurement. The value for rgc is derived from the data of the base year. Parameter mug is the share parameter of the government consumption function and is determined from the SAM in the base year.

$$GI = \sum_{i=1}^{29} (\tau y_i \cdot Y_i \cdot PY_i) + tl \cdot HIL + tk \cdot HIK + GD \quad \text{Eq. (5-20)}$$

$$GT = agt \cdot GI - \sum_{i=1}^{29} (\tau ppi_i \cdot Y_i \cdot PY_i) \quad \text{Eq. (5-21)}$$

$$GC \cdot PGC = rgc \cdot (GI - GS - GT) \quad \text{Eq. (5-22)}$$

$$GC \cdot PGC = \sum_{i=1}^{29} (QG_i \cdot PQ_i) \quad \text{Eq. (5-23)}$$

$$mug_i \cdot GC = QG_i \quad \text{Eq. (5-24)}$$

Government also spends its income into procurement consumption, and public procurement can be divided into ordinary procurement and PPI. Equation (5-25) to (5-27) describes the determination process of ordinary procurement consumption (OPP), and equation (5-28) to (5-30) depicts that of PPI (PPI). The logics are similar with that of non-procurement government consumption. Parameter ropp is the ratio of ordinary procurement to PPI and determined from the data of the base year. Parameter muopp and muppi is the share parameter of the ordinary procurement consumption and PPI consumption function respectively, and they are also derived from the data of the base year. Equation (5-31) is a constraint that the nominal price of ordinary PP and PPI should be equal. Finally, equation (5-32) expresses the relationship between government saving and government income.

$$OPP \cdot POPP = ropp \cdot (1 - rgc) \cdot (GI - GS - GT) \quad \text{Eq. (5-25)}$$

$$OPP \cdot POPP = \sum_{i=1}^{29} (QOPP_i \cdot PQ_i) \quad \text{Eq. (5-26)}$$

$$muopp_i \cdot OPP = QOPP_i \quad \text{Eq. (5-27)}$$

$$PPI \cdot PPPI = (1 - ropp) \cdot (1 - rgc) \cdot (GI - GS - GT) \quad \text{Eq. (5-28)}$$

$$PPI \cdot PPPI = \sum_{i=1}^{29} (QPPI_i \cdot PQ_i) \quad \text{Eq. (5-29)}$$

$$muppi_i \cdot PPI = QPPI_i \quad \text{Eq. (5-30)}$$

$$POPP = PPPI \quad \text{Eq. (5-31)}$$

$$GS = ags \cdot GI \quad \text{Eq. (5-32)}$$

5.2.3.5 Investment and savings

In the TEMIP model, investment is largely divided into investment on physical capital and investment on knowledge capital. Investment on knowledge capital is once again divided into private and public investments. In the model, the total amount of investment is set equal to available saving, and available saving is determined by household and government savings, trade balance and government debt.

Equation (5-33) to (5-35) represents the decision process of physical capital investment. Physical capital investment is made for the portion of available savings (AS) excluding the share of public and private R&D investments (agrd, ard). PKIV represents the investment price of capital goods, and mui is the share parameter of the investment function for each sector, which is determined by the SAM for the base year. Note that R&D industry (S28 and S29) does not have physical capital investment.

$$KIV \cdot PKIV = (1 - agrd - ard) \cdot AS \quad \text{Eq. (5-33)}$$

$$mui_i \cdot KIV = QIV_i, i = 1,2,3, \ldots, 27,30 \quad \text{Eq. (5-34)}$$

$$PKIV = \sum_{i=1}^{27} (mui_i \cdot PQ_i) \quad \text{Eq. (5-35)}$$

Equation (5-36) to (5-38) express private knowledge capital investment (TRI). Knowledge investment (RI) by sector is allocated according to the private R&D investment ratio (ari) by sector derived through the Survey of Research and Development in Korea. QIVP is a total available private knowledge investment goods. Equation (5-39) to (5-41) express public knowledge capital investment (TGRI). Similar to the case of private R&D investment, sectoral R&D investment is determined through sectoral investment ratio (agri) calculated from Survey of Research and Development in Korea. QIPG is a total available public knowledge investment goods. Unlike private knowledge investment, in the public sector, the impact of expanding investment by PPI is not reflected, considering that the beneficiary of PPI is the private sector. Since R&D industries (S28 and S29) does not have production factor of knowledge, they do not have in-house R&D investment in this model.

$$RI_i = ari_i \cdot QIVP \quad \text{Eq. (5-36)}$$

$$TRI = ard \cdot AS \quad \text{Eq. (5-37)}$$

$$TRI = QIVP \cdot PQ_j, j = 28 \quad \text{Eq. (5-38)}$$

$$GRI_i = agri_i \cdot QIVG \quad \text{Eq. (5-39)}$$

$$TGRI = agrd \cdot AS \quad \text{Eq. (5-40)}$$

$$TGRI = QIVG \cdot PQ_j, j = 29 \quad \text{Eq. (5-41)}$$

Total saving (TS) is composed of household saving and government saving as Equation (5-42). Available saving (AS) is determined from total saving minus trade balance (FS) and government debt (GD) as Equation (5-43). Parameter exr is exchange rate.

$$TS = HS + GS \quad \cdots\cdots \text{Eq. (5-42)}$$

$$AS = TS - exr \cdot FS - GD \quad \cdots\cdots \text{Eq. (5-43)}$$

5.2.3.6 International trade (exports and imports)

The TEMIP model assumes a small open economy, which means that domestic economic activities do not affect foreign countries. These assumptions allow the price of imported and exported goods to be determined exogenously. Equation (5-44) and (5-45) represent the price-determining process for exported and imported goods, respectively. The price of domestic export goods (PE) is determined by the exchange rate and the price of international export goods (PWE), and the price of domestic imported goods (PM) is also affected by the exchange rate and the price of international imported goods (PWM). At this time, PWE and PWM are each fixed to 1. Equation (5-46) represents the equation for determining the exchange rate, and the trade balance is considered in the equation.

$$PE_i = exr \cdot PWE_i \quad \cdots\cdots \text{Eq. (5-44)}$$

$$PM_i = exr \cdot PWM_i \quad \cdots\cdots \text{Eq. (5-45)}$$

$$\sum_{i=1}^{29}(E_i \cdot PWE_i) = \sum_{i=1}^{29}(M_i \cdot PWM_i) + FS \quad \text{Eq. (5-46)}$$

In addition, the equations for the production of Armington goods that combine imported and domestic goods are presented in Equation (5-47) to (5-49). γ and δ are calculated from the data of the reference year SAM as the scale parameter and share parameter of the Armington function, respectively.

$$Q_i = \gamma_i \cdot {M_i}^{\delta m_i} \cdot {D_i}^{(1-\delta m_i)} \quad \text{Eq. (5-47)}$$

$$M_i \cdot PM_i = \delta m_i \cdot Q_i \cdot PQ_i \quad \text{Eq. (5-48)}$$

$$Q_i \cdot PQ_i = M_i \cdot PM_i + D_i \cdot PD_i \quad \text{Eq. (5-49)}$$

On the other hand, if export goods and domestic goods are combined with a transformation function, it is expressed as Equation (5-50) to (5-52). At this time, θ and ξ are derived from the reference year SAM as the share parameter and scale parameter of the transformation function, respectively.

$$Y_i = \theta_i \cdot {E_i}^{\xi_i} \cdot {D_i}^{(1-\xi_i)} \quad \text{Eq. (5-50)}$$

$$E_i \cdot PE_i = \xi_i \cdot Y_i \cdot PY_i \quad \text{Eq. (5-51)}$$

$$Y_i \cdot PY_i = E_i \cdot PE_i + D_i \cdot PD_i \quad \text{Eq. (5-52)}$$

5.2.3.7 Market clearing

TEMIP model should follow the general equilibrium framework by imposing the market clearing conditions on the commodities and production factor markets. Equation (5-53) indicates the market clearing for Armington goods for general industries except R&D sectors. Similarly, equation (5-54) describes the market clearing for investment goods especially on knowledge capital. Equation (5-55) to (5-57) depicts the market clearing for production factor markets. Total labor (TOL), total capital (TOK), and total knowledge (TOR) is determined exogenously with the Korean trend of labor, capital, and R&D investment. Finally, equation (5-58) describes the determination of gross domestic product (GDP) and equation (5-59) is the objective function of the CGE simulation which is utility function.

$$Q_i = QH_i + QG_i + QOPP_i + QPPI_i + \sum_{j=1}^{29} QIM_{i,j} + QIV_i, i = 1.2 \ldots, 27 \quad \cdots\cdots \text{Eq. (5-53)}$$

$$Q_j = QIV_j, j = 28.29 \quad \cdots\cdots \text{Eq. (5-54)}$$

$$\sum_{i=1}^{29} L_i = TOL \quad \cdots\cdots \text{Eq. (5-55)}$$

$$\sum_{i=1}^{29} K_i = TOK \quad \cdots\cdots \text{Eq. (5-56)}$$

$$R_i = TOR_i, i = 1,2,3, \ldots, 27,30 \quad \cdots\cdots \text{Eq. (5-57)}$$

$$GDP = HIL + HIK + HIR \quad \cdots\cdots \text{Eq. (5-58)}$$

$$UU = HC \quad \cdots\cdots \text{Eq. (5-59)}$$

5.2.3.8 Dynamics

To assess the policy impact over time, it is necessary to add some equations which reflect dynamics of the model. The dynamics include the changes of production factors and accumulation process of capital stock of both physical and knowledge. The determination of TFP which is derived from the knowledge stock is also considered.

