A Thesis Submitted for the Degree of PhD at the University of Warwick

http://go.warwick.ac.uk/wrap/66549

An Analysis of Regional Innovation Processes Using Operational Research Tools: The Case of South Korea

by

Ungkyu Han

A thesis submitted in partial fulfilment of the requirements

for the Degree of Doctor of Philosophy

Operational Research and Management Sciences

Warwick Business School

The University of Warwick

November 2014

TABLE OF CONTENTS

CHAPTER 4. PAPER 2 — UNDERSTANDING THE TRIPLE HELIX MECHANISM FROM A SYSTEMS THINKING PERSPECTIVE: THE CASE OF SOUTH KOREA........................86

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my main supervisor *Dr Martin Kunc* for his valuable advice and encouragement throughout the entire research process. His academic guidance strengthened my research ability more than I expected. He continually and convincingly conveyed to me a spirit of adventure and excitement concerning research. I gratefully acknowledge his support and generosity, without which the present dissertation could not have been completed. I also give many thanks to *Professor Mette Asmild*, Copenhagen University, Denmark, for her academic advice on my thesis and general studies on efficiency evaluation. Although she left for Copenhagen University after my first year at Warwick Business School, she has continued to offer strong interest in my first paper. I will always remember her enthusiastic support.

Had I not made the acquaintance of *Dr Hwang-hee Cho* at the Science and Technology Policy Institute (STEPI) in Korea, I would have lost a great chance to study towards my PhD research topic. When I was working at STEPI before starting my PhD study, he suggested me to participate in a challenging journey to study about (regional) innovation systems. I also thank *Dr Yoon-Jun Lee, Dr Hee-Jong Kang, Dr Jiyoung Suh, Dr Kwang-ho Lee, and Dr Seok-Hyeon Kim* at STEPI for their continuing interests in my research career. Further, I would like to offer my special thanks to *Professor Keun-tae Cho* at Sungkyunkwan University, Korea, who was my supervisor while I studied towards my master's degree in Management of Technology.

I cannot thank my dearest, multinational friends enough for their friendship: *Christopher Mark Smith*, *Illias Filippou*, *Joey Indo, Juan Pablo Torres*, *Katey Anto*, *Kazim Baris Atici*, *Kenneth Kyunghyun Huh*, *Leandro Galli*, *Loulou Le Guy Ame, Lu Li*, *Mahdi Noorizadegan*, *Martin Nathanael Simanjuntak*, *Orestis Papadopoulos*, *Osman Ghani*, *Penelope Muzanenhamo*, and other colleagues at Warwick Business School. I also would like to express my gratitude towards my university friends (*Joon-ho Chang*, *Jungwoo Beak*, and *Seong-hoon Gwon*) and church friends (*Jong Ho Jeon*, *Kun Wook Lee*, and *Sang-hun Kim*) from Korea for their constant companionship and support. I will never forget the day I first met *Jeongseon Seo* and *Sangwoo Shin*, who have been working towards a PhD at the Science and Technology Policy Research Unit of Sussex University, England. Despite their busy PhD schedules, they were willing to offer me constructive advice and criticism on the direction of my research.

Last but not least, this dissertation would not have been feasible without the unlimited moral support from my wife, *Su-youn Kim*. I would also like to praise her for successfully completing her PhD research and for her overwhelming passion for research.

May God bless all of us forever.

November 2014

Ungkyu Han, getting a load off my mind for the bittersweet future…

DECLARATIONS

■ I declare that this thesis is my own work.

■ This thesis has not been submitted in any other university.

■ During the preparation of this thesis, a number of papers and presentations were prepared as listed below. The remaining sections of this thesis are unpublished.

1. ‘A dynamic analysis of regional competitiveness in innovation processes: the case of Busan, South Korea’, *Research Policy*, Submitted in July 2014.

2. ‘Understanding the triple helix mechanism from a systems thinking perspective: the case of South Korea’, *Research Policy*, Submitted in September 2013.

3. ‘Regional R&D efficiency in Korea from static and dynamic perspectives’ (forthcoming), *Regional Studies*, Accepted in October 2014.

4. ‘Systems thinking to understand a knowledge-producing triple helix innovation process’, Presented at *The International Conference of the System Dynamics Society*, Cambridge, the United States, July 2013.

5. ‘Systems Thinking of a triple helix innovation system from a knowledge-producing institutions perspective’, Presented at *The OR54 Conference of the Operational Research Society*, Edinburgh, the United Kingdom, September 2012.

6. ‘Philosophical insights in system modelling: an application to the field of innovation systems’ (forthcoming), *International Journal of Economics and Business Research*, Accepted in September 2014.

7. ‘Philosophical insights in system modelling : an application to the field of innovation systems’, Presented at *The OR53 Conference of the Operational Research Society*, Nottingham, the United Kingdom, September 2011.

8. ‘Analysing regional innovation process based on corporate competencies using OR tools: the Application on the manufacturing sector in Korea’, Presented at *The UK Chapter of System Dynamics Society*, London, the United Kingdom, February 2011.

ABSTRACT

Considering the pivotal contributions of technological advances and policies in developing regional innovation and competitiveness, this thesis begins with an open question which is '*How do regions fulfil their territorial innovation potential and become competitive based on science and technology from a systems perspective?*' Prior studies have leaned towards a top-down view in evaluating the performances and competitiveness of regions, a correlation-based view in defining relations between resources and performances, and a static view in capturing the behaviour of regional innovation processes. However, these perspectives do not fully account for (1) 'regional diversity' which should consider context-specific conditions across different regions; (2) 'regional structure' in which functions (or capabilities) play a role in bridging the gap between resources (capacities) and performances to construct feedback loops for regional innovation processes; and (3) 'regional behaviour' which should reflect dynamics and evolution in terms of regional innovation, competitiveness, and policy effects.

To comprehensively redress the research gaps in the extant literature, this thesis addresses three sub-questions: (1) *Which regions are competitive in terms of R&D efficiency?*; (2) *How do regional innovation systems operate in the resource−function−performance structure?*; and (3) *How does regional competitiveness behave over time, and what policy(ies) can help or hinder regional competitiveness?* Thus, through a case study focusing on Korea, this thesis aims to accomplish three research objectives. Specifically, it identifies the most competitive

Korean region in terms of regional R&D efficiency and its time-dependent changes (Research Objective 1), a resource-function-performance structure comprising evolutionary innovation processes (Research Objective 2), and, based on this structure, policy measures promoting dynamic regional competitiveness (Research Objective 3).

To achieve this purpose, this thesis employs a ‘three-paper route scheme’, comprising three publishable academic papers. For Research Question 1 (see Paper 1), this thesis investigates the R&D efficiency patterns of Korean regions for the period 2005–2009, through data envelopment analysis from a static perspective and the Malmquist Productivity Index from a dynamic perspective. The analysis results categorise Korean regions into deteriorating, lagging, and improving groups. Further, the results designate Busan as the most promising region with the largest growth in R&D efficiency over the long-term, despite its status as an inefficient region.

Then, regarding Research Question 2 (see Paper 2), this thesis analyses Busan’s knowledge-based triple helix innovation process, by means of a causal loop diagram based on an interviewing method. For further analysis, this thesis examines the effects of system failures and policies on the operation of Busan’s innovation system. The analysis reveals that the effects of system failures and relevant policies spread across the domains of knowledge development, knowledge diffusion, and knowledge deployment. Moreover, the results indicate that the suggested policies appear intuitively effective; however, from a system-based perspective, the policies create counterintuitive effects on knowledge development in the industry and government research institute (GRI) spheres, knowledge diffusion in the university sphere, and knowledge deployment in the university and GRI spheres.

To address Research Question 3 (see Paper 3), this thesis transforms the causal loop diagram, developed in Paper 2, to a simplified system dynamics model of capacity−capability−performance for analysing dynamic regional competitiveness and policy effects on it. According to the analysis results, the increase in the stock of human resources, increase in the success rate for knowledge development, and reduction in the lead time for knowledge commercialisation are highly effective in helping to intensify the governance of reinforcing feedback loops to promote the sustainable development of Busan's regional competitiveness.

ABBREVIATIONS

AMC	Achieved manufacturing costs
BCC	Banker, Charnes, Cooper
CCR	Charnes, Cooper, Rhodes
CLD	Causal loop diagram
CPCI	Completed process innovations
CPDI	Completed product innovations
CR	Change in the number of researchers
CRD	Completed R&D projects
DEA	Data envelopment analysis
DK	Depreciated knowledge
DPKinOR	Depreciated public and university knowledge in other regions
EC	European Commission
ETRI	Electronics and Telecommunications Research Institute
EU	European Union
FDI	Foreign direct investment
GDP	Gross domestic product
GRDP	Gross regional domestic product
GRI	Government research institute
IK	Industrial knowledge
IKNPCI	Usability of industrial knowledge for process innovation
IKNPDI	Usability of industrial knowledge for product innovation

IKtoTK	Ratio of industrial knowledge to total knowledge
InterRTT	Inter-regional technology transfers
IntraRTT	Intra-regional technology transfers
IP	Innovation period
ISR	Innovation success rate
KIPO	Korea Intellectual Property Office
KISTEP	Korea Institute of Science & Technology Evaluation and Planning
KL	Knowledge lifespan
KLinOR	Knowledge lifespan in other regions
KNOW	Knowledge
KOSIS	Korean Statistical Information Service
KRP	Knowledge recipient pool
KRW	Korean currency unit: won
MEST	Ministry of Education, Science and Technology
MoST	Ministry of Science and Technology
MPI	Malmquist productivity index
NK	New knowledge
NPCI	New process innovations
NPDI	New product innovations
NPKinOR	New public and university knowledge in other regions
NRD	New R&D projects
OC	Other costs
OCperCPDI	Other costs per completed product innovation
OECD	Organization for Economic Co-operation and Development

OMC	Original manufacturing costs
OMCperCPDI	Original manufacturing costs per completed product innovation
PCI	Process Innovations
PCIR	Process innovation rate
PCT	Patent Cooperation Treaty
PDI	Product Innovations
PDIR	Product innovation rate
PKinOR	Public and University Knowledge in Other Regions
PKtoTK	Ratio of public and university knowledge to total knowledge
PRDE	Profit effect on R&D expenditure
R	Researchers
R&D	Research and development
RCEPS	Relative contribution of existing products to sales
RDDR	R&D density per researcher
RDE	R&D expenditure
RDERC	Investment effect on researcher change
RDP	R&D period
RDPD	R&D productivity
RDProject	R&D Projects
RDSR	R&D success rate
RMC	Reduced manufacturing costs
RMCperCPCI	Reduced manufacturing costs per completed process innovation
SCBRI	Shinkin Central Bank Research Institute
SCIE	Science Citation Index Extended

SCPDI	Sales from completed product innovation
SEP	Sales from existing products
SME	Small- and medium-sized enterprise
SperCPDI	Sales per completed product innovation
TC	Total costs
TCI	Technical change index
TECI	Technical efficiency change index
THC	Technology holding company
TP	Total profits
TS	Total sales
TTO	Technology transfer offices
TTR	Technology transfer rate
UK	United Kingdom
USA	United States of America
WIPO	World Intellectual Property Organization

CHAPTER 1. INTRODUCTION

This chapter introduces research background to identify a broad open question. With respect to the analysis of regional innovation systems, it defines research gaps in knowledge. Then, on the basis of the overarching question, it specifies research questions, objectives, and methodologies. After a brief description of the historical development of South Korea's regional innovation initiatives as a case, this chapter develops the research design and outline for this thesis.

1.1. Background

The modern history of regional innovation initiatives dates back to Christopher Freeman.[1] He investigated the reasons for the rapid economic development of Japan in comparison to that of European countries and the United States of America (USA) during the second half of the 20th century. His focus was on the view that Japan had intangible strengths that stimulated business innovation, such as strong support for research and development (R&D); production; technology imports; a solid focus on science and technology; and the tight linkages among government bodies, industries, and institutions of higher education at private and public levels (Freeman, 1987; 1995). As a result, Freeman concluded that a strong

---

[1] Christopher Freeman is the founder of Science and Technology Policy Research Unit (SPRU) at the University of Sussex. For his details, refer to his online memorial website (http://www.freemanchris.org/).

national support system, the so-called national innovation system, was the main trigger for technological advancement, which led to Japan's economic success despite Japan's inferior technological excellence. Following this, the systemic initiatives began to spread worldwide in order to improve the economic value of knowledge, stimulate systematic innovation, and encourage knowledge creation activities on the national scale (Edquist, 1997; Freeman, 1987, 1995; Lundvall, 1992; Nelson, 1992, 1993).

However, a host of policymakers and researchers have pointed out that the difficulty in effectively managing the relative dynamics of different sub-national innovation systems leads to inter-regional disparities (Metcalfe, 1995) in terms of profit creation, business development, and infrastructure establishment (Meyer-Krahmer, 1990). To overcome the side effect of nationwide top-down efforts, it was proposed that the focus of territorial innovation initiatives should be institutionally localised to smaller boundaries, that is, regions. In particular, with the rise of the European Union and the currency integration into the euro (€) in the 1990s, the concept of 'regional innovation' was designated as a crucial means to tackle the economic gaps between various European countries (Cooke, 2001; Cooke et al., 1997). This was based on the conviction that policies of regional units help to establish the infrastructure for economic growth through localised innovation, which also results in a technological ripple effect, economies of scale, and sustainable development of regions (Raines, 2002). As the 'region' became a proper unit for innovation, the territorial approaches began to take the form of regional innovation systems (Asheim and Isaksen, 1997). Not only Europe but also less advanced countries have considered regional innovation as a strategic means for promoting economic growth (Bell and Albu, 1999; Juma, 2012; Niosi, 2010).

Similarly with Freeman's efforts to figure out success stories of national innovation, the regional innovation research field has paid tremendous attention to the attributes of successful regions in terms of innovation (e.g. Agrawal and Henderson, 2002; Chung, 2002; Cohen et al., 1998; Fritsch and Slavtchev, 2011; Olof and Urban, 2008; van der Wal et al., 2007). Among the wide array of determinants for successful regional innovation, technological development has been traditionally designated as the most essential factor to stimulate regional competitiveness (Buesa et al., 2010). Along with the increasing popularity of regional innovation as a policy initiative, regional units have been designated for developing and implementing innovation policies (Doloreux and Parto, 2005) that aim to promote regional competitiveness (Asheim and Coenen, 2005*a*; 2005*b*). Given the central role of technological development and innovation policies in promoting regional innovation and competitiveness, it is crucial to address an open question: *How do regions fulfil their territorial innovation potential and become competitive based on science and technology from a systems perspective?*

1.2. Research gaps

In analysing the systemic fulfilment of innovation potential and competitiveness in the regional context, three points have remained as theoretical and practical limitations in the literature: *regional diversity* (Section 1.2.1.), *regional structure* (Section 1.2.2.), and *regional behaviour* (Section 1.2.3.).

1.2.1. Regional diversity: 'Top-down view' versus 'bottom-up view'

Different regions have different conditions such as resource availability (or accessibility) and R&D ability (Feldman, 1994); corporate activities and networks (Giuliani and Bell, 2005); industrial structure (Boschma and Iammarino, 2009); and mechanisms, knowledge flows, and synergistic activities (Herstad and Brekke, 2012). Nevertheless, existing analyses have still leaned towards a top-down view that adopts uniformed criteria to evaluate individual indicators for regional strengths or weaknesses. For example, on a regular basis, international organisations such as the European Union (EU), the European Commission (EC), and the Organisation for Economic Co-operation and Development (OECD) have provided region-wide primary and/or secondary data on human resources, research systems, finance, and outputs ranging from the micro level to the macro level, such as the Regional Innovation Scoreboard (Dijkstra et al., 2011; EU, 2012), Regional Competitiveness Index (Annoni and Kozovska, 2010; EC, 2013), and Innovation Indicators (OECD Statistics website).[2] However, the top-down approach is likely to give much attention to ranking regions or capturing temporary status of strengths and weaknesses of each region. As a result, these authorised reports tend to confine discourses on regional innovation and regional competitiveness to an interpretation of 'eternal winners and eternal losers' in a top-down view.

For innovation policy, the top-down view of regional innovation has limitations in developing innovation policies that help to boost regional competitiveness. Varying region-wide conditions are decisive for the policymaking

---

[2] OECD Statistics website: http://stats.oecd.org/Index.aspx?datasetcode=REG_DEMO_TL2

of innovation modes within each of the separate systems (Smith, 2000). In essence, regional innovation is a fundamentally localised process that is contextualised in each region (Doloreux and Parto, 2005), and, thus, each region is likely to have different strengths and weaknesses in the operation of its innovation process. Consequently, each region requires different policy foci to promote its regional competitiveness (Tödtling and Trippl, 2005). Unfortunately, the top-down analysis does not help to identify actionable policies that are supposed to be specific to each region. For example, many studies have highlighted best practices for regions that are compelled to reach the benchmark set by other regions with greater strengths (e.g. Cambridge [UK], Thames Valley [UK], Bavaria [Germany], Baden-Württemberg [Germany], and Massachusetts [USA]; see Cooke et al., 2001). However, as Tödtling and Trippl (2005) argued, the presence of regional diversity makes it difficult for uncompetitive and inferior regions to duplicate the characteristics of successful regions. In other words, without a consideration of regional diversity, defining which regions are superior to others is maybe either somewhat nonsense or of no use to others in terms of indigenisation, or glocalisation, discourse.

To address regional diversity, this thesis adopts the concept of efficiency in analysing regional R&D performance that considers both input level and output level in the regional knowledge production process. In addition, this thesis defines systemic routines specific to region-wide innovation processes in order to identify each region's attainable actions that help to encourage sustainable regional competitiveness.

1.2.2. Regional structure: ‘Correlation-based view’ versus ‘causality-based view’

The process of innovation is a feedback phenomenon characterised by interconnected cyclical processes (Berkhout et al., 2006; van der Duin et al., 2007). To simplify the analysis approach, some studies assume that regional innovation processes are linear mechanisms that start with resources and finish with performances (e.g. Acs et al., 2002; Godin and Gingras, 2000; Griliches, 1990; Hessels and van Lente, 2008; Patrick, 2002; Tsao et al., 2008; Zabala-Iturriagagoitia et al., 2007). This perception is based on the assumption regarding the correlation between resources and performances. Although this resource–performance structure is effective in analysing the operational performance of systems (Hollanders and Celikel-Esser, 2007), the linear mechanism is not able to account for the feedback operation of regional innovation processes.

Regional competitiveness should explain cause–effect relationships established in the innovation process (OECD, 2000; Polt and Rojo, 2002). Of course, plenty of resources can trigger the development of regional innovation systems. However, resources have often proven insufficient to support competitiveness (Teece et al., 1997). That is, adequate resources do not necessarily lead to excellent regional innovation. To link resources (e.g. funds) to performances (e.g. patents) in a smooth operation of innovation systems, many researchers have conceptualised activities (e.g. R&D function) of individual components or the entire system (e.g. Bergek et al., 2008; Edquist, 2001*a*; 2001*b*; Hekkert et al., 2007; Johnson, 1998). However, the literature has not empirically incorporated the concept of functions into the black box of innovation processes that transforms resources to performances. The lack of understanding of the complex structure of regional innovation systems is attributed to the methodological difficulty in mapping the complex nature of innovation processes (Castellacci and Natera, 2013; Hekkert et al., 2007).

By putting functions between resources and performances, this thesis describes endogenous causalities that comprise the resource–function–performance structure.[3] Specifically, this thesis adopts a bottom-up approach to set up an overall structure of a meso- or macro-level innovation system as a whole. To this end, this thesis utilises a triple helix framework that is composed of inter-relational structures among universities, industries, and government (research institutes) (Etzkowitz, 2008; Etzkowitz and Leydesdorff, 2000). Because the aggregation of knowledge development processes is central to an innovation system (Asheim and Isaksen, 1997), an analysis of the three knowledge producers (universities, industries, and government research institutes) is expected to provide information that helps to build up an aggregate model of the regional innovation system. This attempt enables the observation of smooth flows of innovation-related information and materials. Further, the visual illustration would help to intuitively acknowledge how regional innovation and regional competitiveness proceed in the feedback process of territorial

---

[3] In Paper 3, the term 'resource–function–performance' is replaced with the term 'capacity–capability–performance' in defining a regional structure and in analysing regional competitiveness. Capacity reflects available system proprietary resources mainly including financial and human resources (Wang and Huang, 2007) to determine initial ability for innovation; Capability is a system's ability to expedite resource utilisation for performance generation; and Performance is considered within the context of knowledge development (e.g. patents, Acs et al., 2002; Chen and Guan, 2012; Fritsch, 2002; Griliches, 1990; Henderson and Cockburn, 1996; Nelson, 2009; Rosell and Agrawal, 2009; Weck and Blomqvist, 2008) and knowledge commercialisation (e.g. sales and profits, Foster et al., 2008; Yam et al., 2011).

innovation.

1.2.3. Regional behaviour: ‘Static view’ versus ‘dynamic view’

Dynamism in innovation systems is not new (Bell and Albu, 1999). The notion of systems dynamics is clearly described by Carlsson et al. (2002) as follows: ‘a snapshot of the system at a particular point in time may differ substantially from another snapshot of the same system at a different time’.

The main trigger of systems dynamics is structural complexity (Hekkert et al., 2007). Because of system complexity, the innovation process is ever changing (Autio, 1998; Nelson and Winter, 1982). The dynamic attributes include multiple contexts such as technological patterns (Murmann and Frenken, 2006), innovation environment (Smith, 2000), actors’ capabilities, and system configuration (Carlsson et al., 2002). The complex and evolutionary innovation process does not allow any region to maintain its excellence (e.g. regional R&D efficiency and regional competitiveness) at the same level. On the one hand, with respect to regional R&D efficiency, however, there have been very few attempts to investigate a time-dependent change in R&D efficiency (Archibugi et al., 1999). On the other hand, regional competitiveness should reflect systemic nature (Meyer-Stamer, 2008), and it is as dynamic as the evolutionary innovation process (Porter, 1992). With respect to the utility of innovation policy, regional competitiveness is influenced by policies (Asheim and Coenen, 2005*a*; 2005*b*) that have short-term and long-term effects (OECD, 2009). Further, over time, the policy effects extend across divergent parts of the system (Jervis, 1997). Therefore, policy effects on regional competitiveness should be investigated from a dynamic perspective under the perception of system complexity and evolution. Although some researchers have conceptually discussed the dynamic attributes of regional competitiveness (e.g. Boschma, 2004; Budd and Hirmis, 2004; Kitson et al., 2004; Malecki, 2004; Turok, 2004), empirical investigations on dynamic effects of policy on regional competitiveness are scarce. In addition, regional competitiveness is an inclusive concept (Turok, 2004). However, existing studies have mainly examined partial segments such as physicality (e.g. human resources) and performance (e.g. patents) (e.g. Ström and Nelson, 2010) or have focused on the transient effect of policies that are specific to particular segments in the innovation system, especially financial instruments for R&D, including R&D expenditure (Guellec and van Pottelsberghe de la Potterie, 2003; Lach, 2002), tax incentives (Guellec and van Pottelsberghe de la Potterie, 2003; Koga, 2003), and foreign direct investment (FDI) (Branstetter, 2006).

To address regional dynamics, this thesis couples both static and dynamic examination of R&D efficiency in order to provide more rigorous evaluation criteria to identify the degree of superiority or inferiority of regional innovation systems in terms of scientific and technological knowledge production. Further, this thesis considers both longitudinal change and average improvement in regional competitiveness caused by attainable adjustment of policy interventions. The time-dependent insight into regional R&D efficiency and policy effects on regional competitiveness helps to reflect the consistency of regional operation for innovation.

1.2.4. Research position

Figure 1 illustrates the research position drawn from the above-mentioned research gaps that this thesis seeks to fill. Earlier research leans toward (1) a top-down view, (2) a correlation-based view, and (3) a static view in analysing regional innovation systems. However, these foci are not able to fully account for the diversity, feedback structure, and dynamic behaviour of regional innovation systems. In order to reflect these fundamental features, this thesis tries to adopt (1) a bottom-up view, (2) a causality-based view, and (3) a dynamic view of regional R&D efficiency, and of regional competitiveness and the policy effects on it.

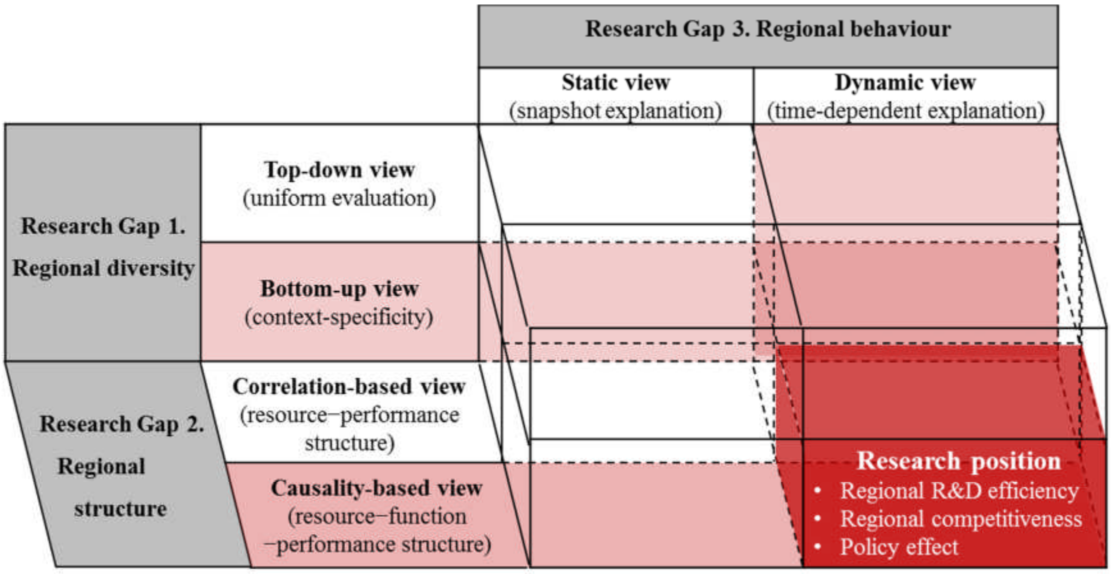


Figure 1. A research position for analysing regional innovation systems

1.3. Research questions

To bridge research gaps in extant literature, this thesis sets up specific sub-questions, which serve as the foundation of research design and are intended to uncover nuanced information related to the success of regional innovation systems. These three sub-questions are as follows:

(1) Which regions are competitive in terms of R&D efficiency? **–** In the knowledge economy, the most competitive region in R&D efficiency may be assumed to have a competitive ability to build up a knowledge base that enables smooth operation of the regional innovation process. Thus, the region with a sufficiently accumulating knowledge can be a good case example for observing operational phenomena of regional innovation. The definition of the most competitive region in R&D efficiency from the static and dynamic perspectives provides an object of research that is analysed to account for Research Questions 2 and 3.

(2) How do regional innovation systems operate in the resource–function–performance structure? **–** The analysis of the resource–function–performance structure established by key knowledge producers helps to capture flows of innovation-related information and materials that fulfil regional innovation and competitiveness. By addressing this question, this thesis develops a qualitative model of regional innovation systems that is the base for answering Research Question 3.

(3) How does regional competitiveness behave over time, and what policy(ies) can help or hinder regional competitiveness? **–** The answers to these questions are intended to capture the static and dynamic level of regional competitiveness and the utility of policy interventions. In doing so, a quantified model is used to carry out policy tests (sensitivity tests) to identify innovation policies that are expected to be effective for promoting regional competitiveness.

1.4. The selection of research methodologies

Operational research (sometimes known as operations research) is one of the advanced scientific analytical tools commonly used in the decision-making process of profit and non-profit organisations (Agrawal et al., 2010; Dean, 1958). Modelling and simulations using operational research techniques mimic an actual system, simplify its key elements, and handle the problems of a large-scale system more efficiently and effectively (Lee et al., 2008).

As seen in Figure 2, this thesis utilises operational research tools to address research questions simultaneously and serially under the umbrella term ‘innovation’.