Equation (5-60) reflects the accumulation process of physical capital stock (KS). Following perpetual inventory method (PIM), physical capital stock is determined by the stock of previous period, additional investment, and depreciation rate (kdep). The value of depreciation rate is employed from the results of Pyo (2003), which is 4.6%. Capital stock at the first period, which is the base year, is calculated from the data of Pyo et al. (2019) that estimated the capital stock in industry level.

$$KS_t = (1 - kdep)KS_{t-1} + KIV_t \quad \cdots\cdots \text{Eq. (5-60)}$$ [6]

Equation (5-61) to (5-64) indicates the accumulation process of private and public knowledge stock. The sectoral knowledge stock (RK, GRK) and total knowledge stock (TRS, TGRS) is accumulated following PIM, and the depreciation rate for knowledge stock is set to 15% which is the value that Lach (1995) estimated with the patent data. Each production sector invests on R&D following pre-determined portion (ari, agri) of total public or private demand. The knowledge stock at the base year is estimated with the method proposed in Hwang et al. (2020).

$$RK_{i,t} = (1 - rdep)RK_{i,t-1} + ari_i \cdot TRI_{i,t} \quad \cdots\cdots \text{Eq. (5-61)}$$

[6] t indicates the time, and t=0 means the base year.

$$GRK_{i,t} = (1 - rdep)GRK_{i,t-1} + agri_i \cdot TGRI_{i,t} \quad \text{Eq. (5-62)}$$

$$TRS_t = (1 - rdep)TRS_{t-1} + TRI_{i,t} \quad \text{Eq. (5-63)}$$

$$TGRS_t = (1 - rdep)TGRS_{t-1} + TGRI_{i,t} \quad \text{Eq. (5-64)}$$

Equation (5-65) is the equation for TFP determination. TFP influences on the production activity, particularly forming the value-added composite. TFP is calculated from the spillover coefficient (spovr) and aggregated private and public knowledge capital stocks (SR, SGR). Spillover coefficient also varies over time following depreciation of knowledge stock. Parameter tfpppi indicates the impact of PPI on production enhancement. Parameter nusr and nusgr indicates the inter-sectoral spillover effect of each knowledge stock. The values for nusr and nugsr is employed from the estimation results of Hwang et al. (2020), which is 0.353 and 0.466, respectively. SR and SGR is calculated from Equation (5-66) and (5-67). Parameter $we_{j,i}$ represents a ratio of intermediate goods supplied from the jth industry in total intermediate inputs of the ith sector. It implies that the value of $we_{j,i}$ is equal to input coefficient when j and i is different sector, and 1 when i = j (Hwang et al., 2020).

$$TFP_{i,t} = spovr_{i,t} \cdot tfpppi_{i,t} \cdot (SR_{i,t}{}^{nusr\ i} \cdot SGR_{i,t}{}^{nusgr\ i}) \quad \text{Eq. (5-65)}$$

$$SR_{i,t} = \sum_{j=1}^{27} (we_{j,i} \cdot RK_{j,t}) \quad \text{Eq. (5-66)}$$

$$SGR_{i,t} = \sum_{j=1}^{27} (we_{j,i} \cdot GRK_{j,t}) \quad \text{Eq. (5-67)}$$

Lastly, equation (5-68) indicates the dynamic process of labor. Total labor (TOL) changes with the pre-determined parameter, gl which is the value from Statistics Korea (2019). Total amount of other two production factors, physical capital (TOK) and knowledge (TOR) is determined from the above equations of dynamics.

$$TOL_t = gl_t \cdot TOL_{t-1} \quad \cdots\cdots \text{Eq. (5-68)}$$

5.2.3.9 Impact of PPI

In order to capture the impact of PPI in economy-wide perspective, the model adds some equations which depict the PPI's impact mentioned in section 5.1. These equations are only simulated when PPI is actually implemented in scenario analysis.

There are two main impact paths of PPI to be reflected in CGE model. First positive impact paths are from PPI to productivity enhancement. As discussed in sub-section 4.3.2, The level of the participation of PPI contract to total public procurement is positively related to the TFP of the industry. Equation (5-69) describes this relationship in mathematical way with the parameter of tfpppi. The equation has a similar form with the regression equation investigated in last chapter. Parameter ohm suggests the effect of PPI on TFP with the level of PPI participation and the value of ohm is 0.0034 to follow the econometric results of sub-section 4.3.2. Since public procurement is only done for the industry sector except public administration and defense (S24) and R&D sector (S28, S29), the value for tfpppi is set to be 1.

$$tfpppi_{i,t} = \left(1 + ohm \cdot \left(\frac{QPPI_{i,t-1}}{QOPP_{i,t-1} + QPPI_{i,t-1}}\right)\right), i = 1,2,3, \dots, 23, 25, 26, 27 \quad \cdots\cdots\cdots \text{Eq. (5-69)}$$

The negative effect of cost inefficiency of suppliers caused by PPI was also applied in conjunction with the productivity effect of sub-section 4.3.2. In this study, part of the increase in productivity resulting from the expansion of the proportion of PPI participating firms in the industry was considered to represent the quality difference between ordinary public procurement products and PPI products. In general, the increase in productivity can be divided into technological progress effect, improving technological efficiency effect, and of scale effect (Melfou et al., 2009). Among them, the increase in productivity due to technological progress was regarded as a quality improvement. In the case of technical efficiency improvement and the effect of scale, it was considered that qualitative changes were not made because it did not lead to changes of the technical frontier as it was caused by changes in the composition of input factors (Kalirajan & Shand, 1999).

Kwack (2006) examined the rate of increase in TFP of Korean manufacturing firms through decomposition analysis. As a result of the analysis, it was analyzed that about 9.4% of the increase in total factor productivity from 1996 to 2004 was due to technological progress. Following this result, in this study, 9.4% of the productivity effect of PPI calculated in sub-section 4.3.2 was the effect of improving product quality, and this was interpreted as an additional cost burden incurred by the firms with PPI contract due to the lack of policy capability of the public institutions. The parameter, rho, of Equation (5-70) reflects this, and it is also configured to be determined by the proportion of PPI among total public procurement at the sectoral level. However, in this case, costs are incurred immediately by the execution of the PPI, unlike the tfpppi decision process, it is calculated as the PPI with the data of the same year. In the case of sectors S24, S28, and S29 without public procurement, the value of τppi is 0.

$$\tau ppi_{i,t} = ohm \cdot rho \cdot \left(\frac{QPPI_{i,t}}{QOPP_{i,t} + QPPI_{i,t}}\right), i = 1,2,3,\ldots,23,25,26,27 \quad \cdots\cdots \text{Eq. (5-70)}$$

5.3 Simulation analysis

5.3.1 Policy scenario setting

5.3.1.1 Business as usual (BAU) scenario

The model described in the previous section will describe the economic situation of Korea by 2030, which is the target year of the analysis. The business as usual (BAU) scenario assumes that there is no exogenous policy shock from the base year of 2015 to 2030. The simulation results from BAU scenario imply that the economic situation of the base year is maintained until the target year. It makes it possible to investigate the policy impact by comparing the changes of macroeconomic indicators in the model driven by policy scenario simulation.

5.3.1.2 Policy scenario setting for analysis

This study aims to assess policy impact of PPI in economy-wide perspective in general equilibrium setting. BAU scenario which depicts the situation of no policy shock indicates that there is no PPI in Korean economy. In order to compare macroeconomic indicators and draw the policy imp act assessment results, this study set the policy scenario of PPI implementation.

Korean government has a policy initiative to increase PPI and set the goal for procurement of innovative products at least 1% of the procurement budget of each public agency or institution. In addition, it has a plan to increase this requirement of PPI after investigating the effect of initial plan of 1% shift to PPI. The products which are eligible for this policy scheme including the ones which has been designated as excellent products, which their impact on productivity has been investigated in Chapter 4, and prototypes that utilize the innovative technology or solutions. This study set the model that the procurement for these products has differentiated effect on the behavior of economic agents compared to the ordinary procurement and investigate the economy-wide impact of PPI based on that.

This study set the policy scenario as public sector shifts the certain portion of its ordinary procurement into PPI. The portion is set to be 10% in 2021 and is increased proportionally as 50% of procurement is done by PPI in 2030. This study sets the policy scenario in line with the policy scheme. The policy scenario assumes that there is no additional budget for PPI implementation and public institution just shifts the product category from ordinary ones to innovative ones. In addition, despite the fact that public sector of Korea consumes intermediate input from both domestic goods and imported goods, this study set the scenario that PPI is done only for domestic products. It reflects that one of the goals for public procurement with the contents of innovation has been import substitution in several countries (Lember et al., 2014; Li & Georghiou, 2016; Li et al., 2020).

Although the base year for constructed model is 2015, the policy shock is implemented from the year of 2021 to secure validity of the simulation results. This means that there is no difference of the results between BAU scenario and policy scenario from 2015 to 2020 and this study will provide the results only after 2021 in the next section.

5.3.2 Simulation results

5.3.2.1 Effects on economic growth and industrial output

Figure 25 depicts the change of GDP in policy scenario (SCN) from 2021 to 2030 compared to that in base scenario (BAU). According to the result, PPI implementation increases GDP in 2030 at 0.282% approximately. There is little improvement of GDP in the early stage of PPI from 2021 to 2022. It is because the negative impact on production cost of PPI can hinder the TFP enhancement impact of PPI. However, from 2023, with the generation of TFP improvement, the national economy can experience the increase of GDP compared to BAU.

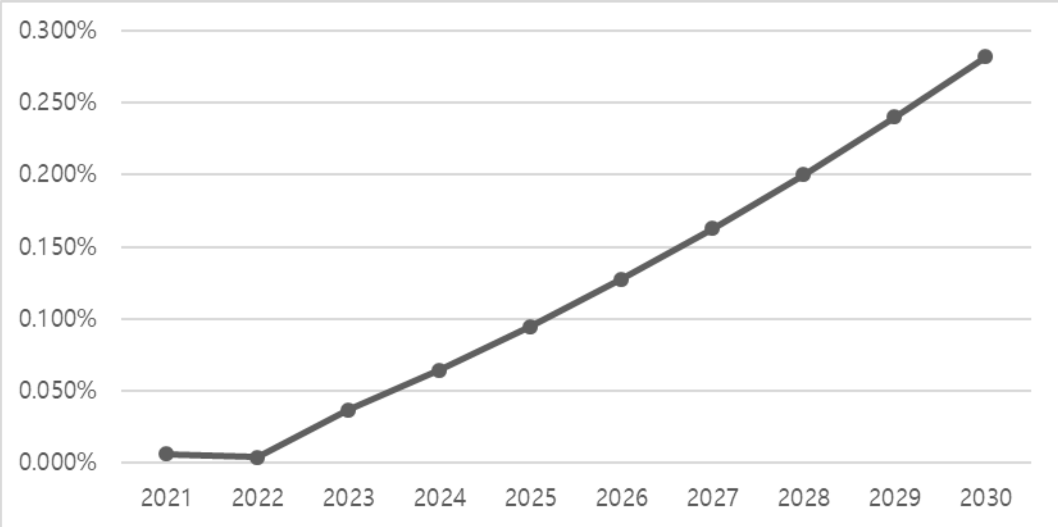

Figure 25. Change of GDP in policy scenario (compared to BAU)

Figure 26 suggests the impact on GDP of two effects, TFP enhancement effect and cost inefficiency compared to BAU. Although PPI generates the inefficiency of cost incurred by private suppliers, it makes a positive impact on GDP up to 6 years after PPI implementation. This is because private suppliers alter their production process of proportion of intermediate inputs and production factors including labor, capital, and knowledge. Since the cost inefficiency effect results in the decrease of production volume, the suppliers can decrease their intermediate input use and increase the utilization of production factors in a short-run in profit-maximization process. That is, the improvement of efficiency in production process can substitute the negative impact on production volume of PPI implementation in a short run. However, as production volume is continuously decreased, private suppliers cannot change their production process without decreasing the expenses no more, and finally the negative impact of additional cost start to be reflected in GDP from 2027. Although GDP is still increasing since TFP enhancement effect dominates the negative impact of PPI up to 2030, public institutions should solve the cost burden driven by PPI which private suppliers can experience since it might hinder the positive effect in TFP and make the direction of GDP change into different way in the long-run.

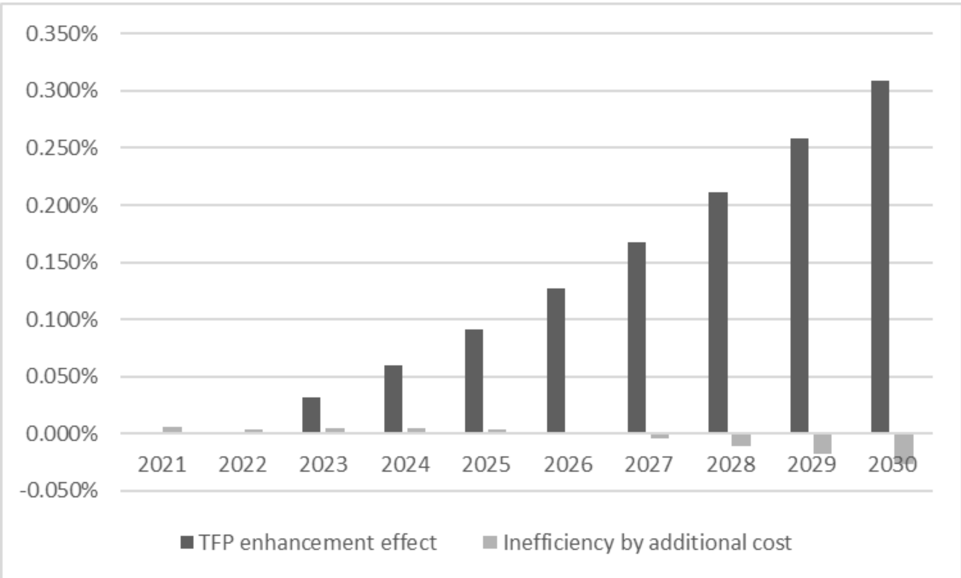

Figure 26. Change of GDP by PPI’s impact in policy scenario (compared to GDP)

Figure 27 depicts the change of total production volume in policy scenario compared to BAU. In 2030, about 0.201% more production is generated in policy scenario than BAU. In 2021 and 2022, since there is no TFP enhancement effect at the first year of PPI implementation, production volume is reduced because of negative impact of PPI. However, from 2023, TFP enhancement effect starts to affect the production, and the positive impact on production of PPI implementation is found. As the amount of PPI increases, the degree of both positive and negative effect gets also higher. In 2023, because the negative effect of PPI driven by additional cost of private suppliers offset the positive effect of PPI by TFP enhancement, so the degree production volume expansion effect is not increased temporarily. However, after that, TFP enhancement effect starts to dominate the negative effect from cost inefficiency, and total output volume is increased further.

Table 19 illustrates the difference of total production volume between BAU and SCN in 2021 and 2030. In 2030, about 17.87 trillion KRW is spent for PPI instead of ordinary procurement, the difference of total production volume is about 9.55 trillion KRW. It can be said that 1 unit of alteration of ordinary PP to PPI can generate 0.53 unit of total production volume increase. Considering that there is no additional government revenue in order to spend the budget for PPI in the policy scenario, expansion of total output compared to base scenario can explain the economy-wide impact of PPI in positive way.

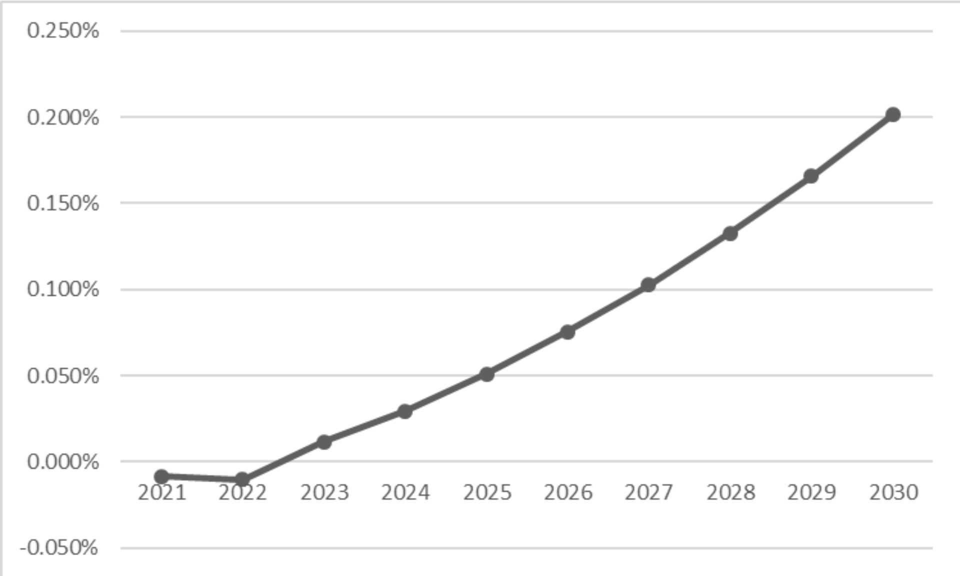

Figure 27. Change of total production volume in policy scenario (compared to BAU)

Table 19. Change of total production volume in base and policy scenario

	Total production volume in BAU (trillion KRW)	Total production volume in SCN (trillion KRW)	Difference of total production volume (% of BAU)
2015	3772.07	-	-
2021	4087.84	4087.50	-0.008
2030	4747.96	4757.51	0.201

Figure 28 describes the decomposed results in total output volume change between TFP enhancement effect and cost inefficiency effect driven by PPI implementation. The results imply that the positive impact from TFP improvement is much larger than the negative impact from additional cost faced by the private suppliers in 2030. However, it is worthwhile to note that the volume of negative impact is also increased as time goes to draw the implication on the PPI's policy design, which should be done to reduce the potential disadvantages of PPI.

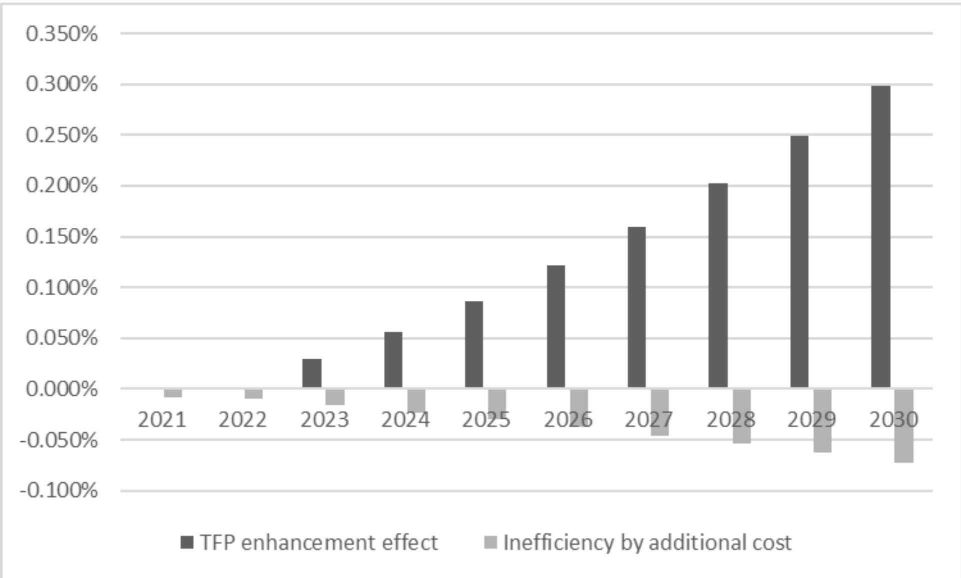

Figure 28. Change in total production volume by PPI's impact in policy scenario (compared to BAU)

Figure 29 and 30 suggests the sectoral difference in change of production volume in 2030. Although most of the sector experiences the production expansion thanks to PPI implementation, service sector's production volume increases more than that of manufacturing or agriculture sector. It is because public sector's activity, which is the primary use of procured goods and services, is highly related to other services including health and social work and education as Figure 29 reveals. Among manufacturing sector, it was found that non-metallic mineral products sector can get more benefit from PPI policy than other manufacturing sectors.

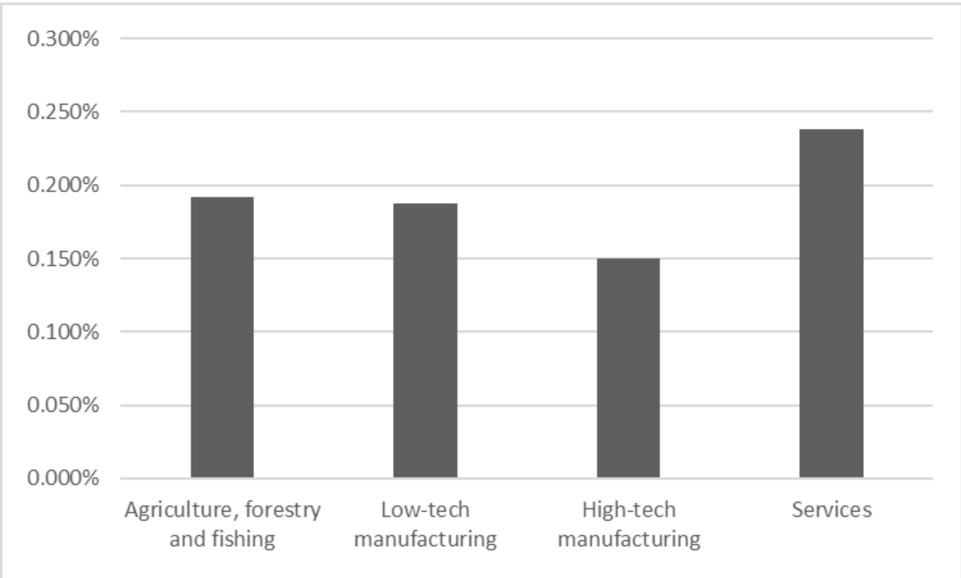

Figure 29. Change of production volume by industries in policy scenario in 2030 (compared to BAU)

It is suggested that PPI implementation can have positive influence on economy-wide indicators including GDP, GDP growth rate, and total production volume. However, it is necessary to find out whether theoretically developed impact paths in Chapter 3 are operated well in simulation analysis in order to check PPI's economy-wide impact more precisely. The next part will suggest the PPI's economy-wide impact with various economic indicators which can show the impact channels of PPI including direct demand-pull, indirect demand-pull, and indirect technology-push as Figure 30 illustrates.