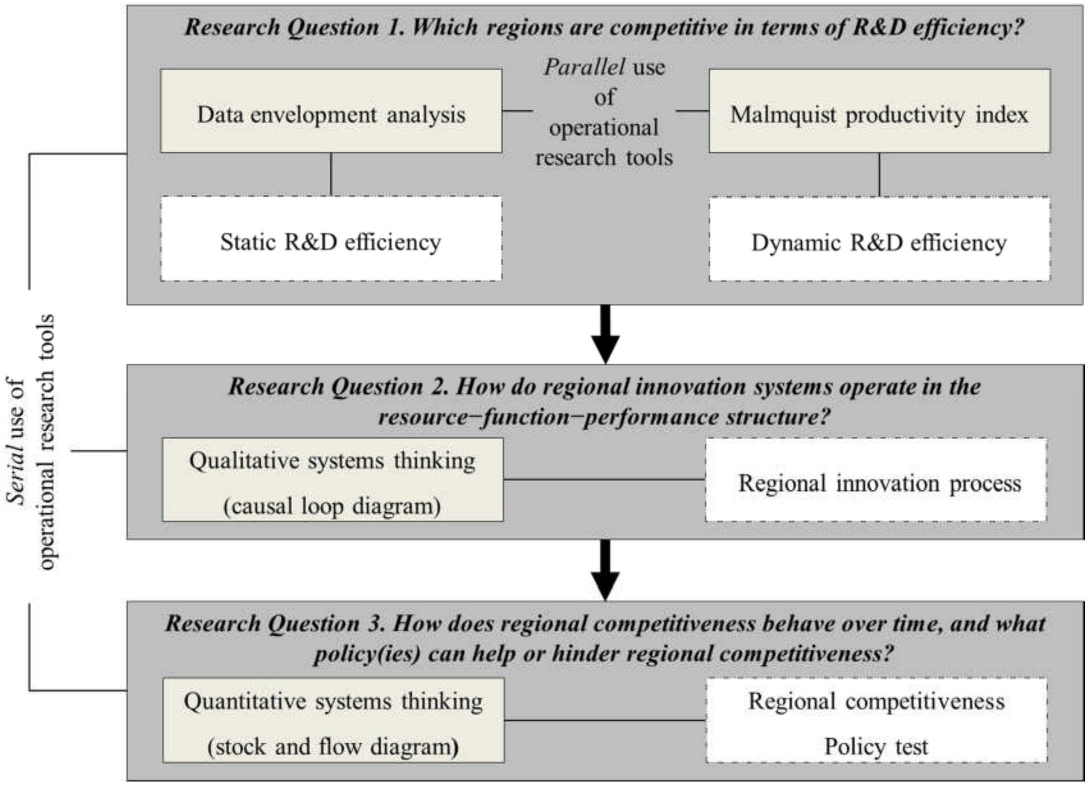


Figure 2. A multi-methodological framework used in the thesis

1.4.1. Data envelopment analysis and Malmquist productivity index

The data envelopment analysis (Charnes et al., 1994) and the Malmquist productivity index (Färe et al., 1994) are simultaneously employed to classify regions in terms of their static and dynamic R&D efficiency for a given time period (for details, see Chapter 3).

Compared to statistical (e.g. regression model) or other non-parametric (e.g. stochastic frontier analysis; Aigner et al., 1977) methods, the data envelopment analysis and the Malmquist productivity index have certain methodological strengths. First, the methods can handle multiple inputs and outputs having different units of measurement (Charnes et al., 1994). Generally, in order to evaluate the innovation performance of the regions, there are several criteria (i.e. multiple inputs and outputs) with different units of measurement (e.g. ‘capita’ for R&D human resource, ‘$’ for R&D expenditure, and ‘count’ for patents). To address this issue, for example, conventional statistical approaches require considerable time and effort to normalise or standardise the values of all the relevant factors. Also, the normalisation or standardisation may necessitate an estimation of the weightages of the factors. Therefore, multiple variables with different units of measurement are likely to lead to issues regarding the application of the methodology. Second, the two methods can be used to evaluate a small sample size having few input and output variables (Dyson et al., 2001). The analysis of such a small sample size is likely to be criticised in the context of the statistical significance of the empirical results. However, the data envelopment analysis and the Malmquist productivity index are non-parametric techniques that can accommodate a small sample size. Therefore, they are useful for investigating countries with a small number of regions.

1.4.2. Qualitative systems thinking: Causal loop diagram

After dealing with the efficiency-based regional diversity, this thesis tries to examine the collective behaviour of the regional actors, and determine how the innovation process works within a regional territory. To this end, this thesis employs a causal loop diagram approach (Galanakis, 2006; Lee and von Tunzelmann, 2005; Morecroft, 2007; Sterman, 2000). By means of the method, this thesis illustrates how the flows of innovation-related information and materials are structured in the regional innovation process (for details, see Chapter 4).

While other similar methods, such as model boundary charts and subsystem diagrams, do not show the relationships between the variables in the model, causal loop diagrams can cover the boundary, architecture, and relationships of the components required to define a system in the model (Sterman, 2000). In particular, this technique clarifies the causality between factors and helps to trace the cause–effect relationships and thus is useful in determining the reasons for particular problems in the system. In other words, it helps to avoid confusion between causation and correlation, which build up relationships among variables. For decision-making, a causal loop diagram can be an effective communication tool that provides a graphical representation based on specific modelling guidelines (i.e. the positive and negative relationships between two variables, reinforcing and balancing the feedback processes, and time delay; Sterman, 2000). The causal loop diagram is used to create a system dynamics model for numerical simulations (Fowler, 2003), which is employed to address Research Question 3.

1.4.3. Quantitative systems thinking: Stock and flow diagram

A system dynamics technique is used for achieving two objectives (for details, see Chapter 5). First, by means of this method, the primary analysis quantifies flows, stocks, and feedback loops to examine the dynamics of regional competitiveness. Based on the analysis results, next, this method is used to investigate how adjustments of particular controlling factors related to policy measures change the regional competitiveness over time.

Methodologically, system dynamics allows practitioners to discover the endogenous sources of particular behaviours of the system (Richardson, 2011). Another advantage of using system dynamics is to focus on the dynamic changes in a system over time based on the decision-making activities, while game theories handle interactions between decision-makers who seek equilibrium in a particular situation (Kim and Kim, 1997). Unlike agent-based modelling which is suitable to observe the behaviour of autonomous entities (Grimm and Railsback, 2005), system dynamics is an efficient approach to modelling the aggregate behaviours that result from interactions among multiple components of the system (Sterman, 2000). In particular, the quantification by system dynamics can cover both problem structuring and problem solving, while a qualitative systems method is able to only structure system problems (Forrester, 1994; Jackson, 2003; Mandinach and Cline, 1994; Richardson, 2011). As a result, the simulations highlight what can be expected in the future and suggest proactive measures for sustainable and developmental regional innovation (Sterman, 2000).

1.5. The selection of a case: South Korea

To address each of the three research questions by using the above-mentioned operational research tools, this thesis utilises the case of South Korea. According to the OECD review of Korea (OECD, 2009; 2012), the country is a successful example of exceptional growth in industrialisation and economy over the past half-century and the country shows one of the highest levels of R&D expenditure across the world. The OECD Science, Technology and Industry Outlook (2012) highlights that after France, Korea had the second highest government budget appropriations or outlays for R&D as a percentage of GDP in 2011. The STI country profile of Korea (OECD STI e-Outlook website) concludes that Korea had the second highest R&D intensity in the OECD after Israel, with business R&D expenditure as a percentage of GDP in 2010.[4] Nowadays, Korea represents a country which has successfully transformed its economy into a knowledge economy. Also, in many technology sectors, the country belongs to the technological front runners.

The historical traces of Korea's regional innovation have been well documented by Park (2001). As seen in Table 1, the development of Korea's regional innovation initiatives is considered in two approaches: industrial policy and science and technology policy. The industrial policies have been directed by the national government, which fully supports the *chaebol*-oriented system and export-oriented industries. With respect to the industrial policy, Korea has experienced a shift in policy paradigm from the decentralisation phase between the 1960s and the mid-1980s to the re-concentration phase until the 1990s. In the decentralisation period, the national government tried to establish large industrial complexes in non-capital regions such as Ulsan, Changwon, Pohang, Kumi, Kwangyang, and Ansan. However, since the conversion of strategic industries to knowledge-intensive sectors in the 1990s, the re-concentration of firms has taken place in capital regions (e.g. Seoul and Gyeonggi). With respect to science and technology, the developmental steps of innovation policies are divided into the government-led phase of the 1960s–1970s and the private sector-led phase from the 1980s to the present. While the focus in the government-led phase was to import advanced technologies from developed

---

[4] OECD STI e-Outlook website: http://www.oecd.org/sti/outlook/e-outlook/sticountryprofiles/korea.htm

countries and transfer them to industries, the private sector-led phase presented a remarkable growth in in-house R&D spending of private sectors.

The development of regional innovation systems in Korea is marked by several characteristics, including top-down government policy (Lee, 2009; Suh, 2009), *chaebol*-dominant industry (Lee, 2009; Park, 2007; Suh, 2009), industrial technology development-oriented policy (Park, 2001), financing-driven government support (Chung, 2002), loosening network (Park, 2007; Suh, 2009), weak industry strategy in certain regions (Park, 2007), weak research-based science-biased interregional industrial support (Chung, 2002), and unbalanced territorial distribution of R&D practitioners (Chung, 2002).

Since the introduction of region-wide frameworks to Korea in the mid-1990s, Korea has experienced a shift in the policy frameworks for national development from the national level onto region-wide approaches that emphasise the increasingly important role of local authorities and local spaces (Park, 2001). The Roh Moo-Hyun administration (2003–2007) legislated regional innovation initiatives, including 'The Special Law on Decentralisation' and 'The Special Law on the Construction of New Administrative Capital' in 2003 and 'The Special Law on Balanced National Development' in 2004. This regional systems approach was maintained by the administration of Lee Myung-Bak (2008–2012; Ministry of Education, Science and Technology [MEST], 2010*a*), through the enactment of 'The Third Regional Science and Technology Promotion Plan' (2008–2012) and 'The Five-Year Comprehensive Regional Science and Technology Promotion Plan' (2009–2012). Such institutional efforts continue under the current administration of Park Geun-hye (2013–present) enacting 'The Fourth Regional Science and Technology Promotion Plan' (2013–

2017).

On the basis of the below table, the current status of Korea’s regional innovation initiatives can be summarised by the coexistence of national innovation initiatives and regional innovation initiatives and the coexistence of government-led and private sector-led R&D. In particular, Korea is characterised by a regionalised national innovation system (Asheim and Isaksen, 1997), where the national government controls region-wide institutional frameworks (Bathelt, 2003). Thus, although each Korean region has its own local government that is in charge of developing and implementing local-based innovation policies, its autonomy is not secured in terms of the size of own funds for science and technology innovation. These characteristics would provide policy implications for less developed countries, such as China, that are headed towards state-led industrialisation under the stronger governance of national approaches than regional ones. Further, a study of Korea is expected to provide the impetus for Korea to undertake future regional innovation initiatives and achieve regional success in terms of the nature of knowledge-based innovation.

Table 1. History of Korea’s regional innovation initiatives

	1960s	**1970s**	**1980s**		**1990s**
Terrestrial innovation initiatives	**National initiative phase** →				
					Regional initiative phase →
Industrial policy	**Decentralisation phase**			**Re-concentration phase**	
	• First 5-Year Economic Development Plan (1962)	• Labour-intensive light industries (e.g. textile and apparel)	• Heavy industries (e.g. petrochemicals, shipbuilding, automobile, and electronics)	• High-technology industries (e.g. semiconductors)	• Knowledge-intensive industries (e.g. information and communications technology)
Science and technology policy	**Government-led phase** →				
			Private sector-led phase →		
	• Establishment of the Korea Institute of Science and Technology (KIST) (1966)	• Establishment of the *Daedeok* Science Town for government research institutes (1973) • Establishment of the Korea Advanced Institute of Science (KAIS) (1971)	• *Chaebol*-driven in-house R&D		Regional SME clusters in technology-intensive industries (e.g. science parks and techno parks)

Summarised from Park (2001)

Korea is composed of 17 administrative regions, as seen in Figure 3. Among them, Sejong (officially named as Sejong Special Autonomous City) opened in July of 2012 (BBC news, 2 July 2012). As Sejong is a newly born assembly area of a number of ministries and national agencies under ‘The Special Law on the Construction of New Administrative Capital’, the city is not characterised by science- and technology-based regional innovation. Also, Jeju is a tourism-driven region, and is thus unlikely to be comparable to other regions with respect to an advanced scientific and technological infrastructure. Therefore, this thesis does not consider Sejong and Jeju in the analysis.

Figure 3. Administrative regions in Korea

1.6. Research design and outline

By analysing the case of Korea, this thesis associates the three research questions with publishable journal papers. Figure 4 illustrates how the three papers are connected, thereby clarifying the entirety of knowledge that this thesis is meant to produce.

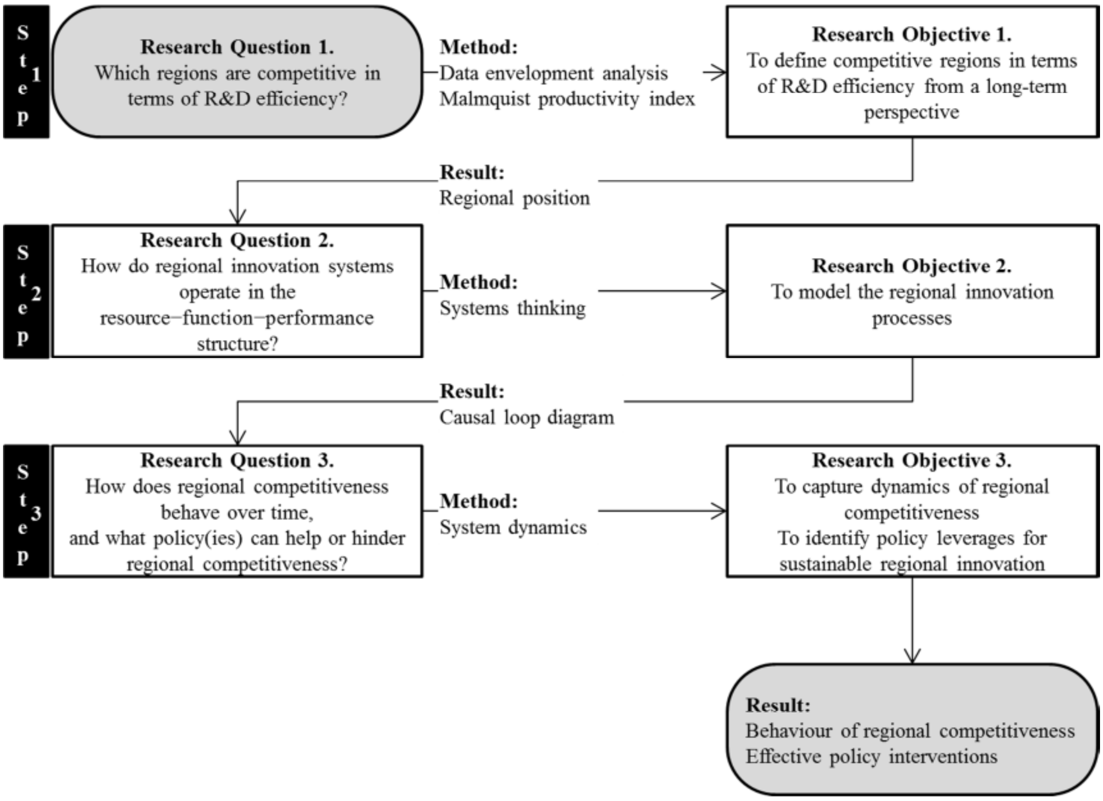


Figure 4. Research design: Question−method−objective−result

This thesis in the first step defines the most competitive Korean region from a long-term R&D efficiency perspective. In the next step, this thesis structures the knowledge-based innovation process of the most competitive region in R&D

efficiency. In the third step, this thesis quantifies the regional competitiveness of the region and policy effects on it by performing simulations in order to offer actionable policies that are expected to promote regional competitiveness of the region.

This thesis is composed of six chapters, as shown in Figure 5: the introduction (Chapter 1: this chapter), the literature review (Chapter 2), the three papers (Chapters 3−5), and the conclusion (Chapter 6).

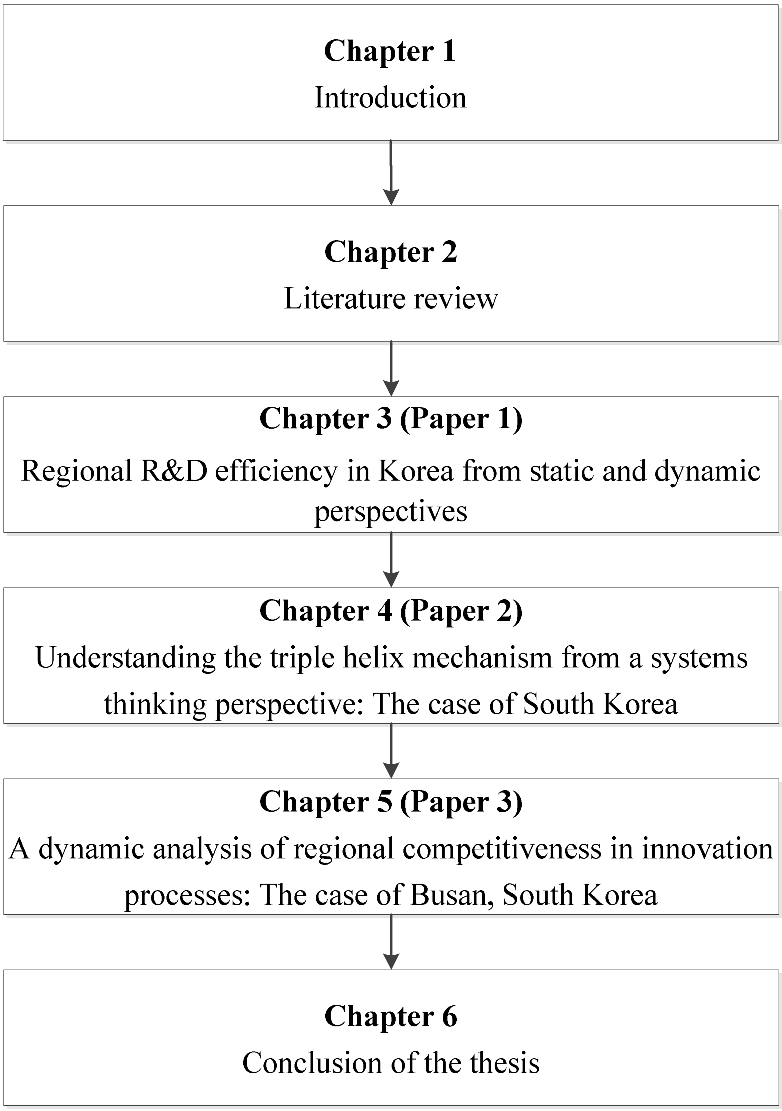


Figure 5. Research outline

After this chapter, which is the introduction, Chapter 2 reviews existing literature on the nature of regional innovation systems. On the basis of this review, the chapter specifies novel insights that would prove useful in the recognition, analysis, and interpretation of regional innovation phenomena, thereby assuring this thesis' theoretical and practical contributions to the field.

Chapter 3 is meant to address Research Question 1, '*Which regions are competitive in terms of R&D efficiency?*', in order to identify the best region in Korea with respect to R&D efficiency. This chapter adopts the data envelopment analysis and the Malmquist productivity index, which shed light on the long-term status of regional R&D efficiency from a static perspective and its consistency from a dynamic perspective.

Chapter 4 aims to respond to Research Question 2, '*How do regional innovation systems operate in the resource−function−performance structure?*' The chapter employs a qualitative systems approach, the causal loop diagram method, in order to describe how core variables of resources, functions, and performances are connected in Korea's knowledge-based regional innovation process.

Chapter 5 addresses Research Question 3, '*How does regional competitiveness behave over time, and what policy(ies) can help or hinder regional competitiveness?*' On the basis of the causal loop diagram developed in Chapter 4, the chapter constructs a simplified system dynamic simulation model with respect to knowledge-based innovation process of the most competitive Korean region in R&D efficiency. Using this quantitative model, the chapter analyses the dynamics of regional competitiveness and discovers potential innovation policies that are expected to encourage regional competitiveness.

Finally, Chapter 6 summarises the major findings, and it highlights contributions of this thesis to the field of regional innovation policy by focusing on regional diversity, regional structure, and regional behaviour. Further, the chapter describes the shortcomings of this thesis with respect to methodology, scope, and framework, and identifies interesting avenues for future research that will redress these shortcomings.

1.7. Anticipated contributions of the thesis

Through the three papers, this thesis contributes to knowledge advances in the theory, methodology, and practice of innovation studies as follows.

- Conceptually, this thesis applies a bottom-up view, a causality-based view, and a dynamic view to the analysis of regional innovation processes. By doing so, this thesis provides theoretical insight into diversity, structure, and behaviour in regional innovation.
- In terms of methodology, this thesis presents a novel and multimethodological use of operational research tools to support the understanding of innovation phenomena of regional systems.
- For practical contributions, this thesis provides an analytic methodology for rational decision-making. Also, this thesis may be a precedent that provides other cases with 'meta narratives' related to sustainable regional innovation systems. The applicable narrative encompasses a robust classification of regions according to their efficiencies, a better understanding of inclusive

knowledge-based regional innovation processes, and a quantification of regional innovation systems.

- In a more practical sense, this thesis provides potential policy recommendations that facilitate regional innovation. The recommendations include discussion on how to improve regional R&D efficiency (see Paper 1), how to sustain the operation of innovation processes under the region-specific structure (see Paper 2), and how to encourage regional competitiveness (see Paper 3).

CHAPTER 2. LITERATURE REVIEW

This chapter reviews existing literature with respect to regional innovation systems. First, the regional theories are outlined, and the main characteristics of regional innovation system theory are clarified. Second, this chapter posits that region-wide initiatives provide motivation and support for the practical study of regional innovation. Moreover, a review of the definitions of ‘region’, ‘innovation’, and ‘system’ provide insight into the regional innovation systems that are the objects of research for this thesis.

2.1. Regional theories

In recent decades, the nature and causes of regional development have increasingly occupied social science, political, and practitioner research thinking in addition to the study focus of researchers from the fields of economics and geography (Dawkins, 2003). Some studies have introduced theories from various perspectives (e.g. Dawkins, 2003; Moulaert and Sekia, 2003; Shinkin Central Bank Research Institute [SCBRI], 2005). The SCBRI researchers categorised regional theories into four types according to two criteria, as illustrated in Figure 6. These criteria were (1) the subject of analysis and (2) the core concept. The first criterion categorises a theory according to an ‘entire region’ or ‘specific industrial cluster’, whereas the second criterion categorises according to the ‘static’ or ‘dynamic’ research perspective.

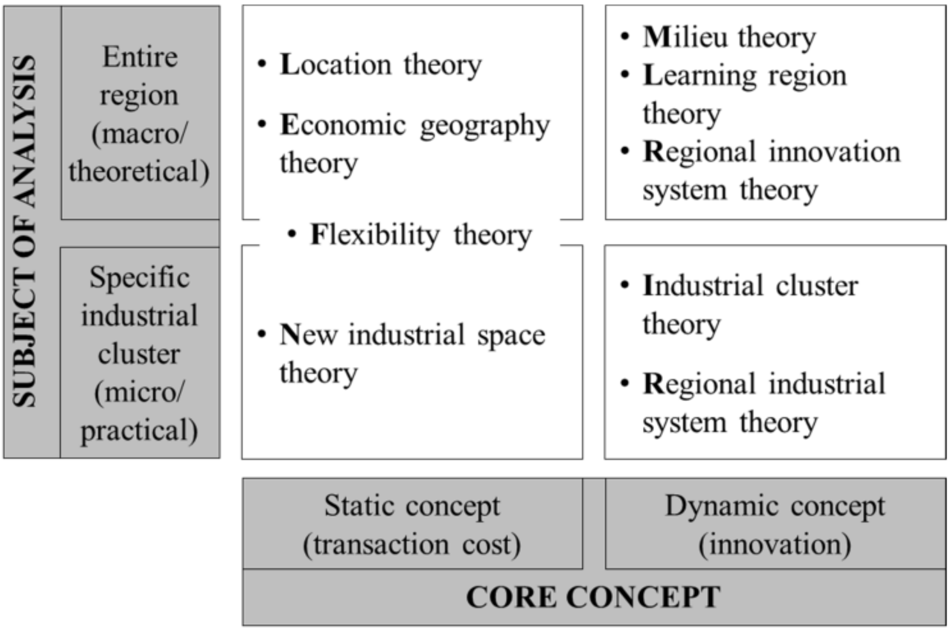


Figure 6. Regional theories (translated from SCBRI, 2005)

Although Figure 6 separates the regional theories, there are substantial similarities in terms of their arguments. Table 2 explains that the economic geography, flexibility, and new industrial space theories are focused on market demand for products/services, whereas the industrial cluster theory expands the market scope to a competition condition. The location and flexibility theories consider the tangible factors such as labour, finance, materials, and/or products/services, whereas the new industrial space, regional industrial system, milieu, and learning region theories consider the intangible (multi-level) social systems. Piore and Sabel (1984) of Italy provide an example of industrial districts with flexible specialisation from a Marshallian perspective. Additionally, the (new) economic geography theory represents a blend of multiple theories drawn from different theoretical roots including cumulative causation, export base, external scale economies, and neoclassical trade theories (Dawkins, 2003). Thus, the application of only one regional theory to the analysis of territorial innovation is difficult (Dawkins, 2003; Moulaert and Sekia, 2003).

Although commonalities exist among regional theories, the four-quadrant matrix by SCBRI (see Figure 6) shows that the theory of regional innovation systems presented in this thesis addresses regional diversity, regional structure, and regional behaviour (see Sections 1.2.1 to 1.2.3 in the Introduction). With respect to regional diversity, the theory of regional innovation systems is based on the concentration of national innovation initiatives on a sub-national scale (Edquist, 1997). With respect to regional structure, the theory of regional innovation systems provides a conceptual foundation for the analysis of the territorial innovation process within the regional context (Cooke, 1998). The concept of regional behaviour is associated with the core theoretical roots of regional innovation systems drawn from the evolutionary theory (Dosi, 1988; Nelson and Winter, 1982) of technological change (Freeman, 1987, 1995). Therefore, the theory of regional innovation systems is suitable for this thesis, which analyses the dynamic operation of science and technology-based knowledge innovation systems of an entire region. The operational process is shaped in the structure of interrelated resources, functions, and performances.

Table 2. Regional theories, excluding the theory of regional innovation systems

Theory	Key argument	Reference
Location theory	Optimal location of industries on the basis of monetary weights of raw materials and end-products	Greenhut (1956); Hoover (1937); Isard (1956); Marshall ([1890] 1961); North, (1955); Weber (1929)
Economic geography theory	Emergence of industry clusters because of significant economies of scale, low transition costs, and labour-intensive manufacturing	Clark et al. (2000); Krugman (1991)
Flexibility theory	Flexible specialisation (labour and capital) and localised networks to respond to dynamic market demand	Piore and Sabel (1984)
New industrial space theory	Flexible production agglomerations to adapt to dynamic market demand	Scott (1988); Storper and Scott (1988, 2003)
Industrial cluster theory	Territorial concentration to stimulate competition in localised innovation and to foster the nation's industrial competitiveness in international markets	Porter (1990, 1996, 1998a)
Regional industrial system theory	Social networks related to flexible specialisation and entrepreneurship in the industrial sector	Saxenian (1994)
Milieu theory	Cultural, political, psychological, physical, and socioeconomic similarity	Aydalot (1986); Camagni (1991), Markusen (1987)
Learning region theory	Collaboration and coordination between firms and environment for collective benefits through a strong but flexible network	Asheim (2001); Cooke (1998); Florida (1995); Morgan and Nauwelaers (1998)

Summarised from Dawkins (2003) and Moulaert and Sekia (2003) on the basis of the classification by SCBRI (2005)

2.2. The importance of regional initiatives

Regional innovation researchers usually claim that nationwide innovation programmes have been weakened by the globalising economy, whereas region-wide initiatives have become the centre of economic activities (Asheim and Gertler, 2005; Asheim and Isaksen, 1997; Bathelt et al., 2004; Braczyk et al., 1998; Chung, 2002; Cooke and Memedovic, 2003; Cooke et al., 1997; Cooke, 2001; Doloreux and Parto, 2004; Doloreux, 2003; Iammarino, 2011; Isaksen, 2001; Malecki and Oinas, 1999; Malmberg and Maskell, 1997; Ohmae, 1995; Park, 2001). Contrastingly, some researchers emphasise the decreasing significance of a territorial focus as a result of globalisation (Graham, 1998; Greig, 2002; Ohmae, 1990; O'Brien, 1992). Lundvall (1992) posits that international innovation interactions occur on a national scale but not at the regional level and, consequently there has been limited change in the role of regional units with respect to innovation. This sceptical view is described as 'the death of distance' by Cairncross (1997).