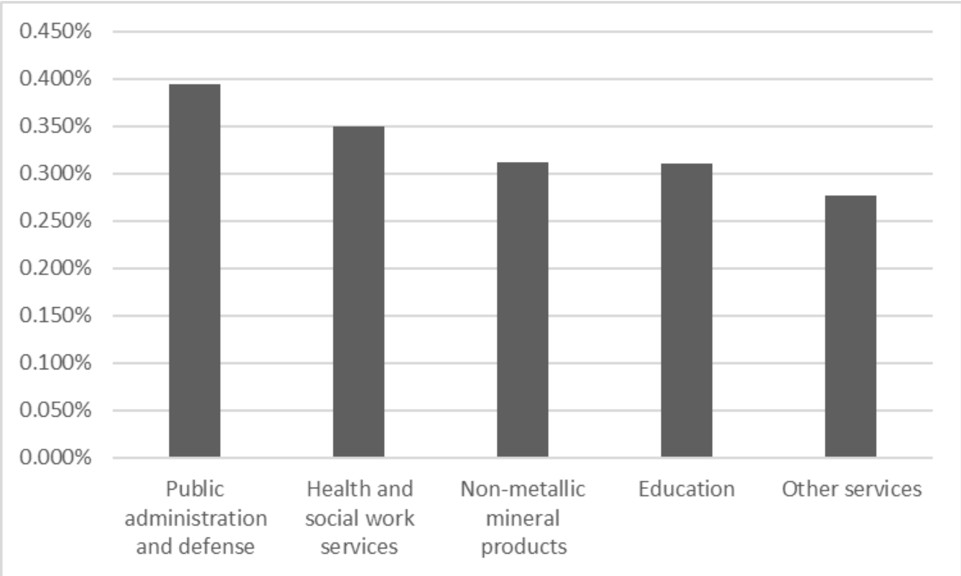

Figure 30. Change of production volume by sector in policy scenario in 2030 (compared to BAU)

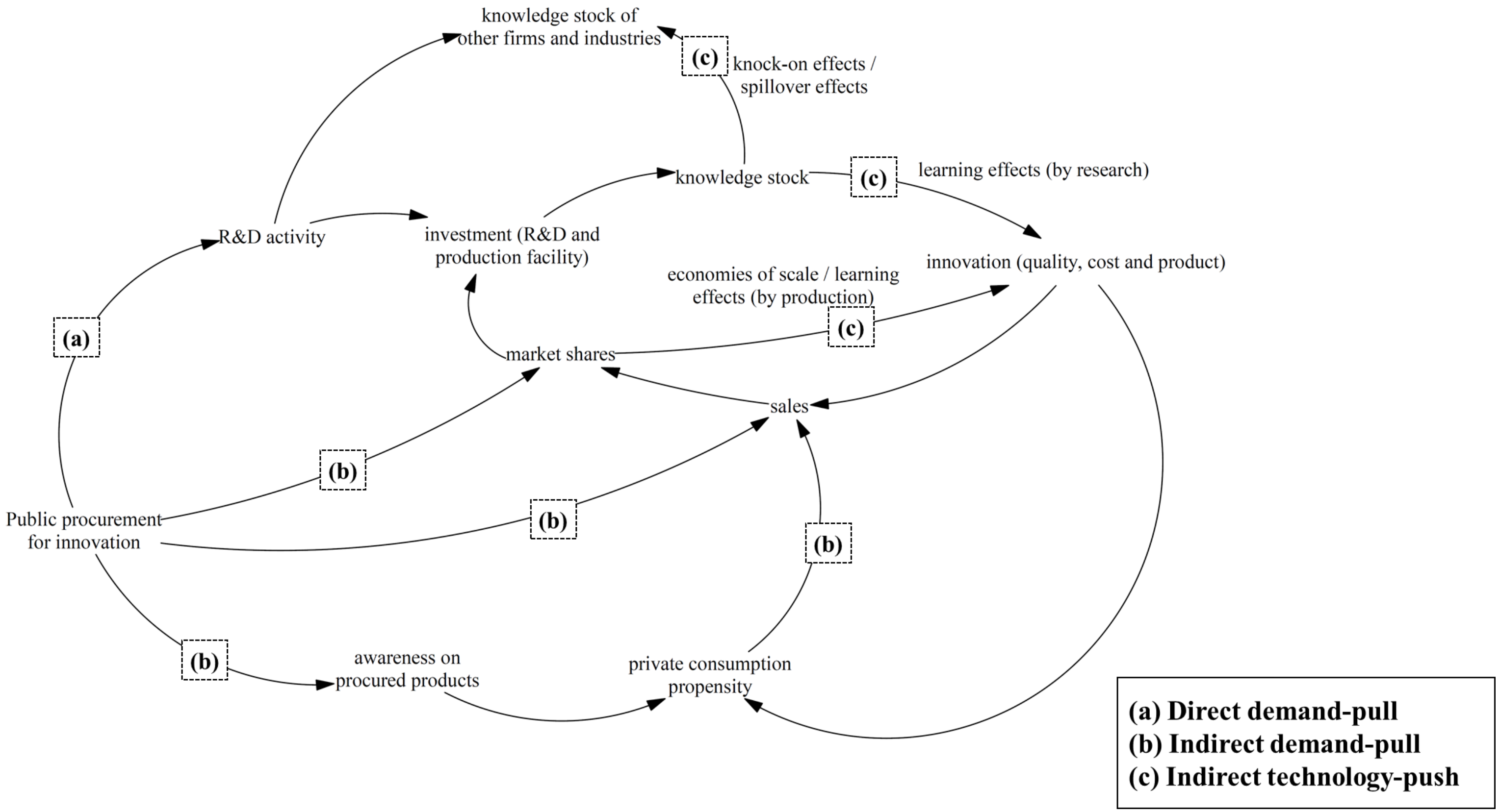

Figure 31. PPI's impact paths with different channels

5.3.2.2 Direct demand-pull effects

Figure 31 is revisited from Chapter 3 for interpretation of simulation results of PPI implementation policy scenario. There were three impact channels, direct demand-pull, indirect demand-pull, and indirect technology-push, were introduced to illustrate the PPI's policy impact paths. The simulation results are understandable upon this framework, and it can be found whether current PPI policy scheme of Korea might generate the theoretically intended and expected policy outcomes or not.

The direct demand-pull effects of PPI are related to the R&D investment. PPI is expected to increase the R&D investment of private sector which procured the product. Figure 32 suggests the change of R&D investment of public and private sector in policy scenario. It is found that both public and private R&D investment increases with PPI implementation. In the short-run, both R&D investment slightly decreases because of negative impact on production volume of PPI. However, with the generation of TFP enhancement effect on the production, R&D investment also starts to be increased. As a simulation result, it can be said that PPI's impact channel of direct demand-pull can be achieved.

When comparing between public and private R&D, the increase rate of public R&D investment is higher than that of private R&D investment. Although public R&D investment also affects the knowledge generation and production process of private sector, it is not directly linked to the PPI's policy impact channel of direct demand-pull.

Regarding this, it can be said that there is room for stimulate private R&D investment more with PPI implementation although it is still higher than the case without PPI. Therefore, the result can imply that it is necessary to consider the additional policy input to generate higher direct demand-pull effect of PPI into private R&D investment expansion.

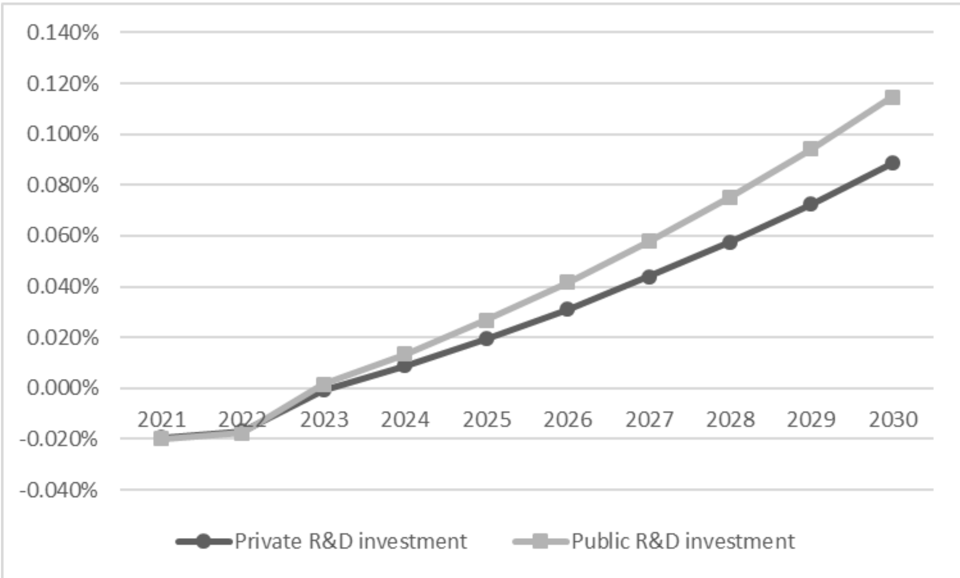

Figure 32. Change of R&D investment in policy scenario (compared to BAU)

The other direct demand-pull impact path of PPI is related to the production facility investment. Since technological and market uncertainty is reduced from the PPI contract, the private suppliers can expand both innovation and production activity. For new or additional production, it is required to expand the production facility to meet the production volume. Figure 33 suggests the change of production facility investment driven by PPI compared to BAU. The result shows that PPI policy has a positive impact on investment expansion in not only R&D but also facility. From the result, it is implied that PPI in Korea can reduce the uncertainty both on technology and demand and private suppliers are helped by PPI to increase their production and innovation activity.

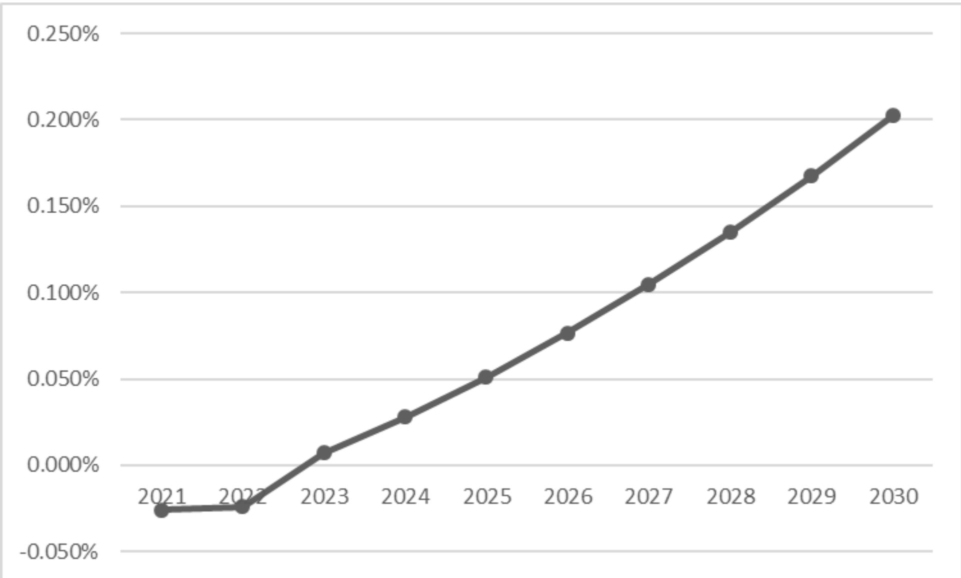

Figure 33. Change in production facility investment in policy scenario (compared to BAU)

5.3.2.3 Indirect demand-pull effects

Indirect demand-pull effects are related to the production volume and sales of the private sector. As seen in figure 27 to 29, private sectors' production volume expands thanks to PPI implementation. For the sales, we can see the difference between BAU and SCN by dividing the consumption into government and household.

Figure 34 illustrates the change of government consumption both non-procurement and procurement. Although government expands its both consumptions, the increasing rate of procurement consumption is higher than that of non-procurement consumption. As policy scenario set as the proportion of PPI to total procurement is increasing up to 50% in 2030, it can be said that government would procure more innovative goods and services with continuous implementation of PPI.