It seems that regional innovation initiatives are not easily construed in the economic globalisation context. The divergent terminologies — globalisation versus regionalisation — are introduced by Porter (1998*b*), who terms them the 'location paradox', describing the increasing competitive advantages of localised industrial clusters in the globalising business world. Porter (2006) commented:

> *'I call it the location paradox. If you think of globalization, your first reaction is to think that location doesn't matter anymore. […] But the paradox is that location*

> *still matters. The U.S. is still the most important space […] the more things are mobile, the more decisive location becomes. […]' (Q&A with Michael Porter, Bloomberg Businessweek, 21 August 2006).*

The location paradox implies that globalisation and regionalisation are not separate, but represent intertwined phenomena affecting contemporary businesses. Regionalisation in conjunction with high competitiveness is central to business response to an intensified competitive global environment. For example, Guangdong province in China has been specialising spatially by attracting foreign investment through '*relocation, outsourcing, and off-shoring of low value-added industries principally from Hong Kong, China, and Chinese Taipei*' (OECD, 2010, p. 140) since the enactment of an open-door initiative. Given the supportive local environment for innovation, Guangdong has endeavoured to intensify localised competition to escape the labour and resource-intensive industrial structures. Thus, although these terminologies — globalisation and regionalisation — appear contrary to each other, regionalisation is as essential to the business world as globalisation. Moreover, as a vehicle for regional innovation, science parks have contributed to the advancement of local economies including job creation, the creation of technology-based small firms, and revitalisation of the regional economy (Vedovello, 1997) (although the Science Park paradox is evident in some cases where science parks have not performed satisfactorily, the development of such parks continues to be a popular policy approach [van Geenhuizen and Soetanto, 2008]).

According to Porter (2003), the vitality and plurality of innovation in the industrial co-location affects the regional economy through factors such as wage rates, employment, and patent growth. The value of regional units is supported by the concept of 'new regionalism' (Halseth et al., 2010; Morgan 2004; Porter, 1990). This concept emphasises that regional competitive advantage is obtained from localised assets, skills, and knowledge. Additionally, national competitive advantage is nurtured once combined with localised innovation. Territorial concentration stimulates investment in local infrastructure by government bodies and educational institutions that are dependent on a local industrial cluster (Porter, 1990). Freeman (1995) emphasised the significance of national and regional settings despite growth in globalised innovation activities. With respect to the formulation of an innovation system, regional innovation contributes to the development of sectoral innovation systems, which focus on the effective development of local economies within region-specific industries (Chung, 2002). A regional unit represents an essential base for the development of innovation policies (Doloreux and Parto, 2004) that contribute to the achievement of national innovation policy objectives and national economic growth (OECD, 2008).

Figure 7 summarises that regional initiatives play multiple roles in multi-level situations. These include local firm response to competition on a global scale; the achievement of national innovation policy objectives and national competitiveness at a country level; and the development of region-specific industries, local economies, and innovation policies at a regional level.

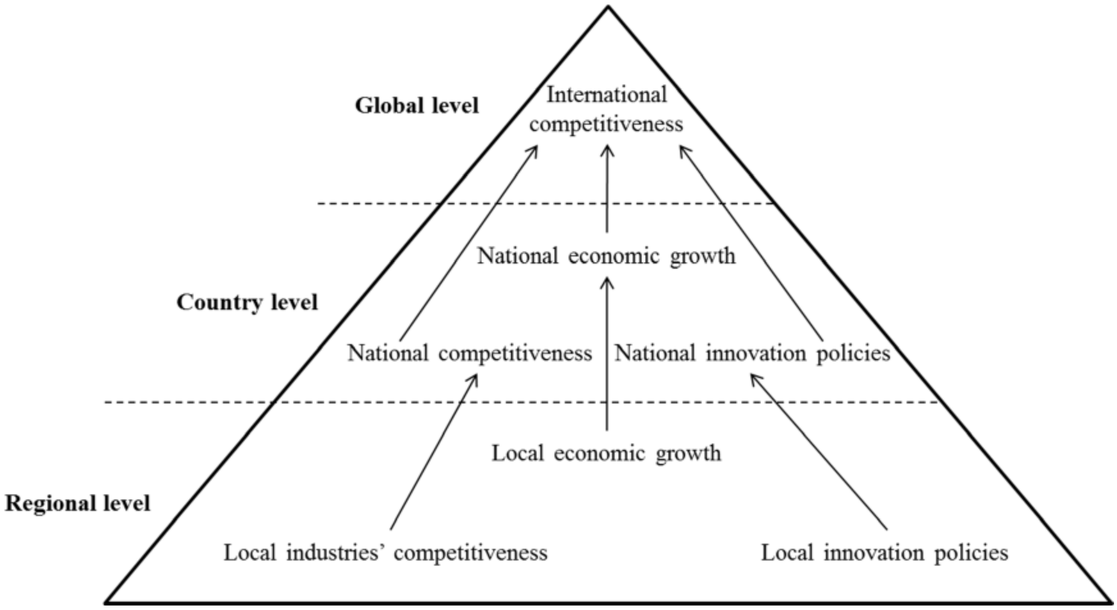


Figure 7. Advantages of regional innovation initiatives

2.3. The concepts of region, innovation, and system

This section reviews the concepts of *region*, *innovation*, and *system* to clarify the research scope of regional innovation systems addressed by this thesis.

2.3.1. Region: City- and province-based administrative governance

A regional innovation system is based on 'locality', which is exchangeable with 'region' (Lundvall and Johnson, 1994; Malmberg and Maskell, 1997; Storper, 1997). The term region is ambiguous in terms of its definition and derives its meaning from proximity. The proximity refers to the centre of region-based innovation systems and varies according to the subjective judgement and purpose of innovation policymakers (Juniper, 2007). Although a regional innovation system is conceptually regarded as smaller in scale than a national system, the term region encompasses diverse territorial boundaries — for example, nations, provinces, and industrial districts (Doloreux and Parto, 2004). Cooke (2001) posited that the perception of a regional system can vary according to its description, such as territorial, administrative, geo-regional, or cultural boundary-based system. Moreover, the regional boundary is determined by the research targets, for example, the province (Gertler and Wolfe, 1998), Quebec (Latouche, 1998), the city (Simmie, 2001), the industrial district (Asheim and Isaksen, 1997), and the NUTS II region (Evangelista et al., 2002) (adopted from Doloreux and Parto [2004]).[5] The ambiguity associated with the definition of region may be attributed to the lack of specific criteria or a consensus on size, homogeneity, governing bodies, and internal cohesion (Cooke and Schienstock, 2000).

The definition of region is necessary to analyse factors such as local competitiveness (Doloreux and Parto, 2004). For example, according to the evolutionary stage of regions, the unit of analysis can be determined as 'capital-city regions', 'high-tech regions', 'services regions', 'high-performance engineering regions', 'reconversion regions', and 'rural, agricultural, or peripheral regions' (Cooke et al., 1997). These categories represent the fundamental purpose and nature of individual regions, and the identification of which requires specific insights, and corresponding analytical approaches.

The majority of analytical practices have concentrated on defining (regional) innovation systems as institutional settings that are focused on economic policies

---

[5] NUTS II is the nomenclature of territorial units coined by Eurostat.

(Doloreux and Parto, 2004). The expressions used in the literature to define an innovation system from an institutional perspective include ‘institutional dimension’ (Andersen and Lundvall, 1988), ‘network of institutions’ (Freeman, 1987, 1995), ‘organisations and institutions’ (Lundvall, 1992), ‘all institutions and economic structures’ (Edquist and Lundvall, 1993), ‘particular institutional infrastructure’ (Carlsson and Stankiewicz, 1995), ‘set of distinct institutions’ (Metcalfe, 1995), ‘policy’ (Cooke et al., 2000), and ‘set of institutions and regulations’ (Archibugi and Lundvall, 2001).

With respect to innovation systems, institutions have traditionally been defined as follows:

> *‘Sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organisations’ (Edquist and Johnson, 1997, p. 46).*
>
> *‘Sets of routines, rules, norms and laws, which by reducing the amount of information necessary for individual and collective action make society, and reproduction of society, possible’ (Johnson, 1988, p. 280).*
>
> *‘Routines, guiding everyday actions in production, distribution and consumption, but they may also be guide-posts for change. In this context, we may regard technological trajectories and paradigms, which focus the*

> *innovative activities of scientists, engineers and technicians, as one special kind of institution' (Lundvall, 1992, p. 10).*
>
> *'Cultural-cognitive, normative, and regulative elements that, together with associated activities and resources, provide stability and meaning to social life' (Scott, 1995, p. 33).*

Based on the above definitions, it is assumed that institutions specify the routines of the overall system by regulating the activities of individual actors.

Additionally, institutions may be established in a region as long as the history and institutional influences have been conducive to the development of such institutions. An innovation system is dependent on the history of each different system (Edquist, 1994). History is understood in terms of regional uniqueness, such as system strengths or weaknesses that affect the evolution of interdisciplinary dimensions such as knowledge, innovation, organisation, and institution. Finally, history often determines the perceived success and failure of territorial innovation (Edquist, 1997). That is, history-dependent regional institutions are interpreted as 'context specificity' as emphasised by Doloreux and Parto (2004).

On the basis of the above argument, this thesis uses the definition of a regional boundary as one that is drawn from a combination of the institutionally localised economy and context specificity, that is, administrative cities and provinces.

2.3.2. Innovation: Schumpeterian innovation

Innovation is at the heart of not only long-run performance of firms (Iona et al., 2008) but also national development (Sarkar, 2007). The concept of innovation, in a narrow view, traditionally refers to science and technology advancements. An emphasis on technology-based innovation was encouraged by Solow (1957), who introduced the aggregate production function. Solow's work underscored the effect of technological advancement on national economic growth. According to Solow (1957), technology-based innovation is a greater factor than labour and capital with respect to the state of a national economy.

Contrastingly, the Schumpeterian innovation — the broadest concept of innovation —maintains that excellence in research findings alone is not evidence of successful innovation; rather, market success after successful R&D has been conducted is required (Betz, 1993; Cooke and Memedovic, 2003; Edquist, 2001*a*, 2001*b*; Nelson and Rosenberg, 1993; Porter, 2006; Schumpeter, 1934, 1975; Smits and Kuhlmann, 2004; Stoneman, 1983).

Central to the Schumpeterian theory of innovation is the dynamics of an economy (Schumpeter, 1934, 1975). The dynamics result from the continuous stock and flow changes of innovation-related knowledge (Autio, 1998). These flows formulate multi-directional relationships and feedback rules among innovation-related activities in the evolution of innovation processes. From the Schumpeterian perspective, technological advances represent an endogenous catalyst to economic development. This notion is consistent with the endogenous growth theory (also known as neo-Schumpeterian theory) (Lucas, 1988; Romer, 1986). With respect to the endogenous process of regional innovation, knowledge disembogues through an innovation process that is composed of several knowledge domains such as knowledge development, knowledge diffusion, and knowledge deployment (Cooke et al., 1997; Lundvall, 1992). Knowledge development is interchangeable with R&D (basic research, applied research, and experimental development) that generates a knowledge base for ideas (OECD, 1993). Knowledge diffusion is the movement of technical expertise, knowledge, or technology from one organisational setting to another (Roessner, 2000). Knowledge deployment refers to the application of knowledge for business.

Therefore, the Schumpeterian innovation, in a knowledge economy, is satisfied when knowledge smoothly flows throughout an interlinked series of knowledge domains (development, diffusion, and deployment) endogenously ranging from the R&D stage to the commercialisation stage thereby stimulating knowledge spill-over in a given locality. This thesis focuses on the phenomenon of knowledge-based innovation, and investigates a regional innovation process that links the knowledge domains in a circular and endogenous operation, as displayed in Figure 8— the so-called knowledge-based Schumpeterian innovation.

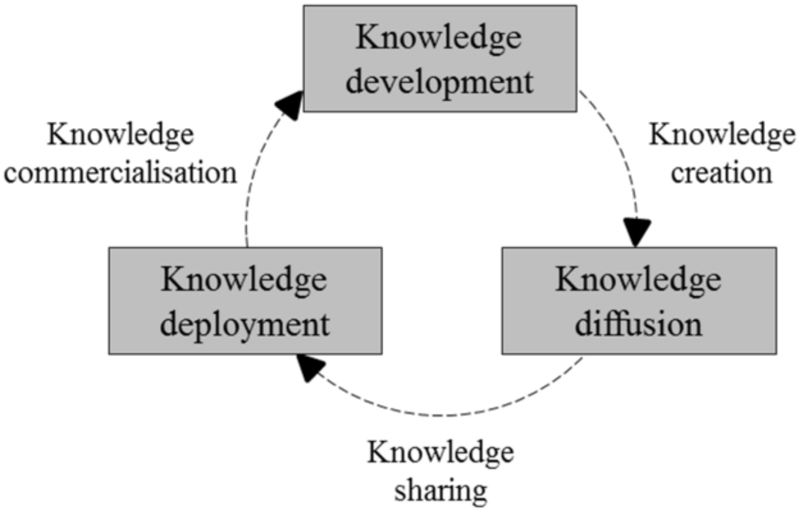


Figure 8. An endogenous circulation of knowledge development, knowledge diffusion, and knowledge deployment

2.3.3. System: Organised structure of resource−function−performance

From an operational perspective, an (regional) innovation process represents the feedback phenomenon (Berkhout et al., 2006; van der Duin et al., 2007) in which resources, functions, and performances are sequentially interconnected.

2.3.3.1. Resources

An innovation system requires various actors that represent the tangible hardware of the system (Andersson and Karlsson, 2004; Braczyk et al., 1998; Buesa et al., 2006; Chung, 2002; Wiig, 1995). The actors establish inter-organisational relations to overcome resource constraints (Trappey and Chiang, 2008). The presence of actors implies organisational physicality defining regional strengths in terms of knowledge production (Chung, 2002). Resources represent the fundamental base that enables actors to carry out innovation-related tasks. That is, without resources, actors alone cannot lead to the operation of regional innovation systems. With respect to science and technology, R&D funds and researchers are integral to resources. R&D expenditures are essential to promote the development of science and technology (Hashimoto and Haneda, 2008; Wang and Huang, 2007). Researchers, who contain tacit knowledge that is difficult to replicate (Lissoni, 2001), are direct contributors to the R&D processes that transform financial inputs into scientific and technological knowledge. The extent to which a regional innovation system has financial and human resources available for R&D activities reflects the system's ability to initiate the operation of innovation processes.

2.3.3.2. Functions

A system contains diverse functions executed by actors that employ resources to attain system performances (Bergek et al., 2008; Edquist, 2001*a*, 2001*b*; Hekkert et al., 2007; Johnson, 1998). In a triple helix framework (Etzkowitz, 2008; Etzkowitz and Leydesdorff, 2000), universities, industries, and government research institutes perform their own traditional functions, such as education in universities, business in industries, and R&D in government research institutes. Thus, universities develop human resources and send R&D professionals to the three spheres, industries launch products to the marketplace for profit, while government research institutes pursue R&D and transfers to industries. In university-industry collaboration, client companies exploit R&D outsourcing purchased services from the university lab; in turn, the university transfers research findings to the sponsor. Consequently, it is assumed that the individual functions are interrelated and shape the flow of innovation-related information including knowledge and materials. Japan's success, despite an inferior technology level (Freeman, 1987, 1995), occurred because each of the innovation-related actors (e.g. universities, industries, and government bodies) performed a role and established inter-organisational relations (e.g. collaboration, competition, and coordination). The country has, therefore, fully incorporated individual and/or collective functions into national development. This history implies that abundant resources do not guarantee an intended level of system performance (e.g. European countries and the USA in Freeman's research). Rather, the functional perspective is required to analyse the operation of an innovation system. Such a perspective enables the consideration of systemic structures of territorial (e.g. nation and region) or non-territorial (e.g. industry sector) innovation settings.

2.3.3.3. Performances

The resources and functions represent the foundation for achieving the innovation system goals. Both the practice and theory of regional innovation systems have encompassed multidisciplinary performances that include science and technology, business, and societal factors (Edquist, 1997; Freeman, 1987, 1995; Lundvall, 1992; Nelson, 1992, 1993). Adopting the Schumpeterian perspective (see Section 2.3.2.), the performances of regional innovation systems can be broadly decomposed into two types: (1) scientific and technological knowledge and (2) the economic benefits of innovation. Scientific and technological knowledge is typically measured by the quantity of academic publications (Brown and Svenson, 1998; Cherchye and Abeele, 2005; Furman et al., 2002; Jiménez-Sáez et al., 2011) and/or patents (Popp, 2005; Fritsch, 2002) within the boundary of knowledge development. The economic benefits of innovation are measured by sales and/or profits (Foster et al., 2008; Yam et al., 2011) within the boundary of knowledge commercialisation attached to the industrial sector. Specifically, sales refer to the expandability of markets and industries with respect to products and/or services, whereas profits refer to the supply of sufficient funds for R&D (re)investment. Thus, the two indicators are essential considerations in building capacity of financial and human resources for sequential R&D in the regional innovation process.

This thesis assumes that the serially interrelated available *resources*, actionable *functions*, and attainable *performances* comprise a systematic structure that is essential to the sustainable operation of a regional innovation process, as illustrated in Figure 9.

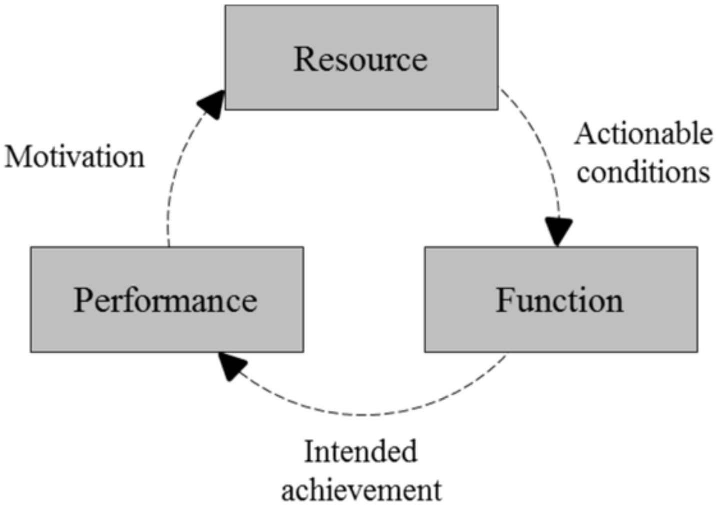


Figure 9. A resource−function−performance structure in the knowledge-based innovation process

2.3.4. Summary of the thesis scopes

Figure 10 summarises three key insights into a regional innovation system noted by this thesis: (1) the context-specific routines established in cities or provinces, (2) the Schumpeterian view of innovation in the knowledge-based process, and (3) an organised structure of resource−function−performance.

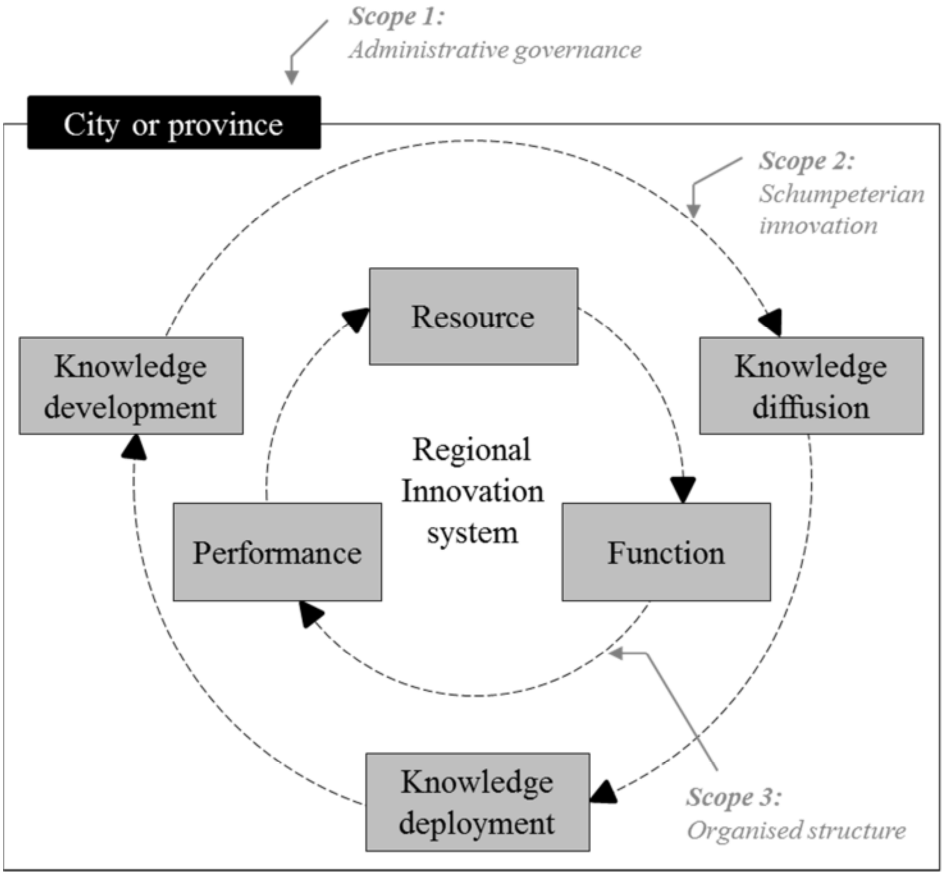


Figure 10. The research scope of regional innovation systems

This thesis assumes that the configuration of regional innovation systems must adopt a ‘puzzle solving’ view to be competitive. All pieces of a jigsaw puzzle are necessary to complete the picture. Similarly, each research scope ([1] the city- and province-based administrative governance, [2] the Schumpeterian innovation, and [3] the organised structure of resources, functions, and performances) is a prerequisite for the complete operation of regional innovation systems. Table 3 shows that the three pieces are linked with the three Research Questions addressed by this thesis.

Table 3. Research Questions and thesis scope of regional innovation systems

	Scope 1: *Administrative governance*	**Scope 2:** *Schumpeterian innovation*	**Scope 3:** *Organised structure*
Research question 1:			
Which regions are competitive in terms of R&D efficiency?	City- or province-based boundary	Knowledge development only	Linear structure of resources and performance
Research question 2:			
How do regional innovation systems operate in the resource−function−performance structure?	City- or province-based boundary	Feedback process of knowledge development, knowledge diffusion, and knowledge deployment	Feedback structure of resources, functions, and performances
Research question 3:			
How does regional competitiveness behave over time, and what policy(ies) can help or hinder regional competitiveness?	City- or province-based boundary	Feedback process of knowledge development, knowledge diffusion, and knowledge deployment	Feedback structure of resources (capacity), functions (capability), and performances

Research Question 1: *Which regions are competitive in terms of R&D efficiency?* The evaluation of regional R&D efficiency is considered within region-wide units that are set by the city- and province-based administrative governance (see Scope 1). However, with respect to the Schumpeterian innovation, the empirical study does not encompass all knowledge domains, but pays attention only to knowledge development (see Scope 2). This limited focus is intended to reflect the dominant and straightforward perception of the central role of scientific and technological advancement in promoting regional growth. For the efficiency analysis, the description of a region-wide structure is confined within a linear process of resource–performance as a black box (see Scope 3).

Research Question 2: *How do regional innovation systems operate in the resource–function–performance structure?* A qualitative systems approach to the knowledge-based innovation process is based upon the city- and province-based administrative governance (see Scope 1), the Schumpeterian innovation (see Scope 2), and the organised structure of resource–function–performance (see Scope 3). The context-specific routines are expanded from a view limited within knowledge development only to an inclusive feedback view of knowledge domains including knowledge development, knowledge diffusion, and knowledge deployment (implementation and commercialisation) (see Scope 2). With respect to these sequential knowledge domains, a typical regional innovation process of cities and provinces (see Scope 1) represents a complex, organised structure of resources, functions, and performances (see Scope 3). Specifically, the notion of resource—function—performance is employed to develop a triple helix model of knowledge-based innovation systems of Korea (see Paper 2).

Research Question 3: *How does regional competitiveness behave over time, and what policy(ies) can help or hinder regional competitiveness?* A quantitative systems approach analyses the innovation systems of city- or province-based regional boundaries (see Scope 1). In contrast to Research Question 2, which uses a qualitative systems thinking to construct a causal loop diagram, Research Question 3 investigates the stock and flow structure that is composed of a series of resources, functions, and performances (see Scope 3). Particularly, to adopt an inclusive angle of regional competitiveness, this thesis applies Scope 3 to the analysis of resources (capacity), functions (capability), and performances from a systems perspective (see Paper 3). The structure is established in the region-wide, knowledge-based innovation process ranging from knowledge development to knowledge deployment (implementation and commercialisation) (see Scope 2).

CHAPTER 3. PAPER 1 – REGIONAL R&D EFFICIENCY IN KOREA FROM STATIC AND DYNAMIC PERSPECTIVES

3.1. Abstract

R&D efficiency has gained great attention in regional innovation research. This study examines the R&D efficiency patterns of 15 Korean regions for 2005–2009. This study employs Data Envelopment Analysis to identify the regions' R&D performances relative to the best practices from the static perspective, and the Malmquist Productivity Index to evaluate their changes in performance within a given timeframe, providing a dynamic perspective. The results classify the Korean regions into deteriorating, lagging, and improving groups and indicate that most regions suffer from declining R&D productivity over time because of an inability of catching up with the best practices.

Keywords: regional R&D efficiency, Korea, Data Envelopment Analysis, Malmquist Productivity Index

3.2. Introduction

Regional innovation aims to bridge the innovation-based economic gap between heterogeneous regions and strengthen their innovation competitiveness on a national scale (The Organisation for Economic Co-operation and Development; OECD, 2008). The European Union (EU, 2006) highlights the role of research and development (R&D) in regional innovation. Some studies have attempted to evaluate regional innovation performance to determine the evidence-based policy implications of regional initiatives (e.g. Autio, 1998; Diez, 2001; Evangelista et al., 2001). However, it is difficult to compare interregional innovation performance, as R&D is not conducted under identical conditions owing to an imbalanced distribution of R&D capabilities across different regions (Feldman, 1994). Thus, the approach to simply analyse an absolute performance aspect, such as the number of R&D outputs, is inappropriate, because it does not consider the maximum attainable performance level for each region (Bosco and Brugnoli, 2010). The study of R&D efficiency has gained substantial attention in recent years as researchers need to also consider resource availability in the assessment of heterogeneous regional R&D processes. Over the past 20 years, the keywords ‘R&D efficiency’, ‘research and development efficiency’, and ‘research efficiency’ appeared in a number of academic journal papers.[6] Despite the abundance of literature on regional R&D efficiency evaluation (e.g. Bai, 2013; Chen and Guan, 2012; Fritsch and Slavtchev, 2011; Guan and Chen, 2010; Zabala-Iturriagagoitia et al., 2007), very few studies

---

[6] According to the results of an on-line search (http://www.sciencedirect.com), 889 journal papers were published with these keywords between 1993 and 2012.

examine this issue from a dynamic perspective (Archibugi et al., 1999). Moreover, because a region's R&D efficiency can change over time, the longitudinal investigation of R&D efficiency can help assess the extent to which a region demonstrates consistency in productivity.

Despite rapid economic growth, Korea's nation-wide approach to innovation resulted in economic disparities between the capital metropolitan areas (Seoul, Gyeonggi, and Incheon) and other areas (Duke et al., 2006). Consequently, Korea began to adopt regional innovation frameworks in the mid-1990s to reduce interregional economic imbalances and reinforce competitiveness (Chung, 2002). The Roh Moo-hyun administration (2003–2008) was the first regime to aggressively pursue regional policy by enacting the 'Special Law on Decentralisation' and 'Special Law on the Construction of a New Administrative Capital' in 2003 and the 'Special Law on Balanced National Development' in 2004 to promote innovation. This administrative ethos has been going on ever to intensify regional science and technology competitiveness through R&D. (The Ministry of Education, and Science and Technology; MEST, 2010*a*).

A study of Korean regions can provide valuable insights for policy-making related to regional R&D systems. Multiple regional innovation systems comprise a national innovation system (Chung, 2002), and they are essential to achieve the objectives of national innovation policies (OECD, 2008). Primarily, Korea is characterised by dirigiste initiatives (Braczyk et al., 1998), which are congruous with regionalised national approaches (Asheim and Isaksen, 1997) in a top-down manner (Howell, 1999). Consequently, from a national perspective (i.e. central government), an intra-country comparison of regional R&D efficiencies is worthwhile to identify the state of regional R&D systems.

This study aims to contribute to the literature on regional innovation by quantifying the respective R&D efficiencies of Korean regions from static and dynamic perspectives. Although regional innovation initiatives were introduced in Korea in the 1990s, the Korean government began to provide region-wide R&D data only recently. Thus, this study employs data only for the period from 2005 to 2009.

Section 3.3. provides a brief explanation of the regional knowledge production process. Section 3.4. introduces the Data Envelopment Analysis and the Malmquist productivity index approaches for the evaluation of regional R&D efficiency. Section 3.5. describes the data used in this study. Section 3.6. presents the empirical findings, followed by a discussion of the results in Section 3.7. Section 3.8. concludes the paper with a summary of the main results, the limitations of the study, and directions for future research.