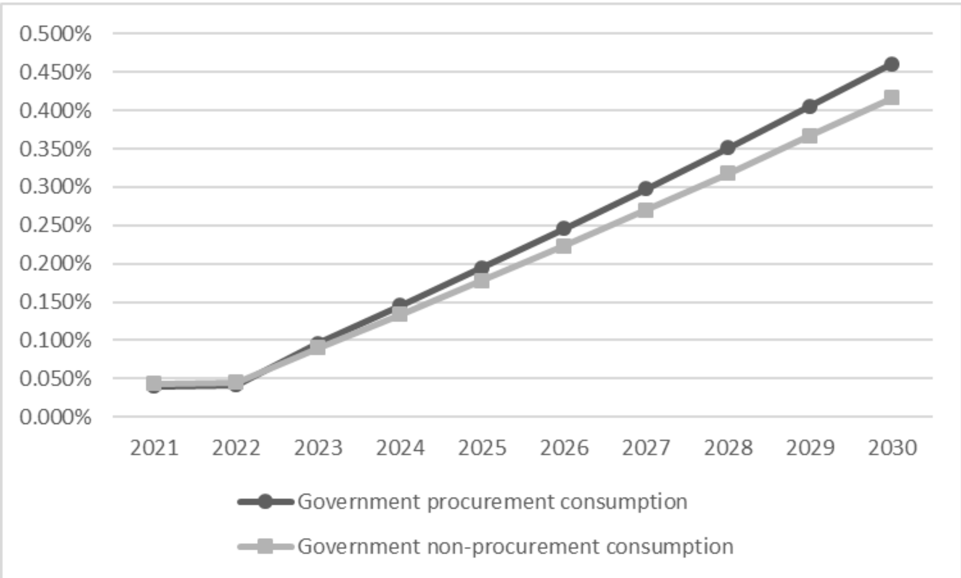

Figure 34. Change in government consumption in policy scenario (compared to BAU)

The change of total household consumption is illustrated in figure 35. Similar with the trend of total production volume, total household consumption also increases up to 2030 from PPI policy. This increased amount of household and government consumption can help the private suppliers to engage more on not only production activity but also innovation activity.

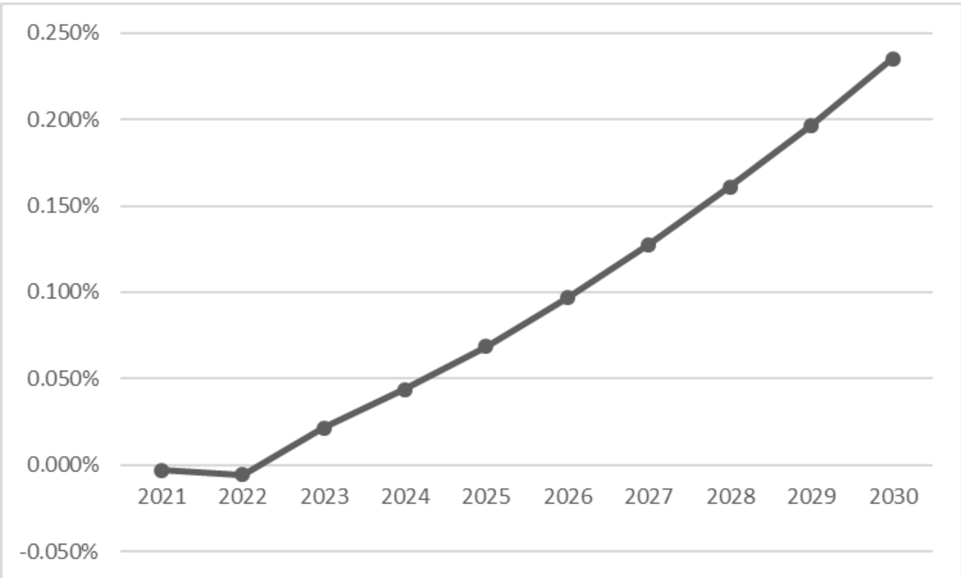

Figure 35. Change of total household consumption in policy scenario (compared to BAU)

5.3.2.4 Indirect technology-push effects

Indirect technology-push effects can be explained by knowledge stock and productivity. First of all, change of total sector-specific knowledge stock is described in figure 36. As PPI implements and the volume of PPI increases, the accumulation of sector-specific knowledge stock from both public and private R&D investment gets faster compared to BAU from 2024. Although PPI can influence negatively on knowledge stock accumulation in short-run, the direction changes with TFP enhancement effect is linked to the production and consumption. This sector-specific knowledge stock is accumulated from the sectoral R&D investment. The sector-specific knowledge stock is a source of learning by research, or learning by searching, effect on productivity. The result of figure 36 suggests that PPI can enhance the learning by research effect with the accelerated knowledge stock accumulation.

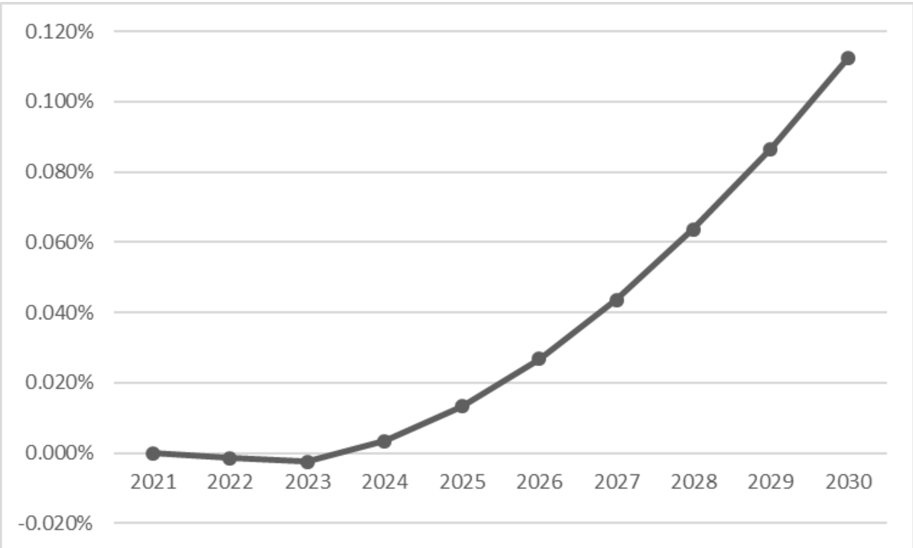

Figure 36. Change in total sector-specific knowledge stock in policy scenario (compared to BAU)

This sector-specific knowledge stock is a source of knowledge stock which considers inter-industry spillover effect. Table 20 shows the change of total knowledge stock with spillover effect. Both private and public knowledge stock increases with the implementation of PPI. As the volume of PPI increases, the accumulation speed of knowledge stock gets also faster. This knowledge stock with inter-industry spillover is also the source of productivity growth since private suppliers in one sector should use the production materials from other sectors and knowledge embedded in the intermediate input can change the productivity in production process.

Table 20. Change of knowledge stock in base and policy scenario

Year	Private knowledge stock			Public knowledge stock		
	BAU (trillion KRW)	SCN (trillion KRW)	Difference (% of BAU)	BAU (trillion KRW)	SCN (trillion KRW)	Difference (% of BAU)
2015	494.30	-	-	129.73	-	-
2025	664.59	664.68	0.013	137.62	137.64	0.013
2030	740.68	741.52	0.113	149.63	149.80	0.111

Private suppliers can achieve productivity enhancement from both reducing the production cost and improving the quality of products. The increased production, described in figure 27, is the driving force of productivity growth with the impact paths of economies of scale and learning by doing. In other words, several factors which can affect the productivity including economies of scale, learning effect both by production and R&D, and inter-industry linkage are all positively related with the implementation of PPI in policy simulation. Figure 37 illustrates the average TFP change between BAU and SCN in 2030.

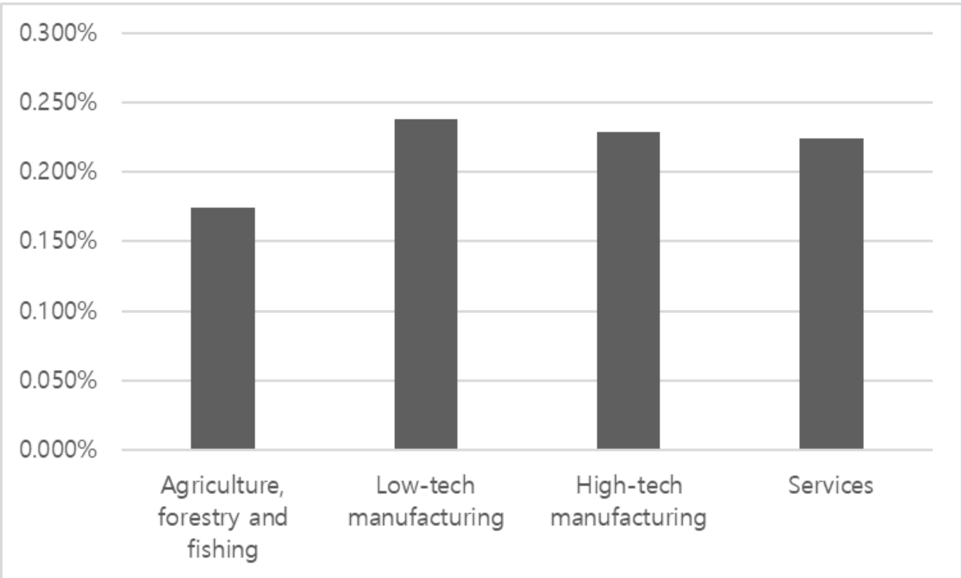

Figure 37. Change of average TFP in policy scenario in 2030 (compared to BAU)

Although service sector experiences higher growth rate in production volume than other sectors as depicted in figure 28, manufacturing sector has higher TFP enhancement by PPI implementation than service sector in average. As mentioned earlier, not only the effect from production including economies of scale and learning by doing but also other factors such as learning by searching, inter-industry linkage can affect on productivity change. Since manufacturing sectors has higher rate of R&D investment and their products is used more in other industries' production process than other sectors, they can achieve higher TFP enhancement effect. The results show that PPI policy scheme in Korea can generate expected industrial effect in indirect technology-push channels.

5.3.2.5 Systematic sensitivity analysis

The CGE model has the advantage of quantitatively presenting policy effects through simulation from the perspective of general equilibrium but has limitations in that the results are dependent on model calibration and external shocks (Chatzivasileiadis et al., 2019). To overcome the uncertainty of the results from CGE simulation, various model validation methods techniques have been established. The TEMIP model used in this study is based on the knowledge-based CGE model, and validation of the model has been confirmed through comparison with the macro-economic trend of past data (Hong et al., 2014). Therefore, here, sensitivity analysis is performed on some of the contents added in this study. Specifically, the systematic sensitivity analysis (SSA) method (Arndt, 1996), which recognizes a parameter as a stochastic variable following a specific distribution and checks the output equilibria determined according to the value of the corresponding parameter, is to be utilized. This study tries to validate the result through sensitivity analysis that observes the output variation according to the change of the input parameter value and confirms the level.

The SSA method can be divided into a Gaussian quadrature (GQ) approach and a Monte-Carlo (MC) approach according to the parameter construction method. Early studies of the SSA method for the CGE model (Arndt & Pearson, 1996; DeVuyst & Preckel, 1997; Preckel et al., 2011) have mainly used the GQ approach using a small number of parameters. However, recently, the use of the MC approach is increasing due to the increase in computing power and comparative methodological flexibility (Villoria & Preckel, 2017). In this study, the productivity improvement effect parameter of PPI, an additionally used parameter, is extracted using the MC approach, and whether the GDP result by the value shows a significant difference with the GDP of BAU is observed.

Specifically, 1000 pseudo-random sample parameters are generated using a normal distribution with a mean of 0.34 and standard deviation of 0.192 calculated in the related quantitative analysis, which is the set value of the policy scenario, for the productivity improvement effect parameter of PPI. In general, the triangular distribution is widely used in SSA using the MC approach (Chatzivasileiadis et al., 2019; Phimister & Roberts, 2017). However, It has been mentioned that normal distribution or t-distribution can be assumed when parameters extracted through quantitative analysis are used in the CGE model (Partridge & Rickman, 1998). After that, 1000 simulations are performed and the extracted 1,000 GDP results in 2030 are compared with the GDP of BAU to determine their significance.

Figure 38 shows the distribution of the 2030 GDP results simulated by reflecting 1000 pseudo-random parameters on the productivity effect of PPI in the model. The dark vertical line is the 2030 GDP result in BAU. Comparison between the results was confirmed for statistical significance using one-way analysis of variance (ANOVA). As a result of the analysis in Table xx, it was confirmed that there is a significant difference between the 2030 GDP when the PPI has an effect of improving productivity and the value without the PPI. This can be understood as having a significant difference in the result values such as GDP according to the policy scenario compared to the BAU.

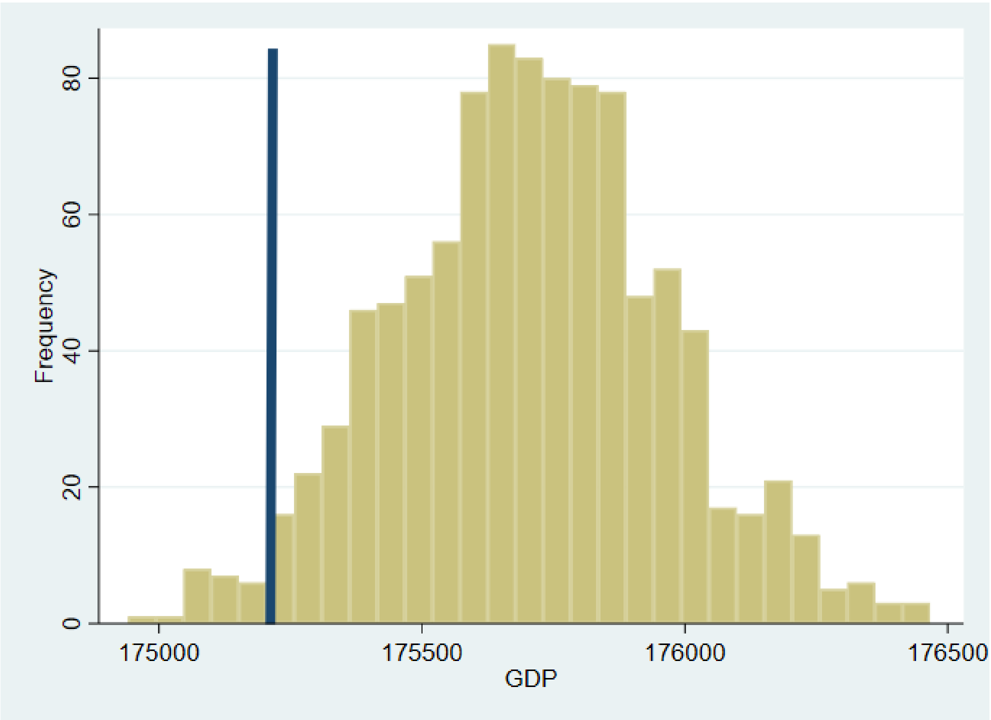

Figure 38. GDP simulated by the different parameters of PPI's productivity effect from Monte-Carlo approach

Table 21. Results of one-way ANOVA of GDP in 2030 between BAU and policy scenario

Source	Degree of freedom	Mean square	F-statistics	P-value
Between groups	1	239437.62	3.63	0.0570
Within groups	999	65936.19		
Total	1000	66109.69		

5.4 Sub-conclusion

In this study, the economy-wide impact of PPI was analyzed by focusing on the Korean economy through the CGE model. This study considered innovation and R&D as endogenous factors in the TEMIP model that considered the accumulation and spillover effect of knowledge and R&D investment as a production factor. In addition, this study reflects the impact of PPI in the form of an equation within the CGE model, taking into account the results of previous studies summarized in Chapter 2 and the proposed analyzing framework and types of PPI in Chapter 3. In this process, the relationship between PPI and productivity which was numerically derived in Chapter 4 was employed in the equation system.

The simulation model used in this analysis considers the positive relationship between PPI and productivity as well as the negative impact of PPI potentially implicated in the generation of additional cost burdens in the private sector. As a result of the analysis, it was found that converting a portion of ordinary public procurement into PPI has a positive effect on industrial growth and economic development. However, with respect to the production volume of the industrial sector, it was also confirmed that the production volume could decrease in the short term due to the negative impact potentially caused by PPI. If the effects on GDP and industrial growth are divided according to the impact paths of PPI, the magnitude of the positive effect resulting from the productivity enhancement by PPI is larger than the that of the negative impact in the short-term and long-term in common. However, it was also confirmed that the magnitude of the negative impact did not decrease in the long term.

The results of this analysis can be analyzed in connection with the impact channel of PPI presented in Chapter 3. Based on the simulation results, it was found that overall higher R&D investment and physical capital investment both from private and public sector were secured in the PPI implementation scenario than in the base scenario, indicating that a direct demand-pull channel where PPI promotes innovation and commercialization activities in the private sector is operated. Moreover, an indirect demand-pull channel in which the total amount of private consumption increases as a part of ordinary public procurement is converted to PPI was also confirmed. Lastly, the amount of knowledge capital accumulated by the learning effect was also higher in the PPI scenario than in the base scenario, and it was confirmed that it had a positive effect on TFP in combination with the effect of increasing production. That is, through the PPI policy experiment scenario for the Korean economy, it was possible to confirm the indirect technology-push channel in which the performance of PPI contributes to productivity through economies of scale and learning mechanisms.

This study has the following implications. First, it is the first study to examine the economy-wide effects of PPI through the CGE model from the academic perspective. Most of the existing studies to assess the economic impact of PPI were analysis at the firm level, and these studies had limitations that their results were drawn in partial equilibrium context. However, as discussed in Chapter 3, as PPI affects the behavior and interactions of various economic agents within the innovation system, the application of the general equilibrium viewpoint is a very important challenge in the policy evaluation of PPI. Some previous studies (e.g. Kim & Kim, 2019) have modeled the effects of procurement activities of innovative products through dynamic stochastic general equilibrium (DSGE) models, but these studies also build models that are not based on real data. On the other hand, this study has established a methodological framework that can quantitatively and numerically present the economy-wide impact of PPI by applying the various impact paths of PPI into the equations of the CGE model. In terms of science of innovation policy, the establishment of such an analysis framework can be said to be of high significance in the context of the increasing need and use of quantitative policy evidence.

In addition, this study examined the overall impact of PPI by considering its potential negative impact, which has been overlooked. As all policies have both positive and negative effects, it is necessary to consider both aspects in order to analyze the economy-wide impact of policies. However, most of the PPI-related studies have focused on demonstrating the excellence of PPI as an innovation policy, and no specific analysis has been conducted on the disadvantages that PPI can cause. However, public sector's cost inefficiency driven by PPI is a matter that must be considered in order to assess the impact of PPI from a policy point of view, and this study, by reflecting it in the form of an equation, tried to capture the economy-wide effect of PPI more realistically.

The CGE framework of this study helps to explore potential policy initiative for PPI performance through setting and description in equations of negative and positive impact paths of PPI. The analysis results showed that in the early stages of PPI implementation, temporary negative effects on the industry output and economy were found due to the cost inefficiency cause by PPI in public sector. From a policy perspective, the simulation results of this study imply that it is necessary to review the temporary negative effects caused by PPI, establish policy measures to react, and consider the conditions for sustainable long-term economic growth effects. From the simulation results, this study can draw an implication for potential innovation policy implementation method including control and diffuse the impact of PPI beyond the simple policy recommendation with PPI’s excellence. Since there is a growing interest in ex-ante policy impact assessment, the CGE framework this study developed for PPI’s economy-wide impact evaluation can help policy makers and practitioners to forecast the potential PPI policy’s influence and set the various innovation policy design.

On the other hand, this study has the following limitations, and through this, the direction of future research can be considered. As suggested in Chapter 3, the policy impacts of PPI are spread through a wide variety of interactions, but this study has a limitation in that it was analyzed by focusing on some factors due to the difficulties of model construction. For example, in the case of direct demand-pull channel, the direct effect of expanding R&D and facility investment by the implementation of PPI is suggested, but this study did not explicitly reflect the relationship in equation system. In addition, the expansion of private consumption for innovative products from signaling and increasing awareness presented in the indirect demand-pull channel of PPI's policy impact paths also made it difficult to analyze because the production sector for innovative products was not constructed separately. However, considering that the macroeconomic effects of PPI were positive even though these pathways were not taken into account, the magnitude of the impact related to GDP and industrial growth from PPI would be larger than if explicit reflection of these effects were added. It is expected that these methodological limitations can be analyzed through design improvement of the CGE model in the future. This work is also very important in terms of securing ex-ante quantitative policy evidence for the PPI, and it is expected that in-depth implications for the policy design of the PPI can be drawn through this.

Chapter 6. Conclusion

6.1 Summary of the study

In addition to emphasizing the significance of innovation as a driving force for economic growth, each country has implemented various innovation policies. Many scholars and policy practitioners are interested in the demand-side innovation policy, tackling the significance of commercialization and diffusion of the innovation results, which was not possible with the traditional supply-side innovation policy. PPI is a representative tool in the demand-side innovation policy, an interpretation of public procurement. The public sector purchases the goods or services as innovation policy measures. Various cases and empirical studies have concluded that public procurement effectively promotes private innovation activities and diffuses innovation results compared to other policy measures.

However, despite the history of academic research on PPI, few quantitative studies on the national economic impact of PPI exist. The academic gap between the growing interest in PPI and policy evaluation from an economy-wide perspective is due to the absence of a theoretical framework for PPI, including taxonomy and impact generation pathways. In demand-side innovation policies, including PPI, the generation of policy impact needs to be understood in the perspective of the interaction of various agents within the innovation system, including the supply and demand sectors and institutions, as it focuses on the commercialization and diffusion of innovation results beyond scientific discovery and technology development. However, most studies that have attempted PPI's policy evaluation have only looked at the input, output, and behavioral additionality, which contracted PPI following the traditional research trend on the policy impact assessment of supply-side innovation policy measures. Accordingly, the results of qualitative and quantitative studies are fragmented and cannot be understood from a comprehensive or systemic viewpoint.