3.3. Regional knowledge production process

An innovation system is an aggregate of the knowledge production processes in an innovation environment (Asheim and Isaksen, 1997). A linear knowledge production function is based on the premise that the innovation process entails a linear relationship between inputs and outputs (Acs et al., 2002; Godin and Gingras, 2000; Griliches, 1990; Hessels and van Lente, 2008; Tsao et al., 2008; Zabala-Iturriagagoitia et al., 2007). Universities, industries, and Government Research

Institutes (GRIs) are the key R&D actors in the process of any knowledge economy (Etzkowitz, 2008). A regional knowledge production function includes universities, industries, and GRIs that consume R&D inputs (e.g. people, money, knowledge) to produce new regional scientific and technological knowledge (e.g. patents, papers) (OECD, 1996; Zabala-Iturriagagoitia et al., 2007; see Figure 11).

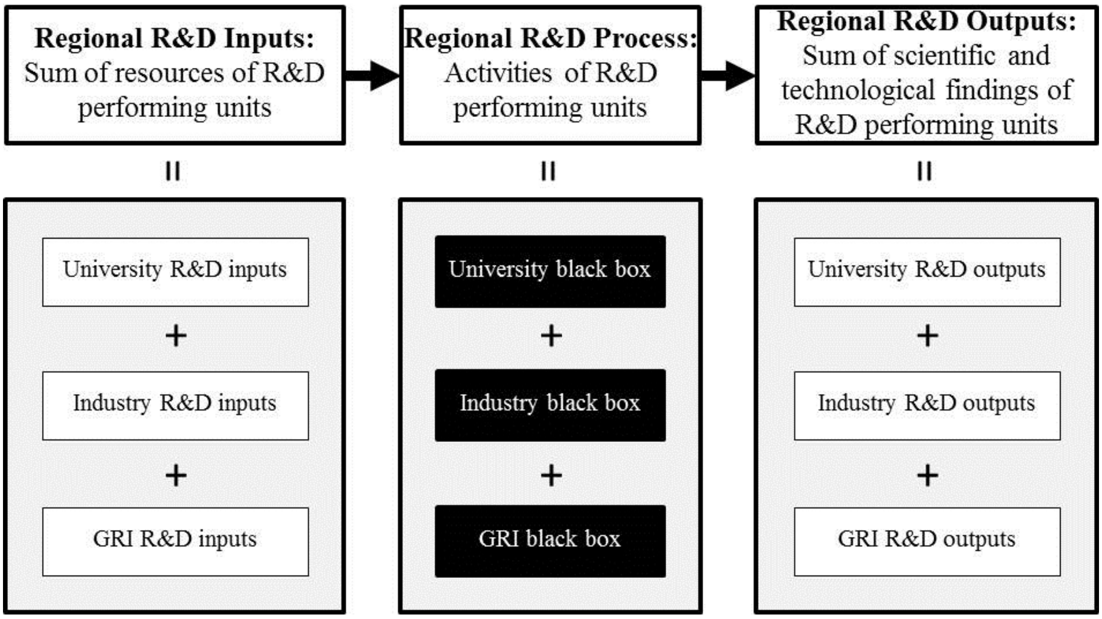


Figure 11. A linear illustration of a regional knowledge production function

Figure 11 demonstrates that a simple regional knowledge production function can be seen as a result of R&D inputs, process, and outputs. Primary R&D inputs are obtained from either internal or external sources of the respective R&D performing units. Thus, regardless of the sources (in-house sources, government, etc.) or R&D actors (universities, industries, or GRIs), a linear approach for evaluating the regional knowledge production process accounts for the total volume of regional

R&D inputs consumed in the process to produce the total volume of regional R&D outputs. In other words, a region's total R&D input level is the sum of resources invested by the universities, industries, and GRIs within the region, which is subsequently transformed into outputs.

The degree to which these regions' knowledge production processes are efficient can be evaluated from either static or dynamic perspectives. Static efficiency reflects the relative positions of regions using the best practices as defined by efficient regions (Charnes et al., 1994). Dynamic efficiency accounts for time-dependent changes in regional positions relative to those best practices, that is productivity increase or decrease (Färe et al., 1994). The regions' relative positions can be determined by an interregional comparison in terms of static and dynamic R&D efficiency, both of which consider the respective efficiencies of each region relative to other comparative regions (i.e. best practices). For example, an inefficient region can improve its relative (static) position if it exhibits increasing productivity, until it (possibly) becomes efficient. In contrast, if a currently static efficient region shows decreasing productivity, then the region would fall behind other comparative regions over time. Considering the patterns of both static and dynamic efficiencies, regions can be allocated in the matrix displayed in Figure 12.

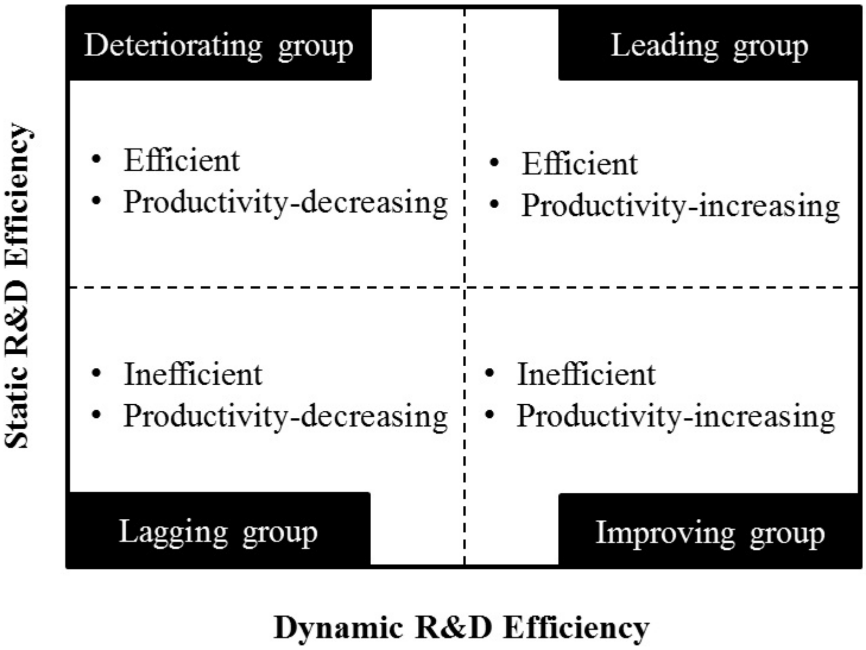


Figure 12. Regional R&D efficiency patterns

The leading group (top-right quadrant) represents an ideal situation in which the regions are both R&D efficient and register an increasing R&D productivity. If these leading regions can maintain their R&D productivity increase, then they would likely face a future characterised as consistently efficient, in both a static and dynamic sense. The deteriorating group (top-left quadrant) is (still) efficient, but suffers from a decreasing productivity over time. Although deteriorating regions are efficient at present, they are likely to lose this position over time due to their decreasing R&D productivity. The lagging group (bottom-left quadrant) is not only inefficient, but also has decreasing productivity. Therefore, the lagging group faces the greatest problems in terms of efficiency patterns; lagging regions are expected to continue their downward trend towards further inefficiency. The improving group (bottom-right quadrant) contains regions that though currently inefficient, but have increasing productivity. These regions can possibly become leading regions if they are able to maintain this productivity increase over time.

Based on the notions outlined above, this study analyses Korean regions' relative positions defined by R&D efficiency patterns. The following section explains the methodology this study employed to analyse these efficiency patterns.

3.4. Methodology

This study employs Data Envelopment Analysis (DEA) and the Malmquist Productivity Index (MPI) to determine R&D efficiency patterns of Korean regions. Because MPI (Färe et al., 1994) is a DEA-based technique, these two methods share common strengths in terms of R&D efficiency evaluation. Commonly used ratio analysis cannot accommodate multiple inputs and outputs (Sherman, 1985). However, both the DEA and MPI can handle multiple input- and output variables with different units of measurement (Charnes et al., 1994). Moreover, unlike statistical methods such as a regression model, non-parametric approaches do not require a specified production function to link inputs with outputs (Berger and Humphrey, 1997). This is relevant in the evaluation of a complex issue such as R&D efficiency, particularly in terms of studying the conversion of R&D inputs into outputs, where true production function is unknown and assumptions related to the nature or shape of the relationship between inputs and outputs cannot be easily justified. DEA allows the observed data to speak for itself by letting a convex envelopment of observations provide a conservative estimate of the frontier of the production possibility set, based on very few assumptions. This is also an advantage relative to other methods, like Stochastic Frontier Analysis (see e.g. Aigner et al., 1977), which requires assumptions not only on the functional form of production function (although some variations are quite flexible), but also the shape of the inefficiency distribution. However, the advantage of needing only few assumptions in DEA comes at the price of statistical properties. DEA efficiency analysis can be criticised for its bias from a statistical perspective, as it uses small samples (Simar and Wilson, 2000). Nevertheless, the use of few input and output variables can overcome issues related to sample size (Dyson et al., 2001).

3.4.1. Data envelopment analysis

DEA is a linear programming-based technique that evaluates the performance of decision-making units (DMUs) relative to an efficiency frontier set on the basis of efficient DMUs (Charnes et al., 1994; Cooper et al., 2007). Methodologically, DEA can be utilised in either a constant returns-to-scale model (the Charnes, Cooper, Rhodes [CCR] model) (Charnes et al., 1978) or a variable returns-to-scale model (the Banker, Charnes, Cooper [BCC] model) (Banker et al., 1984). Compared to a BCC model, a CCR model provides better discrimination among DMUs (Podinovski and Thanassoulis, 2007). Moreover, the BCC model is not well suited for measuring the change in total factor productivity (Grifell-Tatjé and Lovell, 1995), so this study here uses the CCR model.

The regional R&D efficiencies can be improved by either increasing outputs for a constant level of inputs, or reducing inputs for a given level of outputs. However, in practice, it is not easy for R&D policies to achieve intended output levels at a macro context. A regional R&D system is the aggregate of diverse micro-level R&D processes, each utilising inputs to produce new knowledge in different, and complex ways. From a micro-level perspective, managing the level of inputs for a given level of outputs is arguably a more practical way of reaching the efficiency frontier, rather than managing the level of outputs. Therefore, this study in the following analyses adopts an input-oriented approach.

This study uses two methods to calculate DEA scores: the super-efficiency DEA scores for a static regional R&D efficiency assessment, and the standard DEA scores for use in the subsequent MPI score calculation. Many researchers have assumed that an R&D input-output transformation process involves a time delay. The average length of the delay varies according to industry (Goto and Suzuki, 1989) and R&D actors (Adams and Griliches, 2000; Guellec and van Pottelsberghe de la Potterie, 2004). However, the empirical influence of time delay on efficiency is not substantial (Griliches 1990; Hollanders and Celikel-Esser, 2007) and its length is not definite (Wang and Huang, 2007). Therefore, this study simply defines an input-output time delay as one year (i.e. inputs from 2005 and outputs from 2006, etc.).

To assess the static regional R&D efficiency for the period from 2005–2009, this study considers super-efficiency DEA scores, developed by Andersen and Petersen (1993). These are calculated by excluding each efficient region from the reference group in the model that is used to evaluate its efficiency. Super-efficiency scores can be used to rank regions (Zhu, 2009) as they facilitate a discrimination of the efficient DMUs, all of which get an efficiency score of 1 in the standard DEA. The super-efficiency scores for efficient DMUs are equal to or higher than 1; their values represent the degree to which the DMUs can increase their inputs and still remain efficient. For the static super-efficiency DEA model, the variable values for a region are aggregated across the five years under analysis. Thus, to account for the time delay outlined above, the input for a region is the sum of input values from 2005 to 2009 and the output is the sum of values from 2006 to 2010. x_{ij} is the aggregated level of input i used by region j from 2005 to 2009, where $i = 1,\ldots, m$ is the number of inputs and $j = 1,\ldots, n$ is the number of regions. Similarly, y_{rj} is the aggregated level of output r produced by region j from 2006 to 2010, where $r = 1,\ldots,$ and s is the number of output factors. An observation in this analysis is given by the vector of (m) inputs and vector of (s) outputs, (X,Y) $\in R^{m+s}$, where the input and output values are aggregated over the years 2005–2009 and 2006–2010, respectively.

The static input-oriented super-efficiency CCR-DEA score for DMU j' $(X_{j'}, Y_{j'})$ is defined as follows:

$$\theta_{j'}^{super} = \min \theta$$

$$subject\ to \sum_{\substack{j=1 \\ j \neq j'}}^{n} \lambda_j x_{ij} \leq \theta \quad x_{ij'} \qquad i = 1,2,\dots,m;$$

$$\sum_{\substack{j=1 \\ j \neq j'}}^{n} \lambda_j y_{rj} \geq y_{rj'}^{t} \qquad r = 1,2,\dots,s$$

$$\lambda_j \geq 0, \tag{1}$$

where λ_j is the weight of observation (region) j in the benchmark for observation j', and $\theta_{j'}^{super}$ is greater than 1 if region j' is efficient and smaller than 1 if the region is inefficient.

Standard DEA scores are used to estimate MPI scores (Färe et al., 1994). For the MPI, this study considers changes in R&D productivity of each Korean region between the two extreme years (i.e. between 2005–2006 and 2009–2010). Changes in productivity signified by the MPI scores can be decomposed into a shift in the efficient frontier between 2005 (outputs from 2006) and 2009 (outputs from 2010) and the changes in the regions' efficiencies relative to the frontiers in the two years. Let $\mathrm{x_{ij}^{t}}$ denote the level of input i used by region j in the year t, with t =2005, 2009 and let $\mathrm{y_{rj}^{t+1}}$ be the level of output r produced by region j in year $\mathrm{t+1}$. An observation is now given by the vector of (m) inputs in the year t and the vector of (s) outputs in year t + 1, $(X^t, Y^{t+1}) \in R^{m+s}$.

The input-oriented CCR-DEA score for DMU j' $(X^t_{j'}, Y^{t+1}_{j'})$ relative to the frontier for time period t^* (inputs from t^*, outputs from t^{*+1}) is defined as follows:

$$\theta^{t*}\left(x^t_{j'}, y^{t+1}_{j'}\right) = \min \theta$$

$$subject\ to \sum_{j=1}^{n} \lambda_j x^{t*}_{ij} \leq \theta x^t_{ij'} \quad i = 1,2,\dots,m$$

$$\sum_{j=1}^{n} \lambda_j y^{t*+1}_{rj} \geq y^{t+1}_{rj'} \qquad r = 1,2,\dots,s$$

$$\lambda_j \geq 0 \quad j = 1,2,\dots,n \tag{2}$$

3.4.2. Malmquist productivity index

The MPI (Caves et al., 1982; Malmquist, 1953) is used to measure changes in regional R&D productivity over time (Cooper et al., 2007). Methodologically, it is calculated from the standard DEA scores defined in (2) above. The MPI model employed in this study is as follows:

$$MPI\left(x^{05}_{j'}, y^{06}_{j'}, x^{09}_{j'}, y^{10}_{j'}\right) = \frac{\theta^{09}\left(x^{09}_{j'}, y^{10}_{j'}\right)}{\theta^{05}\left(x^{05}_{j'}, y^{06}_{j'}\right)} \times \left[\left(\frac{\theta^{05}\left(x^{09}_{j'}, y^{10}_{j'}\right)}{\theta^{09}\left(x^{09}_{j'}, y^{10}_{j'}\right)}\right)\left(\frac{\theta^{05}\left(x^{05}_{j'}, y^{06}_{j'}\right)}{\theta^{09}\left(x^{05}_{j'}, y^{06}_{j'}\right)}\right)\right]^{1/2} \tag{3}$$

where $\mathrm{MPI}(\mathrm{x}_{\mathrm{j}'}^{05}, \mathrm{y}_{\mathrm{j}'}^{06}, \mathrm{x}_{\mathrm{j}'}^{09}, \mathrm{y}_{\mathrm{j}'}^{10})$ represents the change in R&D productivity between 2005(06) and 2009(10) for region j'. $\mathrm{MPI}(\mathrm{x}_{\mathrm{j}'}^{05}, \mathrm{y}_{\mathrm{j}'}^{06}, \mathrm{x}_{\mathrm{j}'}^{09}, \mathrm{y}_{\mathrm{j}'}^{10}) > 1$ indicates an increase in productivity between 2005(06) and 2009(10); conversely, a value lower than one implies a decrease in productivity during this period. A value of one indicates no change in productivity. Furthermore, model (3) can be decomposed into a technical efficiency change index (TECI) and a technical change index (TCI).

$$TECI(x_{j'}^{05}, y_{j'}^{06}, x_{j'}^{09}, y_{j'}^{10}) = \frac{\theta^{09}(x_{j'}^{09}, y_{j'}^{10})}{\theta^{05}(x_{j'}^{05}, y_{j'}^{06})} \tag{4}$$

$$TCI(x_{j'}^{05}, y_{j'}^{06}, x_{j'}^{09}, y_{j'}^{10}) = \left[\frac{\theta^{05}(x_{j'}^{09}, y_{j'}^{10})}{\theta^{09}(x_{j'}^{09}, y_{j'}^{10})} \frac{\theta^{05}(x_{j'}^{05}, y_{j'}^{06})}{\theta^{09}(x_{j'}^{05}, y_{j'}^{06})}\right]^{1/2} \tag{5}$$

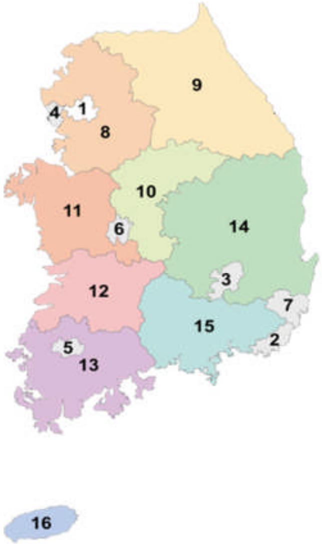
The TECI model (4) indicates whether a region moved closer to or further away from the efficient frontier between 2005(06) and 2009(10) (Cooper et al., 2007). TECI scores reflect the catch-up effect of each region, defined by the ratio of the distances to the efficiency frontier in the two time periods. If one inefficient region is more capable of utilising knowledge production technologies than others, its R&D productivity would improve faster than that of other regions. Consequently, the region's distance from the frontier would decrease over time. The TCI model (5) denotes the change in the best practice (technology) between 2005(06) and 2009(10) (Cooper et al., 2007). TCI scores reflect the frontier-shift effect that is determined by efficient regions. Technological advancements due to innovation extend the frontier level, which implies an improvement in the best practices in terms of regional R&D production. Thus, with respect to R&D, a frontier shift reflects the change in a region's potential for producing knowledge at that specific time. For this study, these two components provide further information on the sources of change in regional R&D efficiency.

3.5. Data

3.5.1. Sample of observations

The analyses employ Korea's regional knowledge production data. Of the sixteen administrative regions, Jeju was excluded, as it is largely a tourism-driven region, and therefore unlikely to be comparable to other territories with an advanced scientific and technological infrastructure. Among the remaining fifteen regions considered in this study, one region is a special city, six are metropolitan cities, and eight are provinces (see Table 4).

Table 4. Key statistics of Korean regions

No.	Region	Type	Area in 2010 (km^2)	GRDP in 2010[c] (billion KRW[d])	R&D relative to GRDP in 2010 (%)	Economically active Population in 2010 (000)	R&D organisation in 2010	Map
1	Seoul	City	605	289,719	2.85	5,180	4,504	
2	Busan	City	766	63,737	1.32	1,633	764	
3	Daegu	City	884	38,580	1.53	1,218	716	
4	Incheon	City	1,027	60,708	2.74	1,390	981	
5	Gwangju	City	501	26,401	1.97	688	394	
6	Daejeon	City	540	27,632	18.14	728	758	
7	Ulsan	City	1,058	62,852	0.72	553	242	
8	Gyeonggi	Province	10,136	266,562	6.87	5,913	5,486	
9	Gangwon	Province	16,613	30,628	0.93	685	253	
10	Chungcheongbuk	Province	7,433	39,470	1.98	753	619	
11	Chungcheongnam[a]	Province	8,629	83,167	3.23	1,003	777	
12	Jeollabuk	Province	8,061	36,632	1.45	835	362	
13	Jeollanam	Province	12,233	59,901	0.81	904	291	
14	Gyeongsangbuk[b]	Province	19,029	80,839	2.26	1,400	652	
15	Gyeongsangnam	Province	10,532	87,419	1.73	1,576	975	
16	Jeju	Province	1,849	10,899	1.03	289	89	

Compiled from Statistics Korea (http://www.kostat.go.kr/eng/), last accessed on 23rd October, 2014; [a] Daejeon excluded; [b] Daegu excluded; [c] Gross Regional Domestic Product, deficient price basis; [d] Korean currency unit: won

3.5.2. Variables and data sources

In DEA and MPI assessments, the total number of observations should ideally be at least thrice that of the total number of variables (Banker et al., 1989) or twice that of the product of the number of inputs and outputs (Dyson et al., 2001). However, it is preferable to include fewer variables for a better discrimination among DMUs (Dyson et al., 2001). Therefore, it is necessary to determine a small number of indicators that can represent the regional knowledge production process of the fifteen Korean regions.

R&D expenditure, R&D staff, and accumulated knowledge are typical inputs that are directly consumed in the R&D process (Guan and Chen, 2010). While financial resources are crucial for stimulating progress in science and technology (Hashimoto and Haneda, 2008; Wang and Huang, 2007), R&D expenditure also generally includes R&D labour costs, which are already considered (Wang and Huang, 2007) as an important input factor. Moreover, R&D expenditure may also include explicit knowledge, as R&D funding covers intellectual property rights, which enable an organisation to acquire existing codified knowledge necessary for R&D. Therefore, this study does not consider R&D staff and accumulated knowledge to be distinct inputs. The study transforms all these different inputs to the R&D process into monetary values and aggregates them into total R&D expenditures. To quantify R&D investment, this study incorporates data from the MEST Survey of

Research and Development in Korea for the period of 2005–2009.[7] Further, in order to mitigate the impact of inflation on R&D expenditures, this study converts the annual R&D expenditures into year 2010 KRWs (i.e. using the fixed base method).

As the knowledge production function relates R&D inputs to outputs that reflect scientific and technological knowledge drawn from an R&D process, it is necessary to define knowledge as the output. Knowledge can be broadly divided into two types: tacit and codified (Audretsch, 1998; Lissoni, 2001). R&D staff inputs tacit knowledge and translates it into codified knowledge. It is ultimately manifested and embedded in the form of technologies, products, and/or services through knowledge externalisation (Nonaka et al., 2000). Therefore, codified knowledge is considered as an output of the R&D process. Additionally, it is easier to quantify codified knowledge, which makes it more suitable for use in quantitative methods. In terms of science and technology, this knowledge codification may be revealed through patents and academic publications.

Patents are a crucial indicator of R&D output (Popp, 2005; Wang and Huang, 2007). Patent quantity is a proxy for the achievements embedded in an R&D process (Griliches, 1990), which has led to its consideration as an output variable. However, unlike some previous studies that counted the number of patents granted by domestic or international property offices (Fritsch and Slavtchev, 2011), this study counts the

---

[7] Since 1963, the Ministry of Education, Science and Technology (MEST) and the Korea Institute of Science & Technology Evaluation and Planning (KISTEP) have carried out this annual survey to collect information for national science and technology policy making and R&D planning. Inspired by the OECD Frascati Manual (1993), it covers multifaceted aspects such as R&D expenditure, R&D workers, and other factors with respect to universities, industries, and GRIs.

quantity of patent applications, because it is impossible to estimate the lead time between the initial application and granting of patents as required for patent examinations (Thursby and Kemp, 2002). Also, patent registrations are the result of examining scientific and technological specifications described in patent applications. In terms of sampling, this indicates that the registered number of patents is already included in number of applications for patents. Thus, a simultaneous consideration of both applications and registrations may result in the double counting of patents. In order to avoid redundancy in quantifying patents, this study only considers the patent applications.

The Organisation for Economic Co-operation and Development (OECD) uses a fractional count method to provide statistics on Patent Cooperation Treaty (PCT) applications. This study collected region-wide information on patent applications by searching for applicants' addresses on the World Intellectual Property Organization (WIPO) website.[8]

Academic publications account for a large proportion of the scientific and technological output of R&D (Cherchye and Abeele, 2005; Furman et al., 2002; Jiménez-Sáez et al., 2011; Wang and Huang, 2007). This study utilises the Science Citation Index Expanded (SCIE) and the annual SCI Database Analysis published by MEST, based on the Web of Science®, Thomson Reuters, to assess the quantity of papers published annually. Thomson Reuters provides access to the world's leading

---

[8] Some patent applicants do not follow the Romanisation system proclaimed in 2000, so the names of Korean regions are seen to be spelled differently in different applications. For example, names, 'Gwangju', 'Kwangju', 'Gwangjoo', and 'Kwangjoo' have been used for Gwangju.

citation databases, including the SCIE, the Social Sciences Citation Index Expanded, the Arts and Humanities Citation Index, and the Conference Proceedings Citation Index (the Science edition as well as the Social Science and Humanities edition). The MEST *SCI Database Analysis* deals solely with SCIE data. In terms of journal categories, SCIE journals contain SCI journals and the two categories are the world's leading academic journals of science and technology.

To assess R&D outputs, this study considers international statistics on PCT applications and on publications in SCIE journals rather than domestic data, because international patents and publications are considered superior to their domestic counterparts. For example, in contrast to international offices, the Korea Intellectual Property Office (KIPO) does not require patent applicants to include a rigid patent reference list. Therefore, domestic patented knowledge may not be of approved quality. Similarly, scientific and technological articles published in international journals may be considered of higher quality than those published in domestic journals, as they undergo a more systematic and critical review process.

The quality of these primary R&D outputs is strongly attached to the adoption by others such as patents by industrial firms, products/services by end-users in the marketplace, and publications by scholars. As the focus of this paper is on the knowledge production process that produces primary knowledge base, the final quality values of patents and publications are not considered in the efficiency analysis. Rather, the analysis quantifies the number of primary R&D outputs.

Table 5 provides data on R&D expenditure adjusted for inflation as the input, and data on PCT applications and SCIE publications as outputs, considering the time delay of one year.

Table 5. Inputs and outputs in evaluating regional R&D efficiency in Korea

Indicator		Data source	Region	Year					
				2005	2006	2007	2008	2009	2010
Input	Amount of R&D expenditure (after inflation adjustment, billion KRW)	Survey of Research and Development in Korea, MEST	Seoul	1654.59	2272.83	2473.51	1526.53	2608.66	-
			Busan	125.88	268.77	348.10	157.94	289.67	-
			Daegu	134.11	141.84	165.25	108.08	189.58	-
			Incheon	421.51	496.88	670.56	250.57	514.55	-
			Gwangju	123.40	173.46	200.91	106.46	188.18	-
			Daejeon	1042.91	1391.83	1343.94	839.92	1555.95	-
			Ulsan	132.89	245.08	141.40	87.52	140.91	-
			Gyeonggi	3433.59	5112.24	4905.86	2883.08	5558.30	-
			Gangwon	55.82	82.69	81.73	54.80	99.00	-
			Chungcheongbuk	142.84	210.54	239.37	136.90	223.42	-
			Chungcheongnam	389.20	529.68	601.88	367.13	759.33	-
			Jeollabuk	92.95	121.64	153.15	130.94	176.22	-
			Jeollanam	61.59	104.73	94.40	69.94	139.22	-
			Gyeongsangbuk	460.05	706.23	555.88	300.12	562.42	-
			Gyeongsangnam	343.83	548.84	514.53	302.99	501.41	-
Output	Number of PCT applications (count)	WIPO website (http://www.wipo.int)	Seoul	-	2,960.00	3,432.00	4,151.00	4,189.00	4,742.00
			Busan	-	256.00	340.00	362.00	289.00	389.00
			Daegu	-	179.00	185.00	275.00	264.00	321.00
			Incheon	-	299.00	347.00	465.00	491.00	557.00
			Gwangju	-	162.00	162.00	210.00	274.00	262.00
			Daejeon	-	770.00	992.00	1,330.00	1,370.00	1,140.00
			Ulsan	-	40.00	58.00	85.00	101.00	125.00
			Gyeonggi	-	2,352.00	2,971.00	3,421.00	3,491.00	4,201.00
			Gangwon	-	60.00	74.00	108.00	106.00	106.00
			Chungcheongbuk	-	109.00	152.00	232.00	203.00	225.00
			Chungcheongnam	-	164.00	197.00	256.00	270.00	327.00
			Jeollabuk	-	79.00	76.00	94.00	97.00	158.00
			Jeollanam	-	67.00	70.00	92.00	98.00	82.00
			Gyeongsangbuk	-	220.00	297.00	482.00	509.00	411.00
			Gyeongsangnam	-	337.00	325.00	483.00	388.00	449.00

Table 5. Inputs and outputs in evaluating regional R&D efficiency in Korea (continued)

Indicator		Data source	Region	Year					
				2005	2006	2007	2008	2009	2010
Output	Number of SCIE publications (count)	SCI Database Analysis, MEST	Seoul	-	17,986.00	19,227.00	19,421.00	23,661.00	27,009.00
			Busan	-	2,530.00	2,661.00	2,843.00	3,553.00	3,791.00
			Daegu	-	1,731.00	1,829.00	1,956.00	2,470.00	2,865.00
			Incheon	-	1,664.00	1,793.00	1,955.00	2,218.00	2,528.00
			Gwangju	-	2,225.00	2,103.00	2,300.00	2,863.00	3,077.00
			Daejeon	-	7,817.00	7,389.00	7,640.00	8,819.00	10,202.00
			Ulsan	-	305.00	358.00	407.00	598.00	844.00
			Gyeonggi	-	7,448.00	7,818.00	8,478.00	10,465.00	12,150.00
			Gangwon	-	1,195.00	1,367.00	1,459.00	1,665.00	2,186.00
			Chungcheongbuk	-	1,061.00	1,192.00	1,291.00	1,479.00	1,802.00
			Chungcheongnam	-	1,297.00	1,370.00	1,440.00	1,952.00	2,338.00
			Jeollabuk	-	1,545.00	1,560.00	1,826.00	2,177.00	2,522.00
			Jeollanam	-	543.00	510.00	546.00	735.00	837.00
			Gyeongsangbuk	-	2,476.00	2,700.00	2,776.00	3,389.00	3,645.00
			Gyeongsangnam	-	1,663.00	1,944.00	1,977.00	2,645.00	2,968.00

3.6. Empirical results[9]

3.6.1. R&D efficiency and its change

Table 6 presents the R&D super-efficiencies and productivity changes of the fifteen Korean regions from 2005(06) to 2009(10). In the super-efficiency model, a score greater than 1 indicates that a region is (super)efficient, while a score below 1 indicates it is inefficient. For the MPI, a score exceeding 1 indicates an increase in a region’s R&D productivity between 2005(06) and 2009(10); a score of 1 suggests no change in a region’s productivity; and a score less than 1 indicates a decrease in the region’s productivity.