Therefore, this study established a theoretical framework with the aim of an economy-wide impact assessment of PPI with the innovation system theory. A quantitative simulation analysis was conducted. Through this, a qualitative and quantitative description of the economy-wide impact of PPI was derived. Furthermore, a theoretical and methodological analysis framework that can be used in the ex-ante policy evaluation of PPI was established. The main findings of this study are summarized below.

In Chapter 2, the possible implementation of public procurement as an innovation policy was identified through the summary of existing studies, and methodological discussions for analyzing the economy-wide impact of PPI were conducted. PPI is known to have a more positive impact on promoting private innovation activities and the commercial success of innovation results than traditional innovation policy tools, including R&D subsidy or tax grant. However, there is a limitation in that such literature has only captured the relationship between policy implementation and the change of the benefitted firms' activities using case studies or econometric methods. Considering that

PPI's policy impact is generated within the innovation system and that the ultimate goal of the innovation policy is economic growth, an analysis of the economy-wide impact of PPI could draw significant academic and policy implications. However, little research using this approach has been conducted thus far. This study highlights the absence of a theoretical framework for PPI as the main reason for this research gap. It concludes that it is necessary to conceive a methodological analysis framework that can interpret PPI in general equilibrium to consider all agents in the economy and their interactions.

Based on the research motivation drawn in Chapter 2, Chapter 3 established a theoretical framework including an exploration of the impact paths of PPI and the type classification and generation of taxonomy. The effect of PPI on private innovation and business growth found in several studies was understood from the perspective of technology-push and demand-pull. This was identified by analyzing the effect of PPI from a system perspective. Additionally, based on the systemic interpretation of PPI's policy impact, the taxonomy of PPI was established, differentiated influence paths for each type were identified, and validation of the theoretical framework was established through an in-depth case analysis of the Korean EV PPI. Therefore, it was found that PPI plays a role in facilitating the interaction of suppliers, private consumers, and public consumers—agents in the innovation system. Additionally, the interaction among them can vary according to market evolution and technological maturity. The Korean EV PPI case is a representative example that shows that the PPI policy mechanism can change depending on market and technology development. When the market volume of EVs in

Korea was low, and there was room for technological development in EV suppliers, it helped market creation and technological improvement, the main impact path of pre-commercial PPI. While PPI was in progress, in the later stages, it was found that the type of PPI changed to commercializing PPI, to diffuse EV to a private consumer with the competitively developed technological specification. The study in Chapter 3 provided an analysis framework for analyzing the micro- and macro-level impact assessment of PPI by considering the integrated theoretical framework of PPI, which did not exist before. Additionally, the constructed taxonomy can interpret various PPI cases in several countries by checking the potential influence and forecasting the expected outcomes.

Chapter 4 empirically investigated the policy impact of PPI to confirm some of the impact paths suggested in Chapter 3. The analysis was conducted at the firm level and aimed at assessing the impact of PPI on the firm and industrial productivity with the procurement of excellent products in Korea. As suggested in Chapter 3, PPI stimulates the motivation for innovation activity by reducing technology and market uncertainty. The learning effect from the R&D stock from the investment positively impacts productivity. Nevertheless, PPI generates large-scale initial demand from the public sector, allowing suppliers to experience reduced production costs and improved product quality through economies of scale. The analysis in Chapter 4 estimated the policy impact by comparing the outcome variables between the firms that performed PPI and those that did not, using the PSM methodology, widely used for impact assessment of innovation policy measures. The analysis results found that PPI significantly affects the increase in the change rate in productivity of the firms in terms of total factor productivity (TFP). However, it was confirmed that there was a time difference between the implementation of PPI and its impact generation on productivity, as the impact appeared two years after the firm performed PPI. A similar trend was identified in the industry-level analysis. It was found that the higher the proportion of firms benefitting from PPI in the industry, the higher the overall productivity level of the industry. The results are meaningful in that they empirically verified the impact paths related to PPI's productivity effect, including economies of scale, learning effect, and industrial spillover effect presented in Chapter 3. Additionally, another contribution of the results is that the quantitative data used for the economy-wide impact assessment of PPI is estimated.

Finally, Chapter 5 contains the analysis of the economy-wide impact of PPI, the final research objective of this study. Confirming the policy impact of PPI in terms of industrial expansion and economic growth is an important academic topic. However, not many studies have been conducted thus far due to the lack of a theoretical framework of PPI and, consequently, inadequate systematic analysis of its impact. However, this study established a theoretical framework for the systematic analysis of PPI and taxonomy and impact paths in Chapter 3. The micro-level empirical analysis in Chapter 4 partially validated this framework. Based on this, Chapter 5 analyzed the policy impact of PPI from an economy-wide perspective considering the impact paths of PPI. The analysis was conducted with the CGE model, widely used for the economy-wide impact assessment of policy. Specifically, the TEMIP model specialized in the analysis of innovation policy was used as the backbone model. The various influence pathways suggested in Chapter 3 were reflected in the general equilibrium model with the results of existing studies and the numerical figures from Chapter 4. As a result of the simulation analysis of the policy scenario in which the Korean government converts a certain portion of ordinary public procurement to PPI, it was found that PPI led to GDP increase and industrial output expansion in the long run. However, in the short run, the cost inefficiency of the public sector triggered by PPI implementation led to a negative effect on economic growth.

The simulation results in Chapter 5 also confirmed some impact paths of PPI presented in Chapter 3. First, the direct demand-pull effect was indirectly verified by confirming that the conversion of some portion of ordinary public procurement into PPI expanded R&D investment and physical capital investment in the entire economy. Additionally, by confirming the knowledge stock and TFP level, it was confirmed that, at the national economic level, the implementation of PPI affected productivity. Finally, indirect technology-push channels such as economies of scale, learning effects, and inter-industry spillover could be understood. Through this analysis, it was possible to confirm the prospect of PPI as an innovation policy for economic growth, secure quantitative policy evidence, and analyze the methodology used in establishing innovation policy, including PPI.

6.2 Implications

This study has the following academic implications. First, a theoretical framework was established for future PPI-related policy analysis. Second, the policy research related to PPI started from a policy impact assessment. Recently, the scope of the research has been expanded to the governance structure for effective PPI and utilization for tackling social problems. Third, the basis of academic studies requires a comprehensive understanding of the impact paths of PPI. Thus, the theoretical framework established in this study can be utilized. Particularly, as the absence of a consensus definition and theoretical framework was highlighted against the backdrop that PPI-related studies were not organized, the analytical framework of this study can be utilized in various academic approaches, grasping the policy impact focusing on the interactions between economic agents from the viewpoint of the innovation system.

The theoretical framework suggested in Chapter 3 is linked to the quantitative model for analyzing the economy-wide impact of PPI from the perspective of general equilibrium in Chapter 5. This means that the basis of the empirical analysis for the ex-ante policy evaluation has also been secured based on theoretical analysis. Further, the CGE model in Chapter 5 can be used for future studies. It contains the negative effect of PPI generated in the public sector and the positive effects of PPI for innovation and production activity. This setting helps improve the consistency of simulation results in reality.

Additionally, the policy implications of this study are as follows. PPI's impact paths from the system perspective presented in this study will help policymakers or practitioners identify PPI's expected influence and utilize it in decision-making and implementation processes. As the complexity of society increases, the policy impact also influences various economic actors and their interactions, making it difficult for policymakers to predict the direct and indirect effects that policy can induce prior to implementation. Thus, the impact path presented in this study will function as reference material in the policy-making process by presenting the policy impact of PPI from a system perspective.

This study showed that replacing some ordinary public procurement with PPI positively affected industrial development and economic growth through the economy-wide impact assessment of PPI. This can be used as proof of policy that can actively utilize PPI in the future innovation policy category. Moreover, the results of this study are meaningful in that it is possible to secure an ex-ante policy evaluation methodology that policymakers can use in analyzing the policy impact of PPI beyond simple numerical findings. In a situation where obtaining policy evidence using both analytical and scientific methods is emphasized in policy decisions, the combination of the theoretical framework of Chapter 3 and the quantitative analysis methodology of Chapter 5 proactively grasp the policy effects of PPI and design policies to maximize the expected policy impact.

As a representative tool of the demand-side innovation policy, PPI has been widely used in many countries in recent years. However, not many governments require to have their policy evidence in advance for PPI policy implementation, obtained through in-depth qualitative and quantitative analysis related to policy design. In this study, by considering the positive policy impacts of PPI, as well as the possible negative impacts, the points to pay attention to in PPI-related policy design were confirmed through the interpretation of the results. Specifically, in the simulation analysis of Chapter 5, it was recognized that the implementation of PPI could potentially cause the private companies that supply PPI to bear a higher cost, and it was reflected. The related effects were decomposed and presented. Therefore, it was found that the negative impact did not decrease in the long run, although the magnitude of the positive impact was larger. Through this, it can be suggested that a policy design that can minimize the additional cost that PPI may incur is necessary. In the absence of this, PPI's long-term national economic effect will be reduced.

6.3 Limitations and future studies

This study suggests future research directions through the following limitations. First, in analyzing the policy impact of PPI at the firm level, it is necessary to check the various impact paths presented in Chapter 3. Although this study investigated the effect of PPI on productivity and R&D investment, which are important outcome variables, Chapter 3 highlighted that various factors, including production facility investment, new product generation, and R&D-related behavior can be influenced by the contract awarding of PPI. Second, considering the impact path of PPI, it will be possible to increase the consistency of the theoretical framework for PPI analysis in the real world. However, it requires a methodological challenge in an econometric way.

This study constructed a policy scenario related to PPI by using the policy initiatives announced by the Korean government. However, as PPI is used in various forms and depths in countries worldwide, a policy reference can be provided by assessing diversified policy scenarios to explore the policy design of PPI suitable for the economic structure of Korea.

PPI is used as a measure of innovation and various tools, including R&D subsidy, tax grants, and public direct R&D investment. This implies that it is necessary to consider the policy mix with these measures in analyzing the economy-wide impact of PPI. Considering that obtaining ex-ante policy evidence means securing data necessary for policy design, classifying and analyzing various policy mixes, rather than conducting policy analysis on the use of PPI alone, would provide more practical policy implications. Furthermore, the TEMIP model used in this study is specialized for innovation policy impact assessment. It is expected that the economy-wide impact assessment of various innovation policy mixes will be possible through the additional equations included in Chapter 5 with PPI's impact on R&D investment, productivity, and price. Consequently, the model modified by this study can be a benchmark methodological reference for innovation policy impact assessment of Korea in the future, when it is upgraded to reflect more complicated impact paths of PPI.

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Appendix 1: Proportion of knowledge capital in total capital income

No.	Sector	Proportion of knowledge capital
S01	Agriculture, forestry and fishery	0.27%
S02	Mining and quarrying	6.51%
S03	Food, beverages and tobacco products	4.08%
S04	Textile and apparel	3.78%
S05	Wood and paper products, printing and reproduction of recorded media	1.24%
S06	Petroleum and coal products	6.42%
S07	Chemicals, drugs and medicines	10.43%
S08	Non-metallic mineral products	3.08%
S09	Basic metal products	2.63%
S10	Fabricated metal products except machinery and furniture	2.63%
S11	General machinery and equipment	11.18%
S12	Electronic and electrical equipment	17.47%
S13	Precision instruments	17.47%
S14	Transportation equipment	14.17%

S15	Furniture and other manufacture products	4.70%
S16	Electricity, gas, steam and water supply	2.03%
S17	Construction	5.30%
S18	Wholesale and retail trade	1.05%
S19	Transportation	0.16%
S20	Accommodation and food services	1.05%
S21	Communications and broadcasting	6.40%
S22	Finance and insurance	0.01%
S23	Real estate and business services	0.01%
S24	Public administration and defense	3.85%
S25	Education services	3.87%
S26	Health and social work	7.71%
S27	Other services	0.08%
S28	Private R&D	-
S29	Public R&D	-

Appendix 2: List of variables and parameters in CGE model

Sets and indices	
i, j	Sectors and goods
rdt	Type of R&D (public and private)
f	Type of production factors (labor, capital, and knowledge)
t	Time (year)
Activity variables	
Y(i)	Total output of sector i
YIM(i)	Total intermediate goods of sector i
RVA(i)	Value-added composite of sector i
QIM(j,i)	Intermediate goods for sector i produced in sector j
TFP(i)	Total factor productivity of sector i
VA(i)	Labor-capital composite of sector i
R(i)	Knowledge capital of sector i
K(i)	Physical capital of sector i
L(i)	Labor of sector i
HIL	Household labor income

HIK	Household capital income
HIR	Household knowledge income
HI	Total household income
GT	Government transfer
QH(i)	Household consumption for sector i
HC	Total household consumption
HS	Total household saving
GI	Government income
GD	Government debt
GC	Government non-procurement consumption
QG(i)	Government non-procurement consumption for sector i
OPP	Government ordinary procurement consumption
QOPP(i)	Government ordinary procurement consumption for sector i
PPI	Government PPI consumption
QPPI(i)	Government PPI consumption for sector i
KIV	Total physical capital investment
AS	Available saving
QIV(i)	Physical capital investment of sector i
RI(i)	Private knowledge capital investment of sector i

QIVP	Total private knowledge capital investment resource
TRI	Total private knowledge capital investment
GRI(i)	Public knowledge capital investment of sector i
QIVG	Total public knowledge capital investment resource
TGRI	Total public knowledge capital investment
TS	Total saving
FS	Trade balance
Q(i)	Armington composite goods of sector i
M(i)	Imported goods of sector i
D(i)	Domestic goods of sector i
E(i)	Export goods of sector i
TOL	Total labor
TOK	Total physical capital
TOR(i)	Total knowledge capital of sector i
GDP	Gross domestic product
UU	Total utility
KS(t)	Physical capital stock at time t
RK(i,t)	Private knowledge capital stock of sector i at time t
GRK(i,t)	Public knowledge capital stock of sector i at time t

TRS(t)	Total private knowledge capital stock at time t
TGRS(t)	Total public knowledge capital stock at time t
SR(i,t)	Aggregated private knowledge stock of sector i at time t
SGR(i,t)	Aggregated public knowledge stock of sector i at time t
Price variables	
PY(i)	Price of total output of sector i
PYIM(i)	Price of intermediate goods of sector i
PRVA(i)	Price of value-added composite of sector i
PQ(i)	Price of Armington composite goods of sector i
PVA(i)	Price of labor-capital composite of sector i
PR(i)	Price of knowledge capital of sector i
PK	Price of physical capital
PL	Price of labor
PHC	Price of household consumption (numeraire)
PGC	Price of government non-procurement consumption
POPP	Price of government procurement consumption
PPPI	Price of PPI consumption
PKIV	Price of investment goods
PE(i)	Price of export goods of sector i

PWE(i)	World price of export goods of sector i
PM(i)	Price of imported goods of sector i
PWM(i)	World price of imported goods of sector i
Parameters	
γy(i)	Scale parameter in production function of final goods of sector i
μy(i)	Share parameter in production function of final goods of sector i
τy(i)	Tax rate for production tax of sector i
aqm(i,j)	Intermediate input requirement coefficient from i to j
pdif(i)	Price difference caused by PPI
γrva(i)	Scale parameter in production function of value-added composite of sector i
μrva(i)	Share parameter in production function of value-added composite of sector i
γva(i)	Scale parameter in production function of labor-capital composite of sector i
μva(i)	Share parameter in production function of labor-capital composite of sector i
tl	Tax rate for income tax
tk	Tax rate for corporate tax
muh(i)	Share parameter in household consumption function of sector i
γh	Scale parameter in household consumption function of sector i
ahs	Ratio of household saving in total household income
agt	Ratio of government transfer in total government income

mug(i)	Share parameter in government consumption function of sector i
muopp(i)	Share parameter in government ordinary procurement consumption function of sector i
muppi(i)	Share parameter in government PPI consumption function of sector i
ags	Ratio of government saving in total government income
agrd	Ratio of public R&D investment in total saving
ard	Ratio of private R&D investment in total saving
mui(i)	Share parameter in investment function of sector i
ari(i)	Ratio of private R&D investment of sector i in total private R&D investment
ard	Ratio of private R&D investment in total saving
agri(i)	Ratio of public R&D investment of sector i in total public R&D investment
agrd	Ratio of public R&D investment in total saving
exr	Exchange rate
γ(i)	Scale parameter in Armington function of sector i
δm(i)	Share parameter in Armington function of sector i
θ(i)	Scale parameter in transformation function of sector i
ξ(i)	Share parameter in transformation function of sector i
kdep	Depreciation rate of physical capital stock
rdep	Depreciation rate of knowledge capital stock
spovr(i,t)	Spillover coefficient of R&D investment on TFP of sector i at time t

nusr(i)	Elasticity of private R&D capital stock of sector i
nusgr(i)	Elasticity of public R&D capital stock of sector i
we(j,i)	R&D transformation coefficient from sector j to sector i
gl(t)	Population growth rate
ohm	Coefficient for PPI's TFP enhancement effect
rho	Coefficient for PPI's cost inefficiency effect
τppi(i)	Coefficient for PPI's impact on additional cost of sector i
tfpppi(i)	Coefficient for PPI's impact on TFP enhancement of sector i

Abstract (Korean)

기술혁신은 경제 성장의 주요한 원동력 중 하나이며, 이에 따라 많은 국가에서 민간 혁신을 촉진하기 위한 다양한 형태의 혁신정책을 시행해 왔다. 최근에는 기술개발 결과의 상용화 및 확산에 초점을 맞춘 수요기반 혁신정책에 대한 관심이 높아지고 있다. 혁신적이지만 아직 시장이 성숙하지 못한 제품 또는 서비스에 대한 공공구매를 뜻하는 혁신지향적 공공구매는 대표적인 수요기반 혁신정책 수단으로 다양한 사례 및 실증 연구를 통해 우수한 혁신 효과가 입증되어 왔다. 하지만 기업 수준의 효과 분석을 넘어 혁신지향적 공공구매의 거시경제적 효과를 분석하고자 한 시도는 아직 없으며, 이에 본 연구에서는 혁신지향적 공공구매의 국가 경제적 파급효과를 분석할 수 있는 이론적, 실증적 분석 틀을 구축하고자 한다.

혁신지향적 공공구매의 효과와 관련한 그 동안의 연구는 혁신지향적 공공구매의 영향 경로가 매우 다양함을 보여준다. 그러나 이러한 연구 결과를 종합할 수 있는 이론적 분석 프레임워크의 부족으로 인해 혁신지향적 공공구매의 혁신 관련 효과가 국가, 산업 또는 사례에 한정하여 해석되고 있다는 한계

가 있다. 이애 본 연구는 다양한 기존 연구의 결과를 시스템 관점에서 재해석하여 혁신지향적 공공구매의 영향 경로를 식별하고자 하였다. 세부적으로, 기술주도 및 수요견인 등 혁신의 동인에 대한 주요 논의를 바탕으로 혁신지향적 공공구매의 정책 효과를 공급자, 소비자, 정부 등 혁신 시스템 내 다양한 주체 간 상호작용으로 이해하는 분석 프레임워크를 구축하는 연구를 진행하였다. 또한, 이를 바탕으로 여러 국가에서 다양하게 활용되는 혁신지향적 공공구매의 정책 사례를 분류할 수 있도록 유형 분류를 진행하였으며, 한국의 전기자동차에 대한 혁신지향적 공공구매 사례에 대한 분석을 통해 구축된 이론적 프레임워크 및 유형 분류의 검증을 시도하였다.

구축된 이론적 프레임워크를 바탕으로 본 연구는 실증적으로 혁신지향적 공공구매의 거시경제적 효과를 확인하고자 하였다. 이를 위하여 우선 혁신지향적 공공구매의 기업 수준의 효과를 부가성의 관점에서 분석하였다. 계량경제학적 방법론을 활용한 분석의 결과 대체적으로 혁신지향적 공공구매는 수행기업의 생산성 향상에 긍정적인 영향이 있는 것으로 확인되었다. 이러한 분석 결과를 토대로 본 연구는 연산일반균형 모형을 활용하여 혁신지향적 공공구매의 거시경제적 효과 분석을 수행하였다. 다양한 경제 주체의 행동 및 상호작

용을 방정식의 형태로 나타낸 연산일반균형 모형을 통해 혁신 시스템 관점에서 해석된 혁신지향적 공공구매의 다양한 영향 경로를 반영할 수 있다. 본 연구에서는 혁신정책의 사전적 정책 평가에 특화된 모형인 TEMIP 모형을 기반으로, 혁신지향적 공공구매의 효과를 명시적으로 반영한 연산일반균형 모형을 구축하였다. 해당 모형을 통한 정책 분석 결과 일반 공공구매 중 일부를 혁신지향적 공공구매로 전환할 경우 장기적으로 산업 발전 및 경제 성장에 긍정적인 영향이 나타나는 것을 수량적으로 확인하였다. 다만, 혁신지향적 공공구매가 초래할 수 있는 공공 부문의 부정적 영향으로 인해 정책 시행 초기에는 거시경제적인 악영향이 발생할 수 있음 역시 지적되었다.

혁신지향적 공공구매의 종합적 효과 분석을 위한 이론적, 실증적 프레임워크의 구축을 통해 본 연구는 혁신지향적 공공구매의 역할 및 정책적 가능성을 확인하는 시사점을 도출하고자 하였다. 특히 이론적으로 그 동안 파편화되어 있던 혁신지향적 공공구매와 관련한 다양한 연구를 종합적으로 판단할 수 있는 분석의 틀을 제공함으로써 향후 관련 연구의 범위 및 깊이를 더할 수 있도록 하는 기여를 할 수 있을 것으로 보인다. 실증적으로는 혁신지향적 공공구매의 거시경제적 효과를 수량적으로 제시한 첫 번째 연구로써, 혁신지향적 공

공구매를 포함한 혁신정책의 평가를 위한 방법론을 제공하여 사전적 정책 증거의 확보 및 이를 통한 혁신정책의 과학화를 위한 실증적, 방법론적 기반을 제시하였다는 점에서 가치가 있다고 할 수 있다.

주요어 : 혁신지향적 공공구매, 혁신정책, 성향점수매칭, 정책분석, 연산일반균형
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