---

[9] For details of calculations, see Appendix A.

Table 6. Static R&D super-efficiency and R&D productivity change by region in Korea

Region	Static R&D efficiency (DEA super-efficiency)		R&D productivity change (MPI)	
	Score	Ranking	Score	Ranking
Seoul	1.116	2	0.988	8
Busan	0.849	5	1.355	2
Daegu	1.029	3	0.803	11
Incheon	0.496	10	0.655	14
Gwangju	0.916	4	1.055	5
Daejeon	0.524	8	1.050	6
Ulsan	0.302	14	0.343	15
Gyeonggi	0.406	13	0.906	10
Gangwon	1.327	1	0.991	7
Chungcheongbuk	0.557	7	0.780	12
Chungcheongnam	0.260	15	0.987	9
Jeollabuk	0.678	6	1.108	3
Jeollanam	0.507	9	1.750	1
Gyeongsangbuk	0.434	12	0.733	13
Gyeongsangnam	0.487	11	1.083	4

As is evident from Table 6 (second column), three regions were found to be efficient in the static model (DEA super-efficiency ≥ 1), while the remaining twelve were inefficient. Seoul demonstrated the second highest efficiency (1.116) despite being the largest producer of PCT applications and SCIE publications between 2006 and 2010 (see Table 5). Despite the strong government-driven industrial relocation policies (Duke et al., 2006), Incheon (0.496) and Gyeonggi (0.406) were found to be very inefficient in their R&D production. The last column in Table 6 demonstrates that six regions improved their R&D productivity between 2005 and 2009 (MPI > 1), and the other nine regions declined in this regard. Although Ulsan has been one of the largest industrial districts in Korea based on its chaebol-driven automobile, shipbuilding, and petrochemical industries since the 1970s (Oh, 1996), the city experienced the most severe decrease in its R&D productivity (0.343).

3.6.2. Technical efficiency change and technical change

The MPI score can be decomposed into TECI and TCI (see models (3), (4), and (5)). While TECI reflects the extent to which a region catches up with the frontier set by efficient regions, TCI illustrates how the technological frontier is improving from the perspective of region in questions.

Table 7. Technical efficiency change and technical change by region in Korea

Region	R&D productivity change (MPI)		Catch-up effect (TECI)		Frontier-shift effect (TCI)	
	Score	Ranking	Score	Ranking	Score	Ranking
Seoul[a]	0.988	8	0.880	7	1.124	10
Busan	1.354	2	1.211	2	1.118	13
Daegu[a]	0.803	11	0.656	11	1.223	2
Incheon	0.655	14	0.586	14	1.119	11
Gwangju	1.055	5	0.924	6	1.141	8
Daejeon	1.050	6	0.858	8	1.223	1
Ulsan	0.343	15	0.296	15	1.157	7
Gyeonggi	0.906	10	0.810	10	1.119	12
Gangwon[a]	0.991	7	1.000	4	0.991	15
Chungcheongbuk	0.780	12	0.643	12	1.213	3
Chungcheongnam	0.987	9	0.847	9	1.165	6
Jeollabuk	1.108	3	1.088	3	1.019	14
Jeollanam	1.750	1	1.446	1	1.211	4
Gyeongsangbuk	0.733	13	0.612	13	1.197	5
Gyeongsangnam	1.083	4	0.958	5	1.130	9
Geometric means across regions	0.920		0.806		1.141	

[a] Static efficient region

Table 7 demonstrates that while countrywide the frontier for R&D production improved, many regions declined in terms of R&D productivity mainly because of decreases in technical efficiency, specifically Seoul, Daegu, Incheon, Ulsan, Gyeonggi, Chungcheongbuk, Chungcheongnam, and Gyeongsangbuk. As seen in the last row in Table 7, although in general the frontier-shift effect showed a positive contribution to R&D productivity change (1.141), the catch-up effect (0.806) was the major factor of the general decrease in R&D productivity change (0.920). This interpretation is confirmed by Kendall's coefficient of concordance test (Conover, 1980), a non-parametric technique to test correlations among more than two variables based on the ranking of a small sample. Table 8 illustrates that R&D productivity change strongly correlates with the catch-up effect at the 0.01 level in terms of ranking (.924***), but not with total TCI change.[10]

Table 8. Results of Kendall's coefficient of concordance test

	R&D productivity change (MPI)	Catch-up effect (TECI)	Frontier-shift effect (TCI)
R&D productivity change (MPI)		.924***	-.143
Catch-up effect (TECI)	.924***		-.219
Frontier-shift effect (TCI)	-.143	-.219	

To identify factors correlated with on the catch-up effect, Kendall's coefficient of concordance test is employed. As early mentioned, an innovation system is a set of knowledge production processes operated in R&D organisations including university labs, industrial firms, and GRIs. Thus, organisation-specific features of the three types of knowledge producers are assumed to be important

---

[10] Hereafter, the sample comprise fifteen regions; *** Correlation is significant at the 0.01 level (2-tailed); ** Correlation is significant at the 0.05 level (2-tailed); and * Correlation is significant at the 0.1 level (2-tailed).

determinants of the regional catch-up effect. Funds, human resources, and infrastructural settings are the basic foundations for the R&D processes. Moreover, since TECI refers to changes over time, the following second-stage analysis considers changes in a number of organisation-specific factors for the knowledge producers: changes in the amount of R&D expenditures, number of researchers, number of R&D organisations, and other related composite factors (e.g. the amount of R&D expenditures per researcher, etc.). From Table 9, it is concluded that changes in industrial resource capacity (expenditures [.638***] and researchers [.390**]) and in the amount of industrial R&D expenditures per industrial R&D organisation (.448**) correlate positively with TECI. In contrast, change in the number of researchers per R&D organisation in the government sector (-.448**) has the largest negative correlation with TECI, followed by changes in the number of researchers per R&D organisation in the university sector (-.352*) and the number of researchers in the university sector (-.333*).

Table 9. Correlation of organisation-specific factors with the catch-up effect

Variable	Knowledge producer	Correlation with catch-up effect (TECI)
Change in the amount of R&D expenditures	University	.162
	Industry	.638***
	GRI	.257
Change in the number of researchers	University	-.333*
	Industry	.390**
	GRI	-.276
Change in the number of R&D organisations	University	.124
	Industry	.067
	GRI	-.048
Change in the amount of R&D expenditures per researcher	University	.276
	Industry	.257
	GRI	.219
Change in the amount of R&D expenditures per R&D organisation	University	.010
	Industry	.448**
	GRI	.048
Change in the number of researchers per R&D organisation	University	-.352*
	Industry	.295
	GRI	-.448**

3.7. Discussion: Regional positions and implications

Based on the results summarised in Table 3, the Korean regions are classified into three groups: deteriorating, lagging, and improving (see Figure 13).

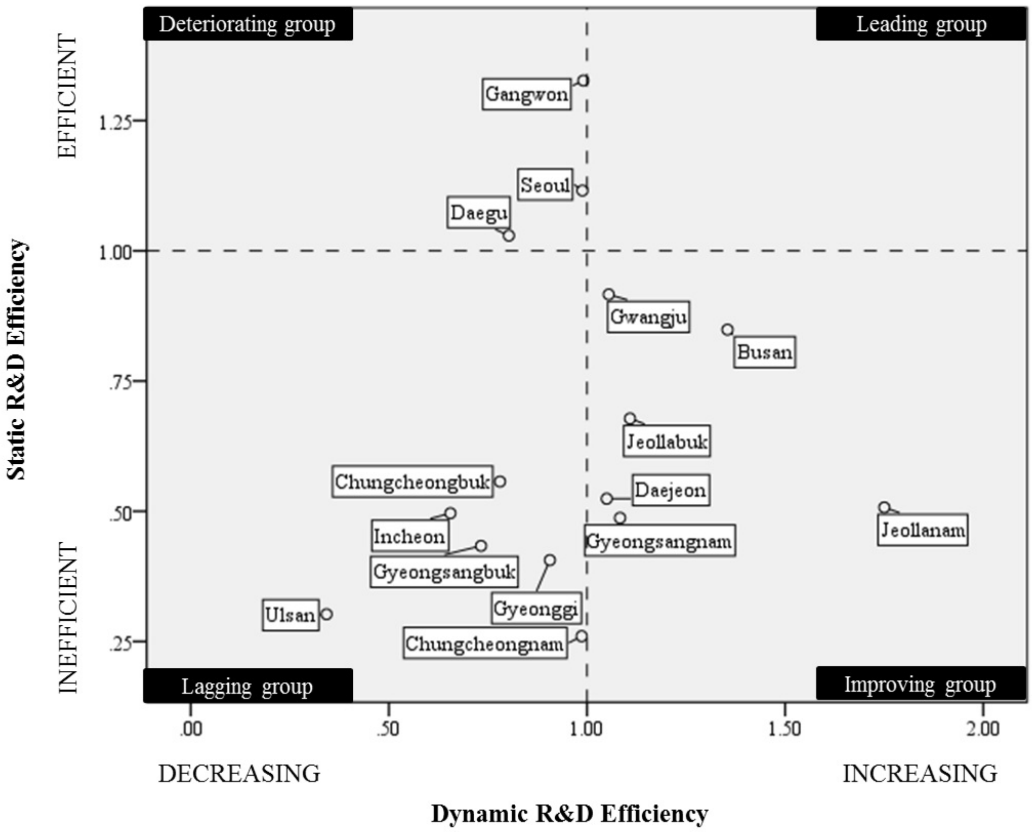


Figure 13. Positions of Korean regions. Dotted lines parallel to the x-axis and y-axis indicate the threshold value that distinguishes efficient regions from inefficient ones (based on an input-oriented super-efficiency CCR-DEA model) and efficiency-increasing regions from efficiency-decreasing ones (based on an input-oriented CCR-MPI model), respectively.

This classification scheme also contains the leading group (top-right quadrant), but no region was categorised there. Interestingly, these results indicate that even Seoul does not belong to the leading group, but is instead categorised as a deteriorating region characterised as efficient but with decreasing productivity Although Seoul has historically enjoyed strong support from the government and has a rich resource-laden infrastructure (Duke et al., 2006), it seems that Seoul does not effectively leverage its advantages as a capital city to increase its R&D productivity, though it is located near the borderline between the leading and deteriorating groups.

As early mentioned, this paper does not account for the quality of R&D outputs, but for the quantity of them in the analysis. Thus, the absence of leading regions does not imply that no Korean regions exhibit R&D excellence. If regions are not located in the upper right quadrant of the matrix, it will mean that they are not both statically and dynamically efficient, that is, being both efficient at present but also showing productivity growth. In the lagging group, Gyeonggi is one of the beneficiaries of government-driven industry development (Duke et al., 2006) and was the largest R&D investor and the second largest producer of PCT applications and SCIE publications for the period from 2005 to 2009. While Gyeonggi has experienced a rapid growth in its industrial and research districts in areas adjacent to Seoul, the massive investment has led to neither static nor dynamic efficiency. Within the improving group, Daejeon presents an interesting case. Daejeon has the largest GRI-research complex in Korea, which was responsible for approximately 56.6% of its total R&D expenditures for the period from 2005 to 2009 (MEST, 2010*b*). During this time period, Daejeon had the third highest R&D expenditures among the regions, spending around 58.6% of the expenditures of Seoul but it was inefficient since the city produced merely around 28.8% of the PCT applications of Seoul. The above cases of Seoul, Gyeonggi, and Daejoen suggest that abundant researchers, finance, and government support do not necessarily imply high static or dynamic R&D efficiency.

While TECI reflects the catch-up effect that accounts for the contribution of change in technical efficiency toward the change in productivity, TCI is the frontier-shift effect of how technical change contributes to changes in productivity (Cooper et al., 2007). Therefore, TECI reflects a region’s efficiency in utilising existing scientific and technological knowledge in their knowledge production process, whereas TCI is the extent to which regions improve through technological innovation. In comparing the practical implications of TECI and TCI, it is evident that the catch-up effect can be improved by exploitative efforts aimed at ‘refinement, choice, production, efficiency, selection, implementation and execution’ to search for new applications of existing scientific and technological knowledge (March, 1991, p. 71). In contrast, the frontier-shift effect can be achieved through exploration efforts focused on ‘search, variation, risk taking, experimentation, play, flexibility, discovery, innovation’ to seek new possibilities of innovation through intensive challenges (March, 1991, p. 71). Therefore, if a region has moved away from best practices over time, it is necessary to improve its TECI score using exploitative approaches. As March (1991) indicates, the exploitative R&D refers to the use of incumbent advanced technologies to produce more knowledge in the long-term. Conversely, if a region suffers from a decline in R&D productivity resulting from a slowdown in technical change over time, its TCI score can be improved through more aggressive R&D investment in technological advancement through innovation.

As shown in Tables 7 and 8, the catch-up effect (TECI) is largely decisive for R&D productivity change (MPI) in Korean regions (with the exception of Gangwon). Therefore, to improve their respective productivities, TECI-declining regions should focus on knowledge spillovers that facilitate the transfer of best practice technologies and apply them to potential production techniques. These regions should also improve their absorptive capacities through secondary R&D that allows for the capture of other organisations’ new techniques or technologies (Cohen and Levinthal, 1989). This would accelerate technical imports and may enhance the catch-up ability of struggling regions. That is, these typically underprivileged regions should preferably adopt less challenging strategies for incremental innovation that is coherent with absorptive capacity corresponding to the regions' traditional scientific and technological competitiveness.

Table 9 indicates that the local industry sector is positively correlated with the regional ability of catching up with efficient regions. Specifically, changes in (a) the number of industrial researchers, (b) the amount of industrial R&D expenditures, and (c) the amount of industrial R&D expenditures per industrial R&D organisation are positively correlated with the regional catch-up effect. The two latter factors (b and c) provide implications for the industry-based regional R&D processes. As indicated, increasing solely industrial R&D organisations does not significantly correlate with the catch-up effect, but its combination with increasing industrial R&D expenditures does. Longitudinally, the increase rate of industrial R&D organisations across regions was 18.71% annually during 2005-2009, while the increase rate of industrial R&D expenditures was 11.67% (KOSIS statistics). Together with a suggestion of increasing industrial researchers, regarding factors (a) and (b), it is estimated that the catch-up effect can be improved only if industrial R&D expenditures increase more than the number of industrial R&D organisations over time.

Conversely, as shown in Table 9, the negative correlation of a change in the organisational density of human resources (i.e. ratio of the number of researchers to the number of R&D organisations) with catch-up effect is commonly found in both university and government sectors. Meanwhile, changing only the number of R&D

organisations in the university and government sectors does not significantly correlate with the regional catch-up effect. These results are related to the optimal number of university and government research organisations relative to the number of researchers. According to the KOSIS statistics, the speed of annual growth in the number of R&D organisations (university: 1.39%, GRI: 12.79%) is slower than the number of researchers (university: 8.33%, GRI: 17.45%) for 2005−2009 in both sectors. In practice, researchers are inevitable contributors to knowledge production. Thus, an adjustment of the number of university- and GRI-researchers is not a recommendable policy focus; rather, a more rapid growth in the number of R&D organisations than researchers in the university and government sectors may be a more realistic policy consideration related to the regional catch-up effect.

3.8. Conclusion

This study used non-parametric techniques to measure the R&D efficiency of fifteen Korean regions for 2005−2009 from static and dynamic perspectives. It analysed the status of Korean regions in terms of efficiency, region classification, and strategic directions for improvement in R&D efficiency. Major findings are as follows.

- The appearance of three efficient regions and twelve inefficient regions clearly indicates an interregional disparity in terms of static R&D efficiency.

- Because six regions are increasing in productivity and nine regions are decreasing in productivity, it seems that there is an imbalance in scientific and technological advancement across the regions from a dynamic R&D efficiency perspective.
- The absence of leading regions is potentially worrying, since it is such regions, which are efficient in both a static and a dynamic sense, that could drive the overall development of the country as well as serve as benchmarks for other regions.
- While technological capacity improved on the national scale, the majority of Korean regions suffered from a decrease in R&D productivity over time that was largely attributable to a decrease in the catch-up effect.

Through exploitative strategies, Korean regions can enhance the catching-up to best practice in order to reach the efficiency frontier. (1) Technical imports and complementary R&D to intensify absorptive capacity would be helpful in bridging the interregional gap in R&D efficiency and strengthen the entire country's scientific and technological competitiveness. For the regional catch-up effect, the R&D policy focus should be on the adjustment of (2) the number of industrial researchers on a regional scale, (3) the amount of R&D expenditures relative to the number of R&D organisations in the industry sector, and (4) the number of researchers relative to the number of R&D organisations in the university and government sectors.

Despite these important findings, this study has some limitations, which suggest new avenues for future studies. First, because of the lack of access to long-term historical data, this study investigated the regional R&D patterns for only five years. Longer time series data may provide more comprehensive guidance for mid- and long-term regional R&D policy planning. More to this, it is intuitively expected that the R&D productivity change stagnates, as regional innovation systems become mature over time. It would be interesting to analyse stagnation phenomena in R&D efficiency and its change between adjacent years within a longer-term timeframe. Second, other intermediate variables should be considered within the regional knowledge production environments. Such factors (e.g. types of R&D performers, regional strategic industries, R&D stages, and quality of outputs) can provide multifaceted insights into regional R&D phenomena. Third, the scope of this study was restricted to Korea. A cross-country analysis using OECD members may aid in capturing the position of Korean regions on the supranational scale. Lastly, more specific investigations of the effect of other factors (e.g. partner accessibility, demographic changes, and industrial shifts) on static and dynamic R&D efficiency could help clarify particular causes and specify policy implications. Despite these limitations, this study highlights one of key issues regarding balanced regional development of Korea by specifically evaluating the differences in the regional R&D efficiencies. Methodologically, the non-parametric quantitative methods used in this study illustrate a possible approach for comparing interregional innovation performance on a national scale for countries with a small number of regions.

CHAPTER 4. PAPER 2 – UNDERSTANDING THE TRIPLE HELIX MECHANISM FROM A SYSTEMS THINKING PERSPECTIVE: THE CASE OF SOUTH KOREA

4.1. Abstract

Recently, a triple helix framework of university–industry–government research institute (GRI) has been proposed to analyse knowledge-based innovation systems. In this paper, we analyse the effects of system failures and policy recommendations experienced by knowledge-producing triple helix actors in Korea using a system-based approach. Our analysis provides evidence that system failures influence all *intra*- and *inter*-sphere knowledge-based processes related to development, diffusion, and deployment. The analysis shows that Korea's triple helix suffers from failures in capability, infrastructure, institution, network, and transition. To redress these imperfections, some policy recommendations are *Relay*-R&D, *Ping-Pong*-R&D, joint technology holding companies, and higher job satisfaction. The suggested recommendations seem intuitively effective to all knowledge-based processes; however, from a systems perspective, the recommendations appear to generate adverse effects on knowledge development in the industry and GRI spheres, knowledge diffusion in the university sphere, and knowledge deployment in the university and GRI spheres.

Keywords: Triple helix, innovation system, systems thinking, causal loop, South Korea

4.2. Introduction

Contributions of the education and government sectors to innovation have led to an increased emphasis on the triple helix spiral between university, industry, and government (Etzkowitz, 2008). A typical illustration of the triple helix is the relationship between innovation activities in universities and industries and decision making in government bodies, such as the Ministry of Science and Technology. In the analysis of knowledge-based phenomena, however, numerous studies have addressed conceptual and empirical interactions between R&D-based innovation stakeholders in charge of knowledge generation, including university labs, industrial firms, and public research institutes (Cooke, 2001; Eom and Lee, 2010; Etzkowitz and Leydesdorff, 2000; Kwon et al., 2012; Leydesdorff and Fritsch, 2006; Leydesdorff and Meyer, 2006; Leydesdorff et al., 2006; Meyer et al., 2003; Park and Leydesdorff, 2010; Park et al., 2005; Ranga and Etzkowitz, 2013; Shapiro, 2007). This paper adopts the knowledge-based perspective of the innovation systems, where the focus is on the stakeholders.

In theory, the triple helix incorporates the three spheres' missions and hybrid organisations' roles in the *intra*-sphere context that promote *inter*-sphere relations (Etzkowitz, 2008). However, the dominant explanations provided by extant literature have been limited to *inter*-sphere relations only (e.g. Etzkowitz and Leydesdorff, 2000; Leydesdorff and Fritsch, 2006; Leydesdorff and Meyer, 2006; Leydesdorff et al., 2006; Meyer et al., 2003). This extensive emphasis on *inter*-sphere dynamics has limited our comprehensive understanding of the triple helix.

Meanwhile, all components of a system are related (Sterman, 2000). This complexity causes operational failures in large-scale systems (Hommen and Edquist, 2008). These system failures can take away capabilities and opportunities for innovation and destroy conditions which underlie the self-operating innovation mechanisms (Metcalfe, 2005). Some studies have adopted the triple helix to analyse the failures of innovation systems (e.g. Intarakumnerd and Chaoroenporn, 2013; OECD, 2011). Yet, there remains a paucity of research that comprehensively analyses the complexity-based system failures in both the *intra*- and *inter*-sphere contexts of the triple helix.

To redress these shortcomings of the literature, our primary objective is to identify the *intra*-sphere mechanisms and incorporate them into *inter*-sphere linkages among the knowledge-producing spheres. This will allow for a better understanding of how the university, industry, and government research institute (GRI) spheres generate trilateral relations between one another. Another objective of this paper is to investigate the emergence and effects of system failures and the manner in which potential recommendations may correct these failures in the triple helix. In pursuing these research foci, we expect to provide a greater degree of transparency into the nature of the triple helix, thus allowing multiple types of stakeholders to share systemic insight into it.

To illustrate our analysis, we evaluate South Korea's (hereafter Korea) triple helix system. The use of the triple helix as a means to promote innovation has steadily increased in Korea (Shapiro, 2007). Recent studies on the country have primarily focused on trilateral collaborations based on co-authorship of academic publications or co-ownership of technical patents (e.g. Kwon et al., 2012; Park and

Leydesdorff, 2010; Park et al., 2005; Shapiro, 2007). Others have used the *Korea Innovation Survey* data to differentially address issues related to collaboration (e.g. Eom and Lee, 2010). Despite their utility, these studies have offered only partial explanations of Korea's triple helix from a systems perspective. Korean innovation initiatives are controlled by the central government at both the regional and national levels (Braczyk et al., 1998). Given these conditions, the Korean case can give practical lessons to other countries in which the central government drives triple-helix-supported innovation initiatives.

To fulfil the research gaps outlined above, we employ a systems thinking approach (causal loop diagrams [CLDs; Sterman, 2000]). As a basis for the construction of the CLDs, we conduct interviews with 33 experts engaged in various activities within the university, industry, and GRI spheres.

The remainder of this paper is organised as follows. Section 4.3. provides a framework for analysing the Korean case. Section 4.4. introduces the systems thinking approach to develop CLDs and the interviewing method to collect salient data. Section 4.5. provides a visualisation of Korea's triple helix (complete with intrinsic system failures). Section 4.6. discusses policy implications based on our observations of the effects of designated system failures and suggested policy recommendations on Korea's triple helix. Section 4.7. summarises our main findings and offers avenues for future research.

4.3. An analysis framework of the triple helix

As already noted, the triple helix model encompasses the primary missions of three spheres (universities, industrial firms, and GRIs) and the secondary roles of hybrid organisations. Although the university, industry, and GRI spheres maintain their respective traditional missions (e.g. education in universities, business in industries, and R&D in GRIs), they also perform some duties that are traditionally performed by other spheres (Etzkowitz, 2008; Etzkowitz and Leydesdorff, 2000). Each sphere aims to achieve simultaneous objectives that are traditionally associated with distinct domains (see rectangular boxes in Figure 14 that cover the R&D and business domains at the same time) by formulating several types of hybrid organisations such as incubators, spin-off firms, technology transfer offices (TTO), and venture capitalists.

Figure 14 conceptualises a typical structure of the triple helix. This structure may provide a basis for illustrating information flow in both the *intra*- and *inter*-sphere contexts. For example, within the university sphere, human resources flow from the education domain to the R&D domain for projects and to the business domain during spinning-off events from universities. Moreover, the university R&D domain transfers research findings to the R&D domain in industries. With respect to hybrid organisations, university spin-offs facilitate the flow of research findings between R&D and business. Incubators also link science and business by providing infrastructure that facilitates the establishment of university spin-offs. TTOs promote the flow of research findings to university spin-offs in the business domain and to industries' R&D domain. The emergence of information flows derived from industries and GRIs are equal in complexity with information flows derived from universities in the *intra*- and *inter*-sphere contexts, illustrating the complexity of a typical triple helix structure.

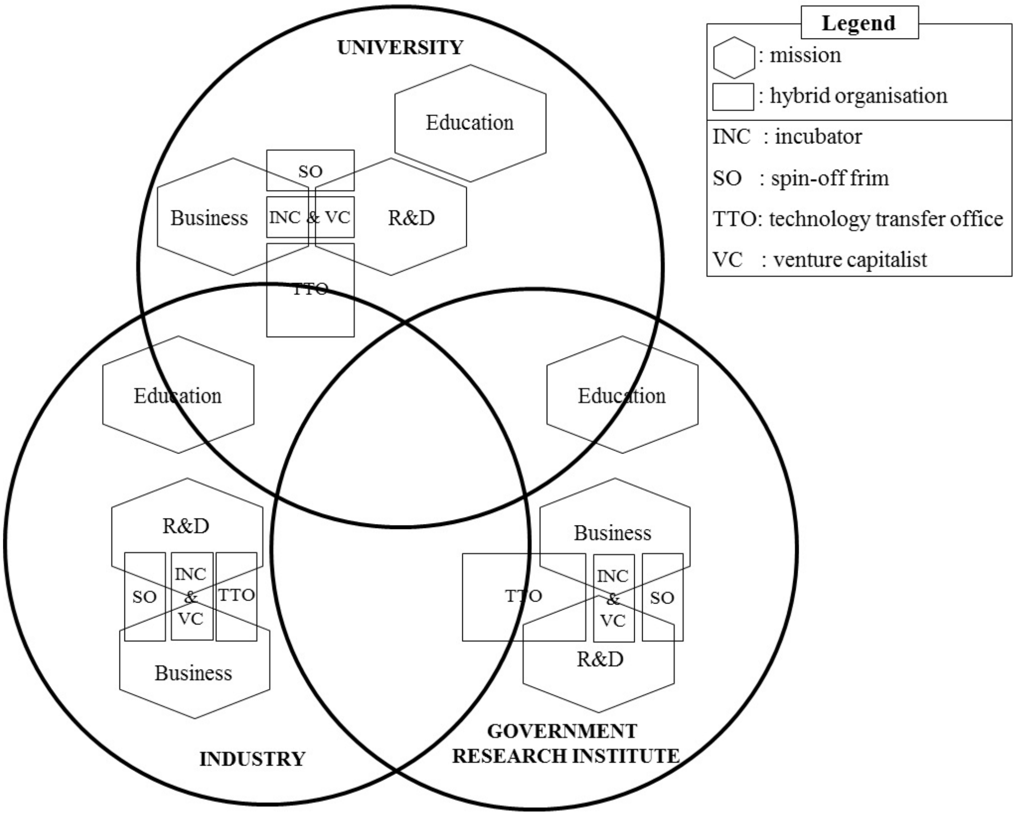


Figure 14. A conceptual triple helix structure: Missions and hybrid organisations

From the perspective of a knowledge economy, the triple helix for innovation can be described as amounting to composite feedback loops that relate knowledge development, diffusion, and deployment (Carlsson et al., 2002; Cooke et al., 1997; Lundvall, 1992; Rickne, 2001). *Knowledge development* refers to R&D that generates scientific and technological knowledge (Organisation for Economic Co-operation and Development [OECD], 1993). It can be promoted by in-house and/or contracted R&D (Beneito, 2006). *Knowledge diffusion* relates to the flow of know-how, technical knowledge, or technology from one organisational setting to another (Roessner, 2000). *Knowledge deployment* refers to the transformation of (codified) knowledge into tangible value (Dvir and Pasher, 2004) through spin-off formation within the spheres (Müller, 2010; van Geenhuizen and Soetanto, 2009) and industrial product and/or process innovations (Abernathy and Utterback, 1978).

The innovation system perspective conceptualises innovation as a complex evolutionary process in which diverse actors behave and interact under market and non-market forces (Bleda and del Río, 2013). Its complexity is the result of ‘highly interrelated connectivity, nonlinear and dynamic functionality, and a large number of elements’ (Milling, 2002). The system’s failures are based on the limited cognitive abilities possessed by the system’s inhabitants relative to the complexity of the system as a whole (Forrester, 1961). Complexity affects all innovation-related processes and therefore requires a holistic management approach (Fonseca, 2002). Systems complexity incites several system failures which can hamper innovation. Woolthuis et al. (2005) reviewed eight types of system failures defined by Carlsson and Jacobsson (1997), Edquist et al. (1998), Johnson and Gregersen (1995), Malerba (1997), and Smith (2000). These failures are summarised in Table 10.

Table 10. Definition of system failures

Type	Definition
Infrastructural failure	Lack of physical settings to support innovation
Transition failure	Inability to adapt to new technological developments
Lock-in/path dependency failure	Inability to adapt to new technological paradigms
Hard institutional failure	Lack of formal regulations and legal systems
Soft institutional failure	Lack of informal institutions such as political culture and social values
Strong network failure	Inability to capture new developments from the outside because of adherence to existing partners
Weak network failure	Inability to establish complementary relationships with others
Capabilities' failure	Inability to develop new technologies

Adapted from Woolthuis et al. (2005)

These potential system failures in innovation systems may be interpreted as structural inabilities that negatively influence interlocked knowledge-based processes in a systemic way. To remedy the above imperfections, it is necessary to correct change(s) in the structural pattern(s) of the system in which innovation emerges (Andersson, 1998). However, it is difficult to identify and implement effective solutions, as an effective solution in one context may be ineffective in another (Forrester, 1971; Lee and von Tunzelmann, 2005). Moreover, the effects of external shocks permeate multiple areas over time (Jervis, 1997). Therefore, policy interventions designed to circumvent or remedy system failures must be considered in multiple contexts. Many of these issues are illustrated in Figure 15.

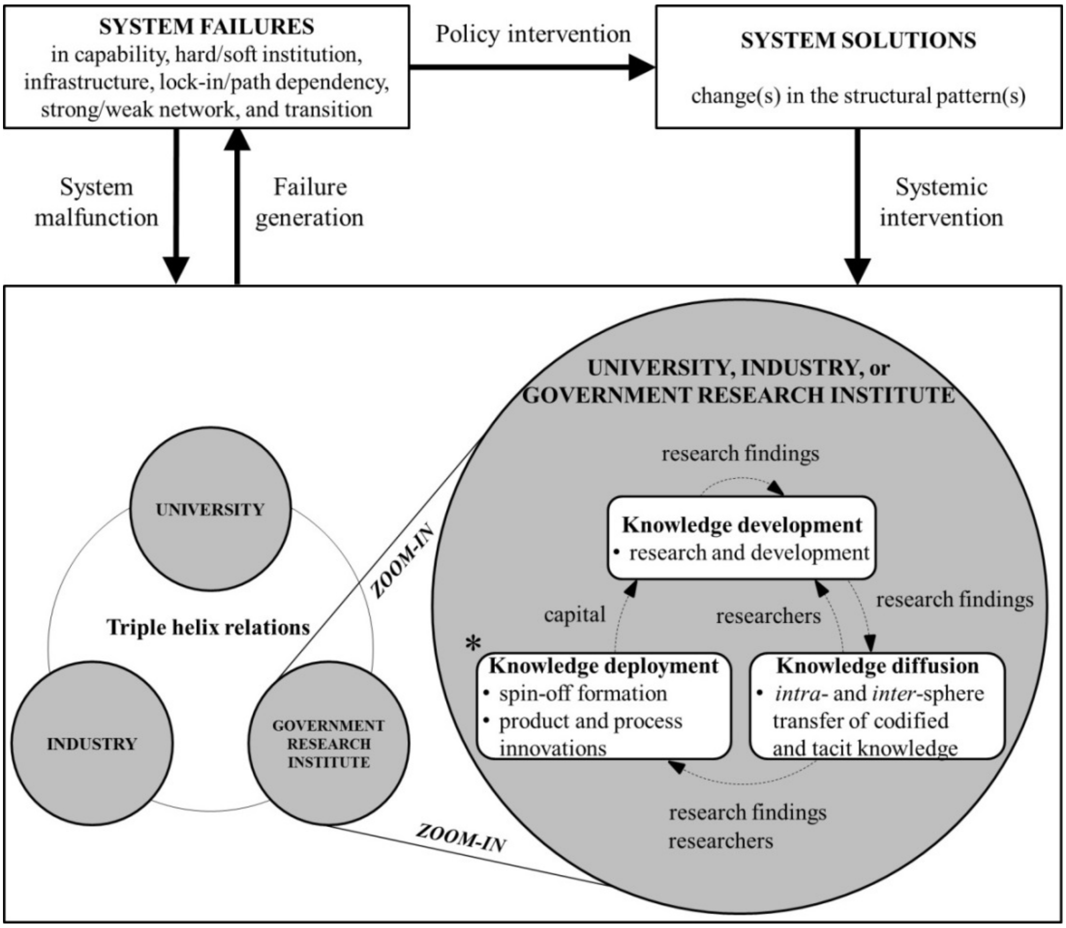


Figure 15. An analysis framework of the triple helix. Whereas spin-offs are formulated by intra-sphere transfer of codified and tacit knowledge, product and process innovations use codified knowledge produced in the industry sphere in the intra-sphere context and codified knowledge transferred from the university and GRI spheres in the inter-sphere context.

In the innovation policy field, systems thinking has been a widely adopted approach to evaluating innovation systems (Dodgson et al., 2011). Systems thinking is based on the premise that a full understanding of a problem's emergence hinges on the association of the system's parts to its whole in a holistic manner (Capra, 1996; Jackson, 2003; Lars, 2006). Therefore, we use systems thinking to explore the effects of system failures and the corresponding policy recommendations on Korea's triple helix with respect to the *intra*- and *inter*-sphere knowledge-based processes. In the following section, we explain the systems thinking approach and interviewing method we employed to address these issues.

4.4. Methodology

Past researchers have largely sought to categorise or introduce types of failures (e.g. Weber and Rohracher, 2012; Woolthuis et al., 2005). A relatively novel approach to this issue is to quantitatively evaluate system failures (e.g. Chaminade et al., 2012). However, there have been few empirical attempts to holistically explore the effects of system failures on the entire system. As such, systems thinking can provide an additional perspective for interpreting system failures. Therefore, in this paper, we employ systems thinking to provide a perspective characterised by non-linearity and feedback loops to complement extant literature in this domain.

4.4.1. Analysis technique: Systems thinking

We employ causal loop diagrams (CLDs) to provide a holistic perspective of systemic structures within Korea's triple helix. The use of CLDs allows for the assignment of a model's boundaries and an understanding of causal structures that dominate the system's behaviours. As such, this method identifies cause−effect relationships among variables within a specified system boundary (Sterman, 2000). Moreover, CLDs are effective means of sharing feedback dynamics with system stakeholders. Several studies have analysed innovation systems using this approach (e.g. Ford and Sterman, 1998; Galanakis, 2006; Kunc, 2010; Lee and von Tunzelmann, 2005; Milling, 2002).

The principles for modelling a CLD are as follows. If an increase (or decrease) in the value of component X causes an increase (or decrease) in the value of component Y, then the sign of the arrow connecting the two variables is '+'. If a change in variable X drives a change in variable Y in the opposite direction, the sign of the arrow that connects the variables is '−'. The combination of multiple links between variables collectively develops a reinforcing (R) or balancing (B) feedback process (see Figure 16). A reinforcing process causes the system to grow exponentially; a balancing process drives the system toward equilibrium. Because dynamic processes between two variables may not be immediate, feedback loops can be subjected to time delays (represented as '||' in the middle of the arrow between variables).

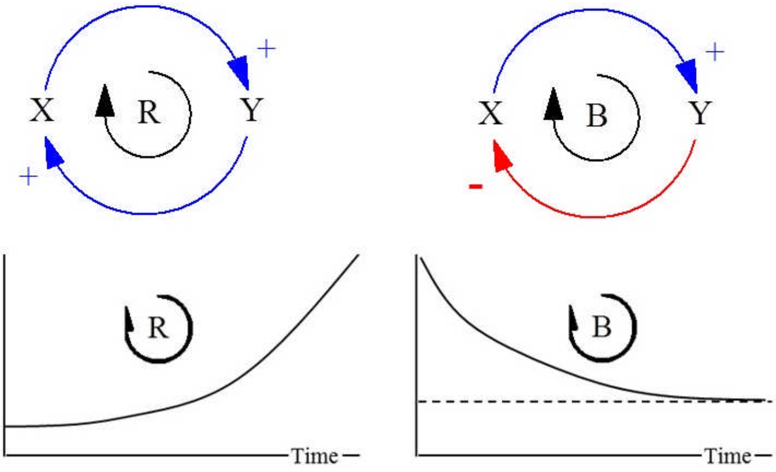


Figure 16. A reinforcing and balancing feedback process

4.4.2. Data collection technique: Expert interview

Interviewing is an effective method for gaining insight into a given research area by drawing from the experiences of others (Seidman, 1998). To analyse Korea's triple helix, we conducted interviews with experts from the Korean university, industry, and GRI spheres between January and March of 2013. We selected 33 respondents based on their respective positions, work experiences, and specialities within Korea's triple helix.

To avoid influencing participants' responses, we did not provide any information related to the ideal structure of a normative triple helix. Instead, we posed open-ended questions, like 'What factors are essential for GRI R&D?'[11] Additionally, we promoted an expanded discussion with respondents, on the parts of the structure of a normative triple helix, using 'what if' questions. For example, we asked, 'If R&D investment increases, which variable(s) is/are directly affected, and how?' The use of 'what if' questions allowed for the confirmation of positive (+), negative (−), or non-significant associations between variables. Additionally, several questions with the same focus were posed in different ways, and we conducted multiple interviews with different experts in the same domain. Through this multi-round interview process, we filtered invalid data to capture the realities of the Korean triple helix.

Along with multi-round interviews, we adopted an investigator triangulation approach (Denzin, 2006). Questions were asked to multiple, neighbouring respondents. For example, R&D researchers (i.e. knowledge producer), technology

---

[11] For details, see Appendix B.

transfer staff (i.e. knowledge distributor), and industrial firms' technology transfer related administrators (i.e. knowledge receivers) all received similar questions regarding the ownership of intellectual property to identify similarities and differences in perspectives. Multiple angles reduced bias and improved the credibility of qualitative data, since it combines multiple perceptions originating from diverse stakeholders (Lietz et al., 2006).

Following primary interviews, we engaged in additional interviews with researchers and public servants who are involved with the innovation policy field. This final round of interviews helped confirm the validity of the triple helix variables and relationships among them.

Because many respondents were opposed to having their voices recorded, all interviews were documented in notes taken by the interviewer. Table 11 provides basic data on each of the participants. To maintain their anonymity, we codified respondents' names and simplified their affiliations.

Table 11. Interview participants in Korea

Code	Affiliation	Position	Dialogue content
R01P	National commission	Deputy director	Innovation system
R02K	Ministry	Deputy director	Innovation system
R03L	Ministry	Senior deputy director	Innovation system
R04B	Ministry	Director	Innovation system
R05L	Policy institute	Senior researcher	Innovation system
R06L	GRI [a]	Principal researcher	GRI
R07P	GRI	Principal researcher	GRI
R08J	GRI	Technical editor	GRI
R09J	Development institute	Senior research fellow	R&D
R10P	University	Associate professor	R&D
R11K	Business association; SME [b]	Chairman	Incubator, spin-off, SME, and R&D
R12K	Business association	Secretary	Incubator, spin-off, SME, and R&D
R13P	Business association	Deputy general manager	Incubator, spin-off, SME, and R&D
R14K	Business administration	Action officer	Incubator, spin-off, and venture
R15H	Business administration	Action officer	Incubator, spin-off, and venture
R16K	Industry-university collaboration centre	Team leader	R&D, incubator, spin-off, technology transfer, and THC [c]
R17S	Techno park	Deputy general manager	Technology transfer and incubator
R18G	Techno park	Manager	Technology transfer and incubator
R19L	University	Professor	University
R20H	Industry-university collaboration centre	Vice president	R&D, incubator, spin-off, technology transfer, and THC
R21N	Industry-university collaboration centre	Senior researcher	R&D, incubator, spin-off, technology transfer, and THC
R22P	Techno park	General manager	Technology transfer, and incubator
R23R	Techno park	Team manager	Technology transfer, and incubator
R24K	Development institute	Director	R&D
R25L	Policy institute	Research fellow	Technology transfer
R26L	Industry-university collaboration centre	Analyst	Technology transfer
R27H	Large company	Section chief	R&D
R28C	Industry-university collaboration centre	Head	University
R29J	Research council	Manager	GRI
R30Y	Government research institute	Team leader	GRI
R31K	Government research institute	Senior researcher	GRI
R32Y	Business administration	Deputy director	SME, venture capital, venture firm, incubator, spin-off, and R&D
R33J	Technology transfer consulting company	Team leader	Technology transfer and technology commercialisation

[a] government research institute; [b] small and medium enterprise; [c] technology holding company (known as venture capitalist)

4.5. The analysis results of Korea’s triple helix

In this section, we illustrate Korea’s triple helix by applying CLD modelling principles on the interview data we collected. First, we demonstrate partial knowledge-based processes (Sections 4.5.1.−4.5.3.). Following the descriptive analyses, we depict the respective system structures of the university, industry, and GRI spheres (Section 4.5.4.). In addition to expert interviews, we seek to leverage extant innovation theories that illustrate commonplace structures related to innovation to construct knowledge-based processes in the following figures.

4.5.1. Knowledge development

Knowledge development aims to produce scientific and technological findings through in-house and contracted R&D. The process is depicted in Figure 17.

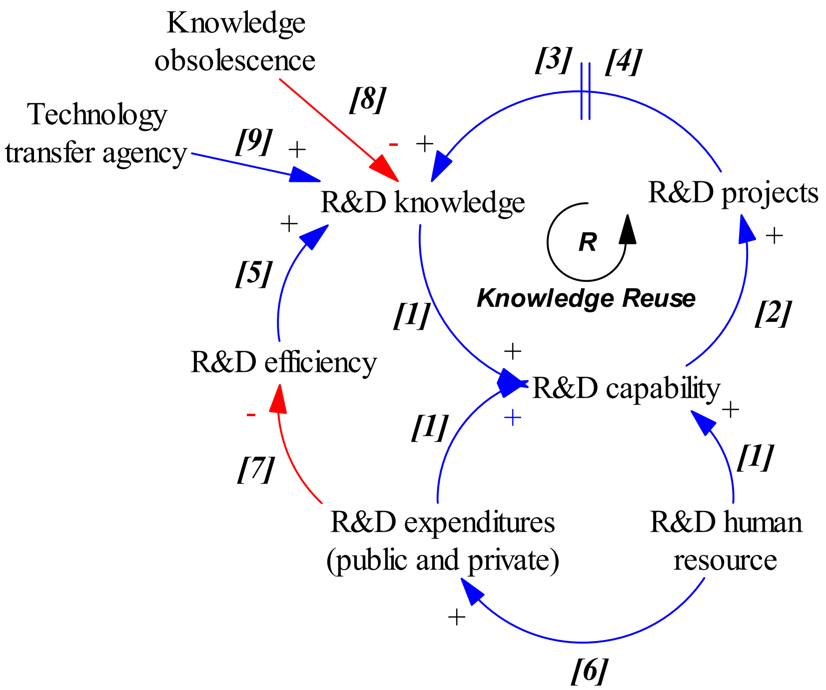


Figure 17. Knowledge development. Numbers in brackets illustrate parts of the figure that correspond to descriptions in the text below.

Financial, human, and knowledge resources are essential factors involved in and stimulating R&D (Guan and Chen, 2010) *[1]* and *[2]* which, in turn, yields an accumulation of knowledge resources (OECD, 2002) *[3]*. This process illustrates the cyclical relationship between accessibility to knowledge resources and R&D in any of the individual spheres (*R: Knowledge Reuse*).

In terms of R&D capability, '*although all three spheres draw financial resources from external funding sources in the public and private sectors, industries and GRIs utilise internal sources of funding*' (R28C, R29J, R30Y, R31K). With respect to the knowledge production cycle, '*industries engage in a profit-based circle that links economic achievements with R&D efforts*' and '*GRIs use financial reserves accumulated from the collection of technology transfer fees and R&D overhead*' (R29J, R30Y, R31K). However, universities do not demonstrate a virtuous circle with regard to their financial resources related to knowledge production. '*Once a project is completed, the relationship between the university and the client is not required to continue. Instead, university faculty proceed to apply for external funds for subsequent projects.*' (R28C). Based on this statement, it seems as though associations between project funders and performers of R&D consist of a series of distinct linear relationships.

In the process of knowledge production, it is necessary to consider industry-specific (Goto and Suzuki, 1989) and institution-specific (Adams and Griliches, 2000) time delays associated with the transformation of input into output *[4]*. Additionally, R&D efficiency, which refers to the ability to perform this input-to-output transformation with a limited use of resources (Suchman, 1967), influences the degree to which new knowledge is used to increase knowledge stock *[5]*. '*R&D failure rates in Korea are very low. The public and private sectors largely attempt to avoid risks for R&D failures. Therefore, arguments related to R&D failures are inconsequential. Instead, efficiency is a more realistic issue to address*' (R06L, R07P, R08J).

Because R&D expenditures typically include researchers' salaries, the acquisition of R&D human resources increases expenditures in that domain *[6]*. Consequently, there exists an inverse relationship between R&D expenditures and R&D efficiency *[7]*.

Additionally, the gradual obsolescence of knowledge reduces the speed with which knowledge can be accumulated (Griliches, 1990) *[8]*. The three spheres demonstrate distinct phenomena in relation to the obsolescence of knowledge. '*On the one hand, industries' R&D knowledge decreases in value in parallel with* *decreases in demand for particular technologies. On the other hand, universities and GRIs suffer from knowledge obsolescence through intra- and inter-sphere technology transfer*' (R06L, R07P, R24K, R33J).

With respect to knowledge accumulation, '*TTOs in universities and GRIs clearly contribute to knowledge accumulation through their patent applications and registrations*' (R06L, R07P, R08J, R16K, R19L, R20H, R21N, R26L, R28C, R33J) *[9]*. However, office participation does not seem to affect the degree to which industries can accumulate knowledge because '*Korea's chaebols-oriented structure makes it possible to invest enormous funds for producing new knowledge. Thus, the influence of TTOs on officialising industry R&D findings is insubstantial*' (R01P, R09J, R11K, R12K, R13P, R24K, R27H, R32Y, R33J).

4.5.2. Knowledge diffusion

Knowledge diffusion refers to inter-organisational flows of codified knowledge embedded in technologies and tacit knowledge embedded in researchers (Audretsch, 1998; Lissoni, 2001). In this section, we describe two mechanisms of knowledge diffusion: codified knowledge diffusion (Section 4.5.2.1.) and tacit knowledge diffusion (Section 4.5.2.2).

4.5.2.1. Codified knowledge diffusion

Figure 18 illustrates flows of codified knowledge from one organisation to another.

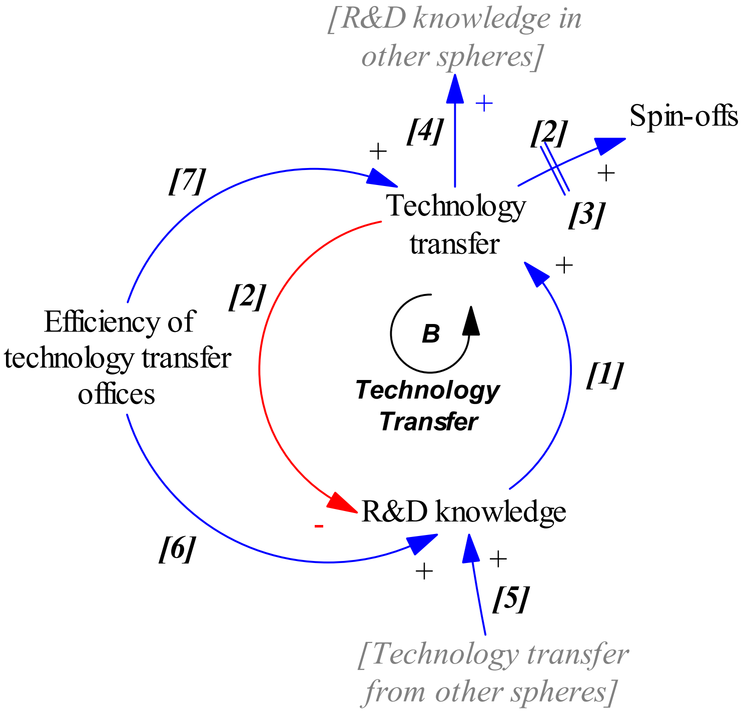


Figure 18. Codified knowledge diffusion. Variables in brackets exist in neighbouring spheres.

The generation of new knowledge yields a greater amount of knowledge resources available for use, thus increasing the amount of technologies transferred *[1]*. Within spheres, spin-offs receive knowledge as a result of the diffusion process. In the spinning-off process, ‘*technology ownership is transferred to spin-off firms*’ (R10P, R16K, R19L, R21N, R24K, R25L, R28C, R30Y, R31K, R33J). Consequently, there exists a balancing loop between technology transfers and the parent organisation’s knowledge resources (*B: Technology Transfer*) *[2]*. When a spin-off is formed, *intra*-sphere knowledge diffusion requires a significant amount of time to occur (Müller, 2010) *[3]*. Conversely, codified knowledge diffusion between spheres depletes technology providers' knowledge resources and increases other spheres' R&D knowledge (*B: Technology transfer*) *[4]*, *[5]*.[12] In the *inter*-sphere context, '*technology transfer occurs from universities and GRIs to industries*' (R25L, R33J). Consequently, the respective codified knowledge levels of universities and GRIs tend to decrease through *intra*- and *inter*-sphere technology transfers.

TTOs are in charge of patent applications and registrations that ensure the ownership of relevant technologies *[6]*. With these patents, agencies promote relationships between industrial and scientific entities (Debackere and Veugelers, 2005) to encourage knowledge capitalisation (Etzkowitz, 2008) *[7]*. The increased efficiency with which TTOs facilitate information flow is likely to reduce the respective codified knowledge levels of universities and GRIs. '*Some universities employ patent lawyers, indicating that the universities' TTOs consult on issues related to patent generation, sales, and licensing and play an active role in transferring technologies to industries*' (R20H, R26L, R28C, R33J). Similarly, '*following the existence of GRI TTOs, the frequency and value of technology transfers have steadily increased from GRIs to industries'* (R30Y, R33J). In contrast to universities and GRIs, '*knowledge transfer within industries is not stimulated by*

---

[12] Codified knowledge transfer occurs by selling or licensing patents or making royalty agreements (Feldman et al., 2002). Among the diverse transfer activities, the acquisition and loss of patent ownership can vary according to whether the licensing agreement is inclusive or exclusive. Whereas the former gives both the provider and the receiver the right to utilise the knowledge, the latter represents the complete transfer of ownership of the knowledge from the provider to the receiver. As such, the provider cannot use the transferred knowledge. In an extreme case, if there is only inclusive licensing, then there is no loss of the ownership to the provider.

the agencies, but instead by incurring significant operational costs of chaebol-oriented industrial structures' (R01P, R09J, R11K, R12K, R13P, R24K, R27H, R32Y, R33J). Additionally, as noted above, technologies are transferred from universities and GRIs to industries for knowledge commercialisation. Thus, industries' codified knowledge is not made obsolete by *intra*- or *inter*-sphere technology transfer.

Industry R&D findings are most closely related to market demand; university R&D findings are most distant. Findings produced by GRIs are at 'an arm's length' to market demand. As stated by some respondents, '*because GRI-based R&D is designed to promote nationwide industrial development, GRIs are more knowledgeable about commercialising their technologies in the market relative to universities'* (R06L, R07P, R08J, R30Y, R31K).

4.5.2.2. Tacit knowledge diffusion

Relative to codified knowledge, it is more difficult to copy tacit knowledge, as it is inherent to human resources. Figure 19 illustrates the flow of tacit knowledge.

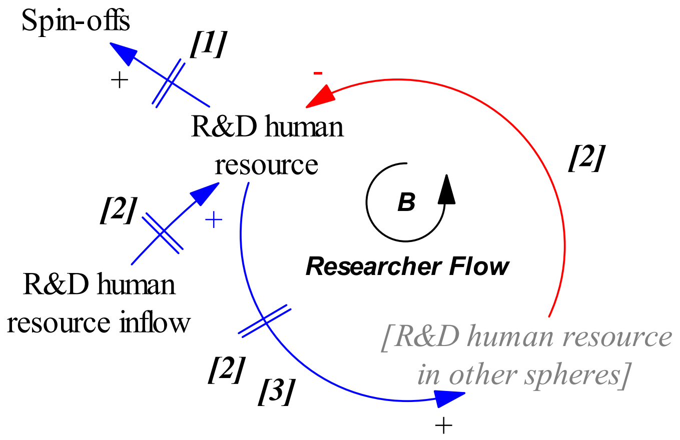


Figure 19. Tacit knowledge diffusion

As mentioned above, the development of a spin-off requires extant human resources at the *intra*-sphere boundary (Etzkowitz, 2008) *[1]*. In this respect, universities '*allow faculty to retain their academic positions while engaging in business-related activities*' (R28C). Similarly, the government guarantees that '*GRI researchers that fail to effectively manage a spin-off can return to their research positions without any disadvantage*' (R06L, R30Y, R31K).

Meanwhile, '*because researchers associated with spin-offs primarily belong to the industry sector, industry spin-offs have nothing to do with changes in the availability of R&D human resources in the industry sphere*' (R09J). Instead, changes in the availability of human resources are largely contingent on *inter*-sphere flow *[2]*. The process of tacit knowledge diffusion within the university sector is different from the diffusion process within industries and GRIs *[3]*. Specifically, '*whereas the provision of professional (but insufficiently experienced) researchers (i.e. graduates) from universities to other spheres takes years (to complete their educations), industries and GRIs are characterised by the fact that their human* *resources transfer to other spheres once they accumulate sufficient experience*' (R02K, R06L, R07P, R09J, R20H, R28C, R30Y).

In Korea, universities are generally regarded as the primary receiver of experienced researchers from industries and GRIs. Industries receive less experienced researchers from universities. GRIs receive a combination of less experienced researchers from universities and experienced researchers from the industry sphere. Generally, highly educated researchers gravitate toward academic positions in the university sphere, treating employment with a GRI as an alternative career path. With respect to this alternative career path, many interviewees claimed that '*because of the respect bestowed upon professors in Korea, moving from the university sphere to the industry or GRI spheres is rare. In contrast, it is common for researchers to transfer from the industry or GRI spheres to the university sphere*' (R02K, R06L, R07P, R09J, R20H, R28C, R30Y, R31K).

4.5.3. Knowledge deployment

To commercialise knowledge, industries take advantage of product and/or process innovations and launch new products and/or services in the marketplace to capitalise on advances in science and technology (Abernathy and Utterback, 1978). These mechanisms are illustrated in Figure 20.

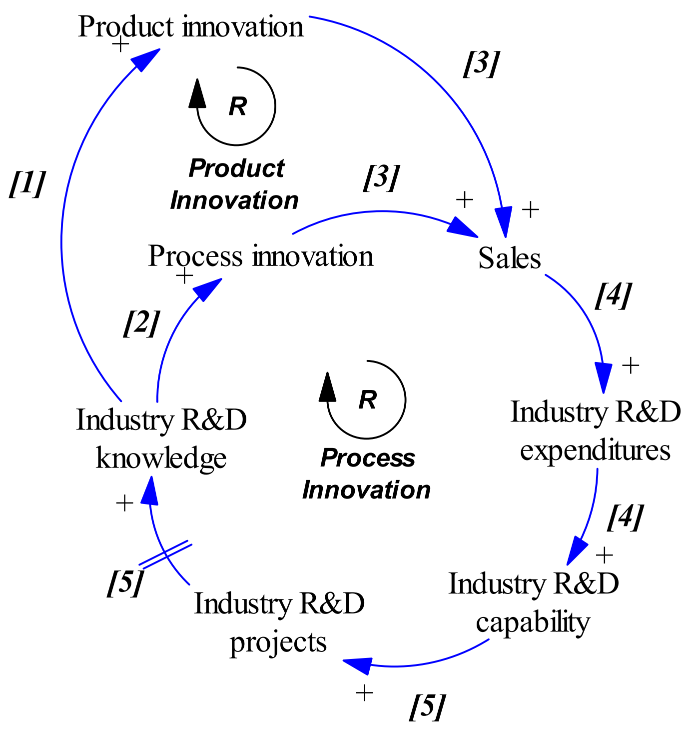


Figure 20. Product and process innovations

Product innovation is geared towards introducing new products or improving existing products. Typically, these innovations are derived from alternative perspectives related to the product’s technical characteristics (*R: Product Innovation*) *[1]*. Comparatively, process innovation refers to the introduction of new or improved production methods that are designed to produce goods more efficiently (*R: Process Innovation*) *[2]*.

Industries can increase sales through product and process innovations *[3]*, which subsequently generate increases in R&D reinvestment *[4]*. In turn, increases in R&D investment can promote the production and accumulation of knowledge *[5]*. According to the Abernathy-Utterback model (1978), product innovation precedes process innovation. However, ‘*the contemporary innovation cycle is sufficiently* *short that product and process innovations are similar in terms of the length of time they require. In particular, at the meso- or macro-level, the plural composition of different industry fields has blurred time-related distinctions with regard to the two innovation processes*' (R09J, R24K). Therefore, it is not necessary to consider the time delay between product and process innovation.

While product and process innovations are industry-specific, spin-offs can be formulated in any sphere. Figure 21 illustrates the development of a spin-off within a particular sphere.

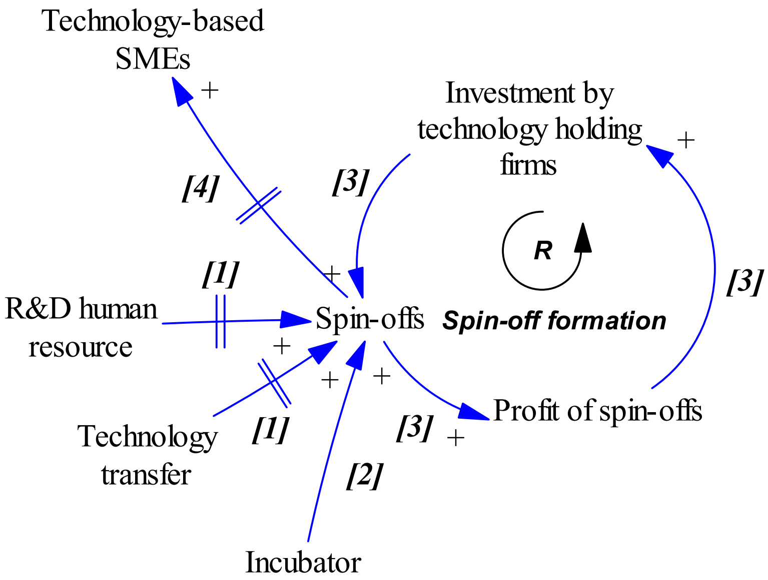


Figure 21. Spin-off formation

This process requires the involvement of former or current members of the parent organisation who have a strong desire to apply research findings to entrepreneurial activities (Etzkowitz, 2008; Shane, 2004). Thus, a greater degree of *intra*-sphere technology or human resource transfer facilitates the formation of a spin-off *[1]*.

Similarly, physical spaces and business services provided by incubators can promote a firm's spinning out (Etzkowitz, 2008) *[2]*. Despite the utility of incubators, there exists a perception that they '*do not incubate tenant firms, but instead focus on rental business operators*' (R09J, R17S, R18G, R22P, R23R, R28C, R32Y). Nevertheless, '*the size of the facilities increase the number of spin-offs, since incubators' low taxes and rental fees can attract new businesses*' (R09J, R28C). However, the size of incubators and the number of spin-offs they generate do not necessarily generate a virtuous circle. This is largely because '*the government has focused on the facilities' hardware (e.g. the number of incubators) rather than the self-operating system*' (R09J, R17S, R18G, R22P, R23R, R28C).

A venture capitalist (also known as a technology holding company; THC) provides financial aid to promote the formation of spin-off organisations (Etzkowitz, 2008). Venture capitalists seek to improve returns on their investments through a strict search and selection process. If selected spin-offs turn a profit, it is likely to attract more funding from other venture capitalists (*R: Spin-off Formation*) *[3]*.

Whereas spin-offs born from universities and GRIs ultimately end up in the industry sphere, '*industries' newly emerging businesses are mainly formed as venture firms created by individuals*' (R09J, R14K, R15H, R20H, R26L, R28C). One interviewee noted that '*after an average of 4.4 years, newly-emerging businesses are listed on the KOSDAQ (Korean Securities Dealers Automated Quotations)*' (R09J). This suggests that spin-offs and venture firms require time to transform into official technology-based SMEs *[4]*.

Table 12 summarises the attributes associated with the respective spheres in Korea’s triple helix. These distinct attributes characterise the different processes related to knowledge. These processes are explored in the following section.

Table 12. Summary of distinct attributes across universities, industries, and GRIs in Korea

Domain	Comparative aspect	Sphere		
		University	Industry	Government research institute (GRI)
Knowledge development	Source of R&D capability	• External funds from the public and the private sectors • Researchers in science and engineering school • Codified knowledge	• External funds from the public and the private sectors, and internal funds • Researchers in R&D department • Codified knowledge	• External funds from the public and the private sectors, and internal funds • Researchers in R&D department • Codified knowledge
	Formation of R&D cycle	• Knowledge-based virtuous circle	• Knowledge- and profit-based virtuous circle	• Knowledge- and reserves-based virtuous circle
	Obsolescence of R&D Knowledge	• Made obsolete by *intra*- and *inter*-sphere technology transfer	• Made obsolete by declining market demand	• Made obsolete by *intra*- and *inter*-sphere technology transfer
Knowledge diffusion	Direction of codified knowledge transfer	• *Intra*-sphere provider for university spin-offs • Ineffective *Inter*-sphere provider for industry	• *Inter*-sphere receiver from university and GRI • Ineffective *intra*-sphere provider for industry spin-offs	• *Intra*-sphere provider for GRI spin-offs • Relative to university, effective *Inter*-sphere provider for industry
	Change in codified knowledge stock	• Decreased by *intra*- and *inter*-sphere technology transfer	• Unchanged by *intra*- and *inter*-sphere technology transfer	• Decreased by *intra*- and *inter*-sphere technology transfer
	Direction of tacit knowledge transfer	• *Intra*-sphere provider for university spin-offs • *Inter*-sphere provider of less experienced researchers for industry and GRI • *Inter*-sphere receiver of experienced researchers from industry and GRI	• *Intra*-sphere provider and receiver for industry venture firms • *Inter*-sphere provider of experienced researchers for university and GRI • *Inter*-sphere receiver of less experienced researchers	• Ineffective *intra*-sphere provider for GRI spin-offs • *Inter*-sphere provider of experienced researchers for university • *Inter*-sphere receiver of less experienced researchers from university, and experienced researchers from industry
	Direction and frequency of tacit knowledge transfer	• Scarce move-out of experienced researchers to industry and GRI • Frequent move-in of experienced researchers from industry and GRI	• Frequent move-out of experienced researchers to university and GRI • Scare move-in of experienced researchers from university and GRI	• Frequent move-out of experienced researchers to university • Frequent move-in of experienced researchers from industry
Knowledge deployment	Market-friendliness of research findings	• Distant to market demand	• Attached in market demand	• Arm's length to market demand
	Inter-sphere activity for knowledge commercialisation	• Codified knowledge transfer to industry	• Product and/or process innovations in industry	• Codified knowledge transfer to industry
	Intra-sphere activity for knowledge commercialisation	• Provider of codified and tacit knowledge for university spin-offs	• Ineffective provider of codified and tacit knowledge for industry spin-offs	• Ineffective provider of codified and tacit knowledge for GRI spin-offs

4.5.4. The system structures for university, industry, and GRI spheres

Based on our descriptions of knowledge development, diffusion, and deployment, Figures 22−24 respectively show the *intra*-sphere mechanisms for universities, industries, and GRIs. The figures also illustrate system limitations associated with crucial linkages in terms of the *intra*- and *inter*-sphere knowledge processes.

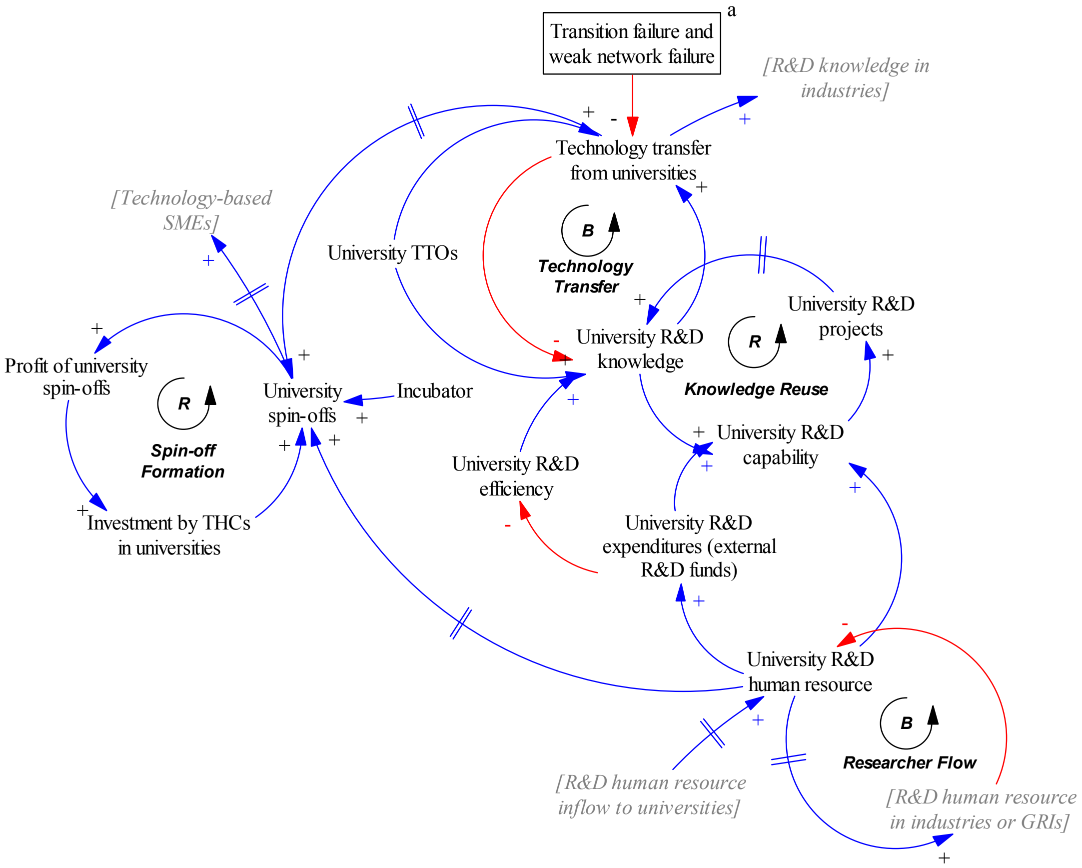


Figure 22. A system structure for the university sphere in Korea

As seen in Figure 22, if new faculty or postgraduate students enter the university sphere, the stock of R&D human resources increases, thus intensifying R&D capability. This increase in R&D capability allows for an increase in the number of R&D projects in which a university can engage. Greater numbers of human resources result in the flow of graduates from universities to industries and GRIs, thus decreasing the abundance of university R&D human resources (*B: Researcher Flow*). A greater number of human resources require greater R&D expenditures. This increase in R&D expenditures reduces R&D efficiency, thus delaying R&D knowledge accumulation. A greater number of R&D projects generate more R&D knowledge, leading to higher R&D capability (*R: Knowledge Reuse*). Moreover, greater knowledge yields increased technology transfer to industries. When this occurs, loss of patent ownership reduces the amount of R&D inherent to universities (*B: Technology Transfer*). Within the university sphere, increased technology transfer stimulates spin-off formation which, in turn, generates profits for spin-offs. This increased profit leads to more investment in the spin-offs by THCs (*R: Spin-off Formation*). In the *inter*-sphere context, there exists a positive relationship between the number of spin-offs that are generated and the technology-based SMEs in the industry sphere.

System Failure. University R&D findings are often difficult to transform into successful marketing campaigns for new products and/or services within the industry sphere. Interviewees noted that university-based research is often '*too basic to be commercialised in the short term because technologies developed in laboratories are unlikely to be pragmatically applicable. As a result, industrial firms tend to be reluctant to buy or rent technologies developed by universities*' (R20H, R25L, R28C, R30Y). Moreover, '*faculty members generally lack business-oriented mind-sets. As such, university-based research findings that are industry-focused are rare*' (R26L, R28C, R20H). Within the university sphere, researchers' lack of business-oriented mind-sets can negatively affect university spin-off formation. These conditions together illustrate the lack of a link between science and business inside and outside university settings (see Box 'a' displayed in Figure 22).

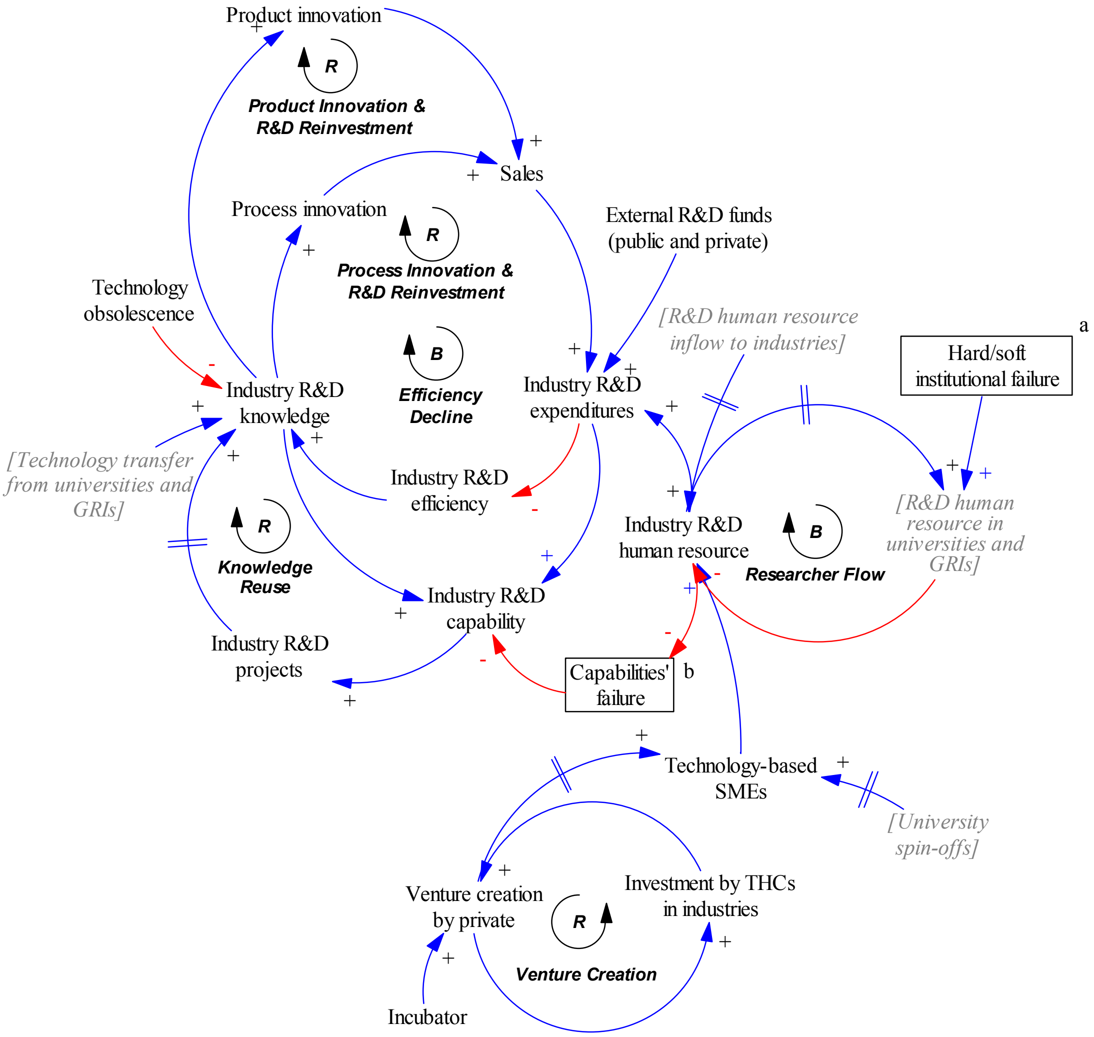


Figure 23. A system structure for the industry sphere in Korea

Figure 23 illustrates that within the industry sphere, a higher degree of private venture creation sponsored by THCs induces greater investment among THCs (*R: Venture Creation*). Greater contributions of university spin-offs to technology-based SMEs that increase the availability of human resources dedicated to R&D incite the eventual transfer of those human resources to universities and GRIs (*B: Researcher Flow*). The increased prevalence of human resources helps to improve R&D capability. This improved R&D capability stimulates the development of more R&D projects which, in turn, results in the accumulation of R&D knowledge. This serves as the basis for the R&D capabilities needed for subsequent projects (*R: Knowledge Reuse*). However, a greater number of human resources require an increase in R&D expenditures. This reduces R&D efficiency, slowing the process by which R&D knowledge is accumulated. High levels of R&D-related knowledge are associated with more product and process innovations. These innovations increase sales, requiring higher levels of R&D expenditure (*R: Product Innovation & R&D Reinvestment*) (*R: Process Innovation & R&D Reinvestment*). In conjunction with knowledge and human resources, R&D expenditures promote R&D-related capabilities that contribute to the further development of R&D projects. However, higher R&D expenditures are likely to hamper R&D efficiency to some degree (*B: Efficiency Decline*).

System Failure. While both the industry and GRI spheres suffer from leakages of experienced researchers to universities (see Box 'b' in Figure 23), industries may be at greater risk for these leakages. Traditionally, the Korean education system is characterised by '*prestige bestowed upon university-based research positions and job security associated with professorship (with GRI* *positions serving as backups)*’ (see Box ‘a’ in Figure 23) (R06L, R07P, R09J, R02K, R30Y, R31K, R28C, R20H). Although industries and GRIs continuously strive to replace lost R&D human resources by hiring university graduates, these relatively inexperienced newcomers may not be sufficiently trained when they begin their employment.

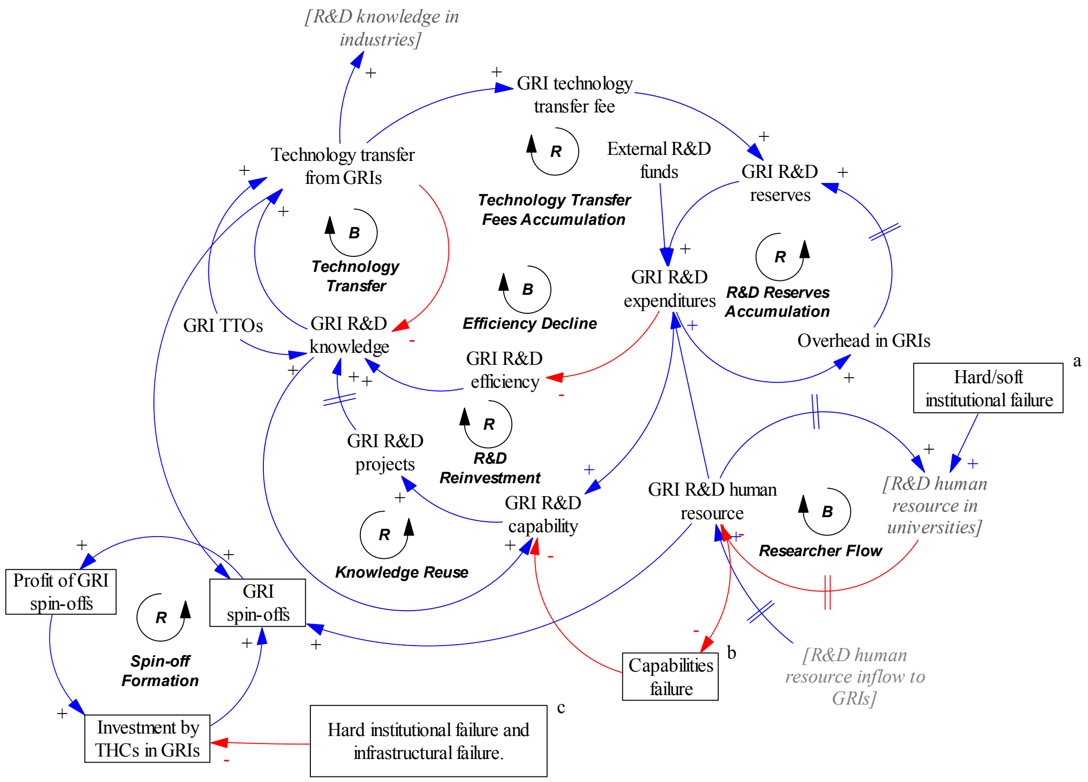


Figure 24. A system structure for the GRI sphere in Korea. The dotted arrows generally do not exist in the Korean case. However, to promote a better understanding of system failures of the GRI sphere, we included the dotted arrows and the reinforcing loops of spin-off formation in this figure.

According to Figure 24, new researchers in the GRI sphere increase the number of R&D human resources in that sphere, thus improving R&D capabilities and increasing the number of R&D projects. In the same fashion as universities and industries, when a greater number of R&D human resources transfer to other spheres, there is a general decrease in the number of GRI R&D human resources available (*B: Researcher Flow*). Similarly, a greater number of R&D projects generate more R&D knowledge, leading to higher R&D capability (*R: Knowledge Reuse*). However, the generation of more R&D knowledge also incites a greater degree to which technology is transferred to industries. This leads to a reduction in R&D knowledge in the GRI sphere due to the loss of patent ownership (*B: Technology Transfer*). Increases in technology transfers to industries require technology transfer fees that facilitate the accumulation of R&D reserves, which are also collected from R&D overheads as part of R&D expenditures (*R: R&D Reserves Accumulation*). By generating more reserves, GRIs can relieve some of the pressure caused by R&D expenditures, thus improving GRIs' capabilities to engage in more R&D projects. These projects serve as sources of technology transfer fees, thus completing the cycle (*R: Technology Transfer Fees Accumulation*). However, large numbers of R&D human resources increase R&D expenditures. This increase in expenditures reduces R&D efficiency and delays R&D knowledge accumulation which, in turn, reduces the extent to which technology can be transferred. As a result of this decrease in technology transfers, technology transfer fees decrease, resulting in reductions of R&D reserves. From this, R&D expenditures decrease, thus increasing R&D efficiency over time (*B: Efficiency Decline*).

System Failure. Similar to the industry sphere, the primary system failure within the GRI sphere is associated with the loss of experienced researchers to universities (see Box 'b' in Figure 24). As noted by interviewees, '*highly educated researchers prefer to have academic positions in universities because of the social value of professorship in Korea* (see Box 'a' in Figure 24)*, and the 5-year longer* *age-limit of retirement relative to GRIs under the current law* (see Box 'a' in Figure 24)' (R06L, R07P, R09J, R02K, R30Y, R31K, R28C, R20H). Another problem faced by GRIs is the lack of regulations and THCs required to effectively produce spin-off firms (see Box 'c' in Figure 24). Some respondents noted, '*Korea*'s *central government treats the number of GRI spin-offs as a performance indicator for national R&D programmes*' (R03L, R04B, R05L). However, in terms of institutional and infrastructural perspectives, the '*Electronics and Telecommunications Research Institute (ETRI) is the only organisation that possesses a THC that assists in the formation of spin-offs in the public sector*' within Korea (R29J). Therefore, it is impossible to claim that Korea's GRIs specialise in entrepreneurial activities or that GRIs formulate a virtuous circle for spin-offs in their sphere (see dotted arrows composing 'R: Spin-off Formation' displayed in Figure 24).

Table 13 summarises system failures that were identified in interviews. The list demonstrates that Korea's triple helix mechanism faces difficulties in infrastructure, transition, institution, network, and capability in particular knowledge domains.

Table 13. System failures in Korea’s triple helix

Failure type	System failure	Knowledge domain
Infrastructural failure	Non-existence of technology holding companies in GRIs (except for ETRI) [a]	Knowledge deployment
Transition failure	Inactive technology transfer from universities to industries	Knowledge diffusion
Hard institutional failure	Professorship-friendly retirement scheme, job security, work environment, compensation, incentives Non-existence of regulations for the formation of spin-offs in GRIs (except for ETRI)	Knowledge development Knowledge deployment
Soft institutional failure	Respect bestowed upon professors	Knowledge development
Weak network failure	Loss of relationships between universities and industries in terms of technology transfer	Knowledge diffusion
Capabilities’ failure	Frequent exodus of experienced researchers from industries and GRIs to universities	Knowledge development

[a] Electronics and Telecommunications Research Institute

4.6. Discussion

Innovation systems represent complex contexts in which multiple types of actors interact. Thus, it is necessary to explore the effects of system failures and policy recommendations from a holistic and systemic perspective. In this section, we discuss the effects of system failures and offer policy recommendations to address them. Following the primary discussion, we provide policy implications for the triple helix.

4.6.1. System failure effects

From a systems perspective, the effects of system failures are not confined to a specific knowledge domain, but influence a series of multiple knowledge-based processes within and across spheres. The inadequacy of experienced researchers in the industry and GRI spheres is likely to hamper the development and accumulation of pertinent knowledge. Therefore, the slowdown in knowledge stock discourages technology transfer from GRIs to industries. In the industry sphere, firms tend to have insufficient knowledge resources for product and process innovations. As a result, unsuccessful commercialisation in the market reduces R&D reinvestment in the industry sphere. In conjunction with a weak link between science and business in the GRI sphere, this inadequacy can impede technology transfer to spin-offs in the public sector.

Within the university sphere, the lack of technology transfer to industries may further weaken knowledge commercialisation in the industry sphere. As a result of research findings generated by universities that are not industry-friendly, industries may be discouraged to serve as financial sources for university R&D. As a result, this reduces knowledge stock in universities that can be used for the formulation of university spin-offs.

4.6.2. Policy recommendations suggested by interviewees and the effects

According to the system failures we have identified, we offer several policy recommendations suggested by interviewees. Although our suggestions are not the only measures to remedy the designated failures, these make sense in the way that the respective system failures require specific corresponding initiatives to solve them.

4.6.2.1. Conducting Relay-R&D and Ping-Pong-R&D between universities, industries, and GRIs

These suggestions are related to weak network failure and transition failure between universities and industries indicated in Figure 22. *Relay*-R&D aims to facilitate the production of industry-friendly R&D outcomes to remedy the weak network and transition failures between the university and industry spheres. Therefore, this initiative primarily seeks to render R&D findings applicable to the general marketplace and to improve *inter*-sphere technology transfer to industries. Universities produce basic research findings that are transferred to GRIs '*which are more capable of applying those findings in the marketplace*' (R30Y). The GRIs then perform further R&D activities to facilitate the application of the universities' findings in industrial settings. Ultimately, industries receive the GRI R&D findings and conduct developmental research geared towards inciting demand within the market. *Ping-Pong-R&D* is expected to establish mutual flows of knowledge between universities and industries for the sake of relieving weak network failure and transition failure between universities and industries. Because industries tend not to acquire technologies from universities because of the limited degree to which they can be commercialised, industries first transfer existing knowledge that they wish to commercialise to universities. Once universities recognise the specific needs of industries, they are likely to address the scientific and technological requirements of those industries. These initiatives increase technology transfer to industries and increase knowledge stock in the industry sphere, thus promoting product and process innovations. Given the increased profits gained in the market, the industry may intensify R&D collaborations with, or outsourcing to, universities and GRIs. This is likely to increase the budgets for the university and GRI R&D, giving universities and GRIs more opportunities to engage in R&D activities.

However, these alternatives do not guarantee the simultaneous utilisation of knowledge in the *intra*- and *inter*-sphere contexts. For example, if universities engage in excessive *inter*-sphere technology transfer, then the sphere will afford fewer opportunities to transfer knowledge to form spin-offs. To redress this issue, universities must increase investment in R&D to produce sufficient knowledge to allow the university sphere to be entrepreneurial. This recommendation would only work under the assumption that the R&D actor has an industry-like, self-operating virtuous circle relating economic achievements and R&D reinvestment. However, universities are institutionalised non-profit organisations that do not have internal funding sources to directly invest in R&D.

4.6.2.2. Promoting job satisfaction in industries and GRIs

This is suggested to aim to relive hard/soft institutional failure and capabilities' failure faced in industries and GRIs, as described in Figures 23 and 24. The improvement of job satisfaction is expected to mitigate the effects of hard/soft institutional failure on R&D-related activities in the industry and GRI spheres and improve R&D capabilities. This initiative includes several components, including a retirement scheme, job security, positive work environment, compensation, and other incentives for acquiring and retaining experienced researchers. By doing this, industries and GRIs can increase the stock of R&D human resources available within those spheres that are more capable of producing and accumulating knowledge. The increased knowledge stock provides more opportunities to transfer GRI-based knowledge to the industry sphere, and positively affects knowledge stock for product and process innovations in the industry sphere. Increased technology transfer to GRIs also leads to an increase in technology transfer fees that are accumulated as R&D reserves for subsequent GRI research. Given this, GRIs are likely to increase R&D reinvestment.

However, this suggestion can deplete financial resources for R&D. In particular, GRI R&D is funded not only by external funds from the public and private sectors, but also by limited internal funds like accumulated R&D reserves. In this case, increases in salaries paid to experienced researchers increases total R&D costs. This reduces the inflow of R&D reserves available for in-house R&D in the long-term. Therefore, GRIs face significant financial constraints which offset the positive effects of experienced researchers on the efficiency of R&D projects.

Specifically, because industries are comprised of profit-making organisations, financial stressors negatively impact R&D reinvestment in that domain.

4.6.2.3. Establishing university-GRI joint THCs

We suggest that GRIs promote joint THCs with universities to redress hard institutional and infrastructural failures that preclude spin-off formation in the public sector, as shown in Figure 24. Whereas GRIs lack formal regulations and physical settings that facilitate *intra*-sphere knowledge deployment for commercialising research findings, '*every Korean university has THCs*' (R28C, R20H), and thus '*universities have more experience in spinning out than GRIs*' (R06L, R30Y). Intuitively, this collaborative effort reinforces GRIs' capacities to create a self-operating mechanism for spinning out in the public sector. Moreover, it may help embed knowledge related to research-based business in GRIs, allowing industry-friendly R&D to promote *inter*-sphere technology transfer to industries in the long run. *Inter*-sphere technology transfer increases internal funds that have been accumulated on the basis of technology transfer fees. In addition, industry-friendly research findings may encourage industries to engage in concerted R&D efforts with GRIs, thus increasing R&D reserves in the GRI sphere.

However, GRIs' excessive reliance on university THCs can restrict their spin-off efforts to university settings. Therefore, joint THCs would likely weaken GRIs' capacities to create a self-operating mechanism for spin-offs in the public sector in the long run. Alternatively, it may be useful to establish GRI THCs separately from universities. However, this would not be effective in the short term, given the lack of experience in forming spin-offs and limited government support.

Table 14 summarises the intuitive and counter-intuitive effects of policy recommendations considered above.

Table 14. Summary of effects of policy recommendations

System failure	Recommendation	Expected effect			Non-desired effect		
		Knowledge development	Knowledge diffusion	Knowledge deployment	Knowledge development	Knowledge diffusion	Knowledge deployment
Weak network failure and transition failure between university and industry	*Relay*- and *Ping-Pong*-R&D	• Higher knowledge stock in industry • Increase in budget for university and GRI R&D	• More *inter*-sphere technology transfer from university to industry	• More product and process innovations in industry		• Fewer *intra*-sphere technology transfer for spin-off formation in university	• Fewer spin-off formation in university
Capabilities' failure and hard/soft institutional failure in industry and GRI	Higher job satisfaction	• Higher stock of R&D human resources in industry and GRI • Higher knowledge stock in industry and GRI • Higher stock of technology transfer fees in GRI • Higher stock of R&D reserves in GRI	• More *inter*-sphere technology transfer from GRI to industry	• More product and process innovations in industry	• Higher total R&D costs in industry and GRI • Reduced inflow of R&D reserves available for in-house R&D in GRI • Lower efficiency of R&D projects in industry and GRI • Reduced R&D reinvestment in industry		
Hard institutional failure and infrastructural failure in GRI	University-GRI joint THC	• More industry-friendly R&D findings in GRI • Higher stock of technology transfer fees in GRI • More contracted R&D efforts between industry and GRI • Higher stock of R&D reserves in GRI	• More know-how of spin-off formation in GRI • More *inter*-sphere technology transfer from GRI to industry	• More spin-off formation in GRI			• GRIs' excessive reliance on university THCs • Reduced GRI capacity for spin-off formation

4.6.3. Policy implications

Given the policy recommendations outlined above, it seems that universities, industries, and GRIs leverage their competencies to effectively operate the knowledge-based triple helix. Counter-intuitively, however, a solution to one system failure can generate a system failure in other domains or only serve as a limited resolution to the problem which it is intended to fix. Therefore, it seems impossible to promote innovation in the triple helix by correcting its inherent system failures. Therefore, if the policy recommendations are expected to have immediate positive effects, are the recommendations valid or unnecessary?

To answer these questions, it is necessary to recognise that it is not realistic to find any solutions that will simultaneously address all system failures. Instead, it is more useful for policymakers to understand the contradictory relationships between intuitive and counter-intuitive solution effects from a systems perspective.

Practically, they should understand that no single policy can deliver positive effects across an entire system. Instead, as argued by Lee and von Tunzelmann (2005), multiple policies are required to solve the multitude of problems that pervade complex systems. As such, recommendations that address various system failures should incorporate a simultaneous consideration of the intuitive and counter-intuitive effects that the recommendations generate. In sum, policymakers must identify the unexpected effects of their intended policies by adopting a systems perspective that considers the interrelated effects of system failures and policy recommendations. In doing so, they would be able to develop more realistic triple helix innovation policies, which help lower risk and realise the system's optimum potential.

4.6.4. The limitations of this study

We used multiple high-level models to analyse causal influences of system failures and policy recommendations on the Korean triple helix. Despite this study's utility, it suffers some limitations. In this paper, we developed a triple helix for only Korea. Our reference models have limited applicability to more unique examples where the triple helix system has yet to be realised (e.g. African countries). Additionally, we used qualitative data gleaned from interviews for our analyses. This qualitative analysis cannot completely avoid subjective interpretations of what interviewees deliver, and thus it requires more scientific analysis to provide quantitative validation for decision-makers.

4.7. Conclusion

In this paper, we provided novel insight that expands our understanding of the Korean triple helix by incorporating *intra*-sphere dynamics among triple helix actors. Moreover, we introduced a methodological approach that illustrates the causal linkages within and between spheres. We revealed several potential system failures and policy recommendations to address them:

- The performance of *Relay*-R&D and *Ping-Pong*-R&D between universities, industries, and GRIs was suggested to solve failures of weak networks and transitions between universities and industries.

- The promotion of job satisfaction among workers in industries and GRIs was suggested to solve failures of capability and hard/soft institution in industries and GRIs.
- The establishment of university-GRI joint THCs was suggested to solve failures of hard institution and infrastructure in GRIs.

Ultimately, the adoption of a system-based perspective allowed us to draw the following conclusions:

- System failures and their associated recommendations affect the triple helix's collective knowledge development, diffusion, and deployment processes in both the *intra*- and *inter*-sphere contexts.
- Intuitively, some policy recommendations may successfully solve recognised system failures.
- Counter-intuitively, however, there is a limit on the degree to which any one policy recommendation can mitigate the effects of system failures; a recommendation to resolve a particular failure can lead to another failure in the other domains.

Finally, this study offers promising avenues for future research. It would be interesting to categorise multi-type frameworks geared towards more flexible applications to specific innovation systems. Such research would provide insight into how certain system failures emerge in specific contexts. Additionally, it would be useful to leverage quantitative panel data to accommodate the dynamic nature of the triple helix to provide policymakers with more reliable evidence. Further, quantitative data would allow for the use of algorithmic simulations to analyse triple helix dynamics, as argued by Etzkowitz and Leydesdorff (2000).

CHAPTER 5. PAPER 3 – A DYNAMIC ANALYSIS OF REGIONAL COMPETITIVENESS IN INNOVATION PROCESSES: THE CASE OF BUSAN, SOUTH KOREA

5.1. Abstract

In recent decades, regional units have been emphasised to design innovation policies. However, the effect of such policies on regional competitiveness is an on-going concern. This study incorporates a knowledge-based innovation process into the regional competitiveness mode of capacity–capability–performance. Based on this framework, a system dynamics model is employed to identify policy interventions that positively affect the sustainable development of regional competitiveness in Busan, a region in South Korea. The analysis results indicate the importance of human resources rather than R&D expenditure. Further, shortening the lead time for knowledge commercialisation is more effective than for knowledge development, whereas a success rate adjustment is more effective when it is applied to knowledge development rather than knowledge commercialisation. These interventions strengthen the governance of reinforcing feedback loops throughout the regional innovation process of Busan and, as a result, promote the sustainable development of the city's operational competitiveness.

Keywords: knowledge-based innovation system, regional competitiveness, innovation policy, system dynamics, Korea

5.2. Introduction

Regional innovation has become increasingly important in recent decades (Doloreux and Parto, 2005). To improve regional competitiveness, efforts have been made to develop and implement regional innovation policies (Asheim and Coenen, 2005*a*, 2006*b*). Policymakers strive to bring about technical changes and innovation that can improve the operation of innovation systems (Edquist, 2001*a*, 2001*b*; Edquist and Hommen, 1999; European Commission [EC], 2013; Lundvall and Borrás, 2005). However, the efficacy of innovation policy implementation is an on-going concern. Policy decisions generate uncertainty and, sometimes, counterintuitive effects (Lee and von Tunzelmann, 2005; Marcus, 1981; Sterman, 2000) that spread across multiple parts of a system over time (Jervis, 1997). Because of these uncertainties, '*there is good reason to think that policy can make a very big difference to regional development and yet at the same time it is very hard to know exactly what the right policy is*' (Krugman, 2003, p. 43).

The scepticism concerning the relationship between policy implementation and regional competitiveness is attributable to the lack of understanding of the policy effect mechanism. This incognisance occurs because of difficulties associated with mapping complex innovation processes (Castellacci and Natera, 2013; Hekkert et al., 2007). The main policy evaluation themes in the literature include monetary instruments such as direct and indirect R&D funding (Guellec and van Pottelsberghe de la Potterie, 2003; Lach, 2002), tax incentives (Guellec and van Pottelsberghe de la Potterie, 2003; Koga, 2003) and foreign direct investment (Branstetter, 2006). Although some research notes the need to observe systemic multi-stage innovation from R&D to commercialisation, existing studies are inadequate in providing policy evaluation activities with a systems perspective of cause−effect relationships within regional innovation processes (OECD, 2000; Polt and Rojo, 2002).

This study analyses policy effects on regional competitiveness from a system dynamics perspective (Sterman, 2000) and uses Busan, a Korean region, as an example. Although Busan is designated as a leading Korean city in terms of its economy along with Seoul, a peer review report for Busan (Duke et al., 2006) notes that Busan suffers from 'rust-belt' decline and, thus, has declared a new slogan, 'Dynamic Busan', to remedy the image of a decaying local economy and to motivate Korea's decentralisation and rebalancing policies. The report made a diagnosis that Busan has not clearly defined what the city needs or how goals will be achieved. From a policy perspective, by identifying effective policy interventions, this study aims to specify what Busan should adjust to achieve the goal of robust development of regional competitiveness in the context of a knowledge-based innovation. As a result, this study is expected to provide policy implications for the sustainable growth of Korean regions.

To address this aim, this study has two specific objectives. The first is to synthesise the core structures that determine the operation of Busan's knowledge-based innovation and to apply these to a regional competitiveness perspective. The model can then be used to identify structural sources that influence systemic governance over regional competitiveness. The second objective is to conduct simulations that evaluate corresponding regional policy effects on regional competitiveness. For policymakers, this simulation-based methodology encompasses multiple stages of the innovation process, and the analysis provides empirical evidence for facilitating rational policymaking.

Section 5.3. of this study reviews existing literature to define a conceptual framework for the regional innovation process. Section 5.4. introduces system dynamics to analyse the regional innovation process of Busan. Section 5.5. discusses the implementation of system dynamics analyses: problem articulation, model formulation, testing and policy formulation and evaluation. Section 5.6. discusses policy implications for the sustainable operation of a regional innovation system. Section 5.7. concludes the paper with major contributions and directions for future research based on the limitations of this study.

5.3. Regional competitiveness in an evolutionary knowledge-based innovation process

Knowledge and innovation are inextricably bound (e.g. Asheim and Coenen, 2005a, 2005b; Binz et al., 2014; Frenz and Ietto-Gillies, 2009; Muller and Zenker, 2001). In a knowledge economy model, organisational interactions form feedback loops to aid the flows of innovation-related information and materials among the development, diffusion and deployment of knowledge (Carlsson et al., 2002; Rickne, 2001). In particular, knowledge deployment is specified as (a) knowledge implementation for innovation activities and (b) knowledge commercialisation for transforming products or services into market value (Dvir and Pasher, 2004; Maier, 1998; Smith and Barfield, 1996). Thus, through a specific lens, the knowledge-based innovation process can be conceptualised within four boundaries: (1) knowledge development, (2) knowledge diffusion, (3) knowledge implementation and (4) knowledge commercialisation.

Regional competitiveness is decomposed into capacities, capabilities and performances that are embedded in the knowledge-based innovation process. *Capacities* reflect available system proprietary resources to determine initial ability for innovation. R&D expenditure and R&D personnel are essential physical resources that trigger the operation of knowledge-based innovation processes (Wang and Huang, 2007). *Capabilities* are a system's ability to expedite resource utilisation for performance generation (Almond and Powell, 1967; Amit and Schoemaker, 1993; Bergek et al., 2008; Hekkert et al., 2007, 2011; Johnson, 1998). On the one hand, because an innovation system represents aggregate knowledge production processes (Asheim and Isaksen, 1997), R&D activities represent the system's ability to build a knowledge base. On the other hand, product and process innovations are prerequisites for the commercialisation of knowledge (Adner and Levinthal, 2001; Chen and Guan, 2012; Porter, 1980; Smolny, 1998; Zhang and Li, 2010). *Performances* are considered within the context of knowledge development and commercialisation. Patents are widely used proxies that account for technological knowledge produced through R&D in knowledge development (Acs et al., 2002; Chen and Guan, 2012; Fritsch, 2002; Griliches, 1990; Henderson and Cockburn, 1996; Nelson, 2009; Rosell and Agrawal, 2009; Weck and Blomqvist, 2008). Consistent with Schumpeter's (1934) 'Economic Development', the market value of new or improved products and/or services is a significant indicator. Sales and profits represent the financial performance of industry's technological innovations (Foster et al., 2008; Yam et al., 2011). Sales reflect the market expandability of products and services, whereas profits reflect the residual funds available for R&D investment and business stability.

Competitive capacities, capabilities and performances may enable high fluidity of knowledge flows that contribute to smooth operations of the knowledge-based innovation system (OECD, 1997). Figure 25 illustrates the following knowledge-based innovation process: (a) financial and human resources enable (b) R&D activities to create (c) new knowledge in university labs, industrial firms and public research institutes (Cruz-Cázares et al., 2013). This knowledge is transferred to the industry sector (Caldera and Debande, 2010). In addition to the knowledge produced by industrial R&D, the transferred knowledge is used to conduct (b') product and process innovations in the industry sector (Abernathy and Utterback, 1978). The industrial innovations launch new or improved products/services leading to (c') financial benefit (e.g. sales and profits) in the marketplace. The earnings build (a) financial capacity, which then enables R&D organisations to employ (a) researchers to implement (b) additional R&D projects.

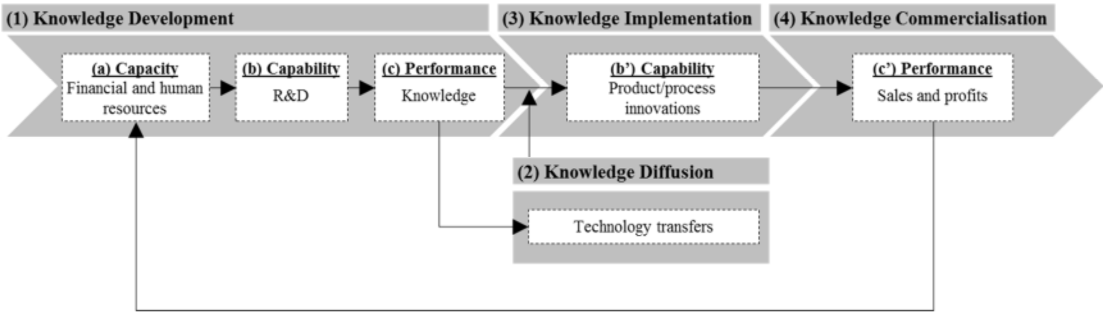


Figure 25. A knowledge-based innovation process

The feedback structures and changes in the flows of knowledge stocks form time-based innovation mechanisms, which stimulate the dynamics of the innovation system (Autio, 1998; Diez, 2001; Nelson and Winter, 1982). Regional competitiveness reflects the systemic nature of the evolutionary innovation process (Meyer-Stamer, 2008). As a result, the dynamics of knowledge flows embedded in the feedback structures create dynamic regional competitiveness over time, as illustrated in Figure 26.

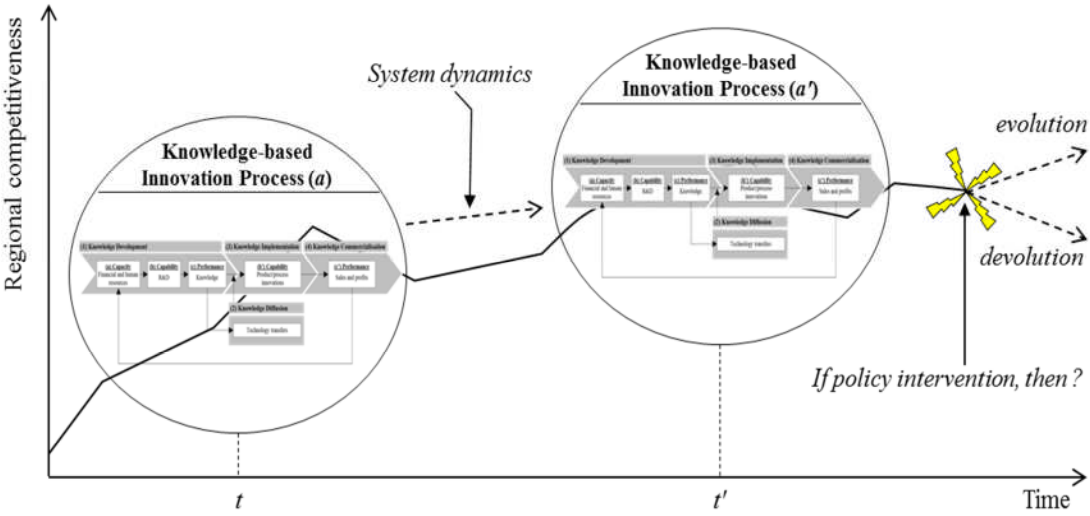


Figure 26. Dynamics of regional competitiveness in the knowledge-based innovation process

Meanwhile, policy influences regional competitiveness (Asheim and Coenen, 2005a, 2005b) and creates dynamic ─ short-term, long-term, or both ─ effects (OECD, 2009) that spread across multiple parts of the system over time (Jervis, 1997). Compared with no intervention, the dynamic feature of policy effects allows the consideration of four evolutionary directions of regional competitiveness (see

Figure 27). Policy A (top-right quadrant) improves regional competitiveness in both the short and long term. Policy B (top-left quadrant) is not ideal from a long-term perspective; however, it can be defined as appropriate within the given timeframe from t to t' because it promotes improvement despite a slow development phase. Policies C and D are seen as ineffective interventions. On the one hand, policy C (bottom-right quadrant) is not appropriate within the timeframe because it results in decreased improvement although it has long-term potential beyond the timeframe, which is attributed to an increase in time-based growth. On the other hand, policy D (bottom-left quadrant) is the least appropriate intervention because it leads to a decrease in both average change and time-based growth.[13]

---

[13] In this study, *average change* is estimated by calculating the average differences between incremental simulation results (e.g. between 1% adjustment and 2% adjustment, between 2% adjustment and 3% adjustment, etc.) in terms of regional competitiveness indices across years (i.e. from 2003 to 2011 in this study). In addition, *time-based growth* is estimated by calculating the change of differences between polar years (i.e. between 2003 and 2011 in this study) in incremental simulation results in terms of regional competitiveness indices.

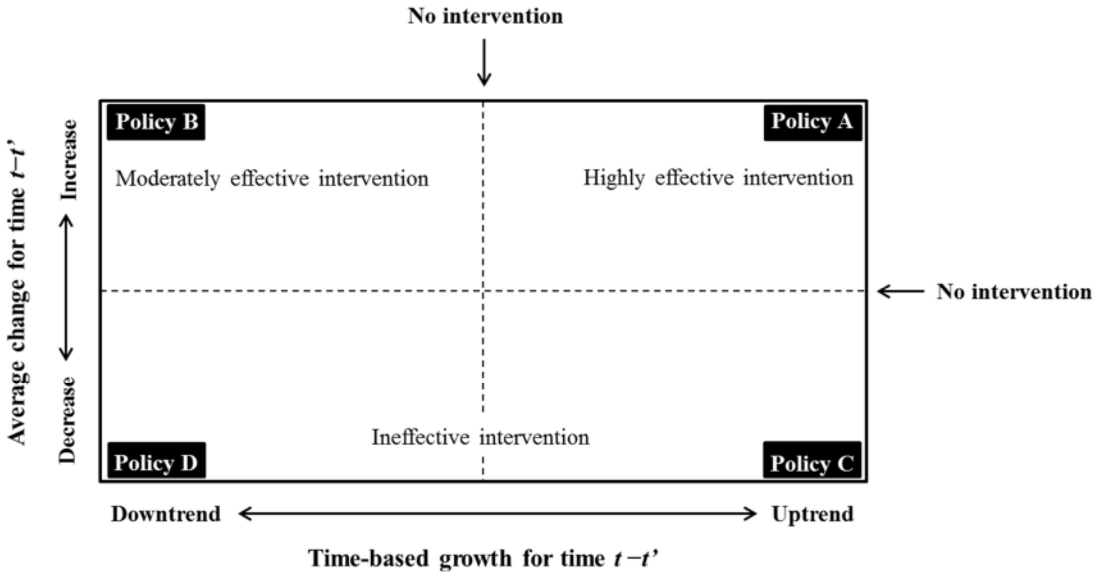


Figure 27. Types of policies

Considering the effect of the described policy interventions, this study provides explanations for the way in which innovation policy determines the dynamics of Busan's regional competitiveness using a system dynamics method.

5.4. Modelling and analysis methodology: System dynamics

The policy evaluation approaches employed in the literature are limited and mainly adopt descriptive statistics using Likert-scaled surveys and/or subjective opinions from interviews or expert review (OECD, 2006), regression modelling (Moser, 2005) or economic modelling (Branstetter, 2006). Simple statistical data and subjective descriptions respond to individual perceptions (or wishes for the future) of policy benefits at a particular point in time. The precision and interpretation of analysis results vary depending on sampling error (Särndal et al., 1992) and the characteristics of focus group interviewees (Weiss, 1994). A regression analysis requires a theoretical relationship between independent variables and dependent variables (Hair et al., 2010). Therefore, the analysis results depend on the conceptualised relationship between policies and effects. Additionally, the regression model requires a substantial sample size to produce statistically reliable results. Consistent with regression analysis, economic modelling also assumes a fixed relationship between inputs and outputs (c.f. Branstetter, 2006). The economic model for complex system structures includes risk for biased interpretations with respect to input–output correlations, rather than a cause–effect relationship between system components.

In contrast, system dynamics is a scientific approach that provides objective data for evidence-based policymaking (Sterman, 2000). The purpose of using system dynamics is to explain time-based behaviours of variables that constitute an entire system (Meadows, 1980). System dynamics modelling may or may not require theoretical connections between independent and dependent variables. In some circumstances, theory informs the rich set of cause−effect structures, or feedback processes, previously identified by scholars (Sastry, 1997). In other circumstances, policymakers inform the perceived cause−effect structures, mental models, determining the behaviour of regional innovation systems (Sterman, 2000). Therefore, system dynamics modelling can test existing theories over time or evaluate policymakers' intuition.

Compared with a qualitative systems approach (Galanakis, 2006), quantification by system dynamics is useful for identifying the quantitative impact of solutions by observing particular system behaviours (Forrester, 1994; Jackson, 2003; Mandinach and Cline, 1994; Richardson, 2011). While agent-based modelling observes the emergent dynamic behaviours of autonomous individual entities within the system (Grimm and Railsback, 2005; Lopolito et al., 2013), system dynamics models represent the aggregate behaviours that result from interactions among the multiple innovation system components (Sterman, 2000) providing a clear audit trail of the impact of policies.

By identifying the endogenous cause−effect structures that constitute Busan's knowledge-based innovation process, this study employs system dynamics to evaluate the aggregate behaviours of regional competitiveness and policy effects within a defined timeframe. The modelling process consists of five steps (Sterman, 2000): problem articulation (Section 5.5.1.), model formulation (Section 5.5.2), testing (Section 5.5.3) and policy formulation and evaluation (Section 5.5.4).

5.5. Modelling the knowledge-based innovation system of Busan

Busan has 10 strategic industries: port logistics; mechanical parts and materials; tourism and conventions; film and information technology; finance and futures; bio-marine; silver mining; footwear manufacturing; processed marine products; and textiles and fashion (Duke et al., 2006). According to Statistics Korea, Busan's Gross Regional Domestic Product (GRDP) was 63,737 billion Korean Won (KRW) in 2010, which is just below the average GRDP (79,072 billion KRW) across

Korean regions. Busan's R&D expenditure relative to GRDP (1.32%) in 2010 was recorded as the 10th among 16 regions. The number of economically active people in Busan was 1,633,000 in 2010—after Gyeonggi (5,913,000) and Seoul (5,180,000). In terms of the number of R&D performing units, Busan was ranked 6th, after Gyeonggi (5,486); Seoul (4,504); Incheon (981); Gyeongsangnam (975); and Chungcheongnam (777). Along with Gyeongsangnam and Ulsan, Busan encompasses Korea's southeast economic zone. Busan is the second largest city in Korea, after Seoul. It is also the largest international port city in Northeast Asia and the fifth largest in the world (Duke et al., 2006). As one of the leading locations in Korea's southeast economic zone and in the country, Busan can provide important insight into the sustainability of territorial innovation on both a regional and national scale.

5.5.1. Problem articulation

In the system dynamics analysis, system problems are identified by observing reference modes within a time horizon. To this end, 33 in-depth, multi-round interviews were conducted between January and March of 2013.[14] The participant responses explained the structure of Busan's knowledge innovation process and confirmed the regional competitiveness indices that are displayed in Figure 28.

---

[14] The interviewees were involved in regional innovation system initiatives and included science and technology planning office managers and R&D project leaders/managers in the government sector, heads and managers of technology transfer centres, researchers and central and local government officials in science and technology policy, chief executive officers and R&D project leaders/managers of industrial firms.

R&D expenditure was just over 300 billion Won in 2003. Busan increased this by an average of 15.97% per year and, in 2011, this expenditure had increased by 2.73 times that of 2003. The number of researchers steadily increased at an annual growth rate of 6.88%, and the number in 2011 was reported to be 1.63 times that of 2003. The frequency of new R&D projects increased at a rate of 15.97% annually, increasing the amount of new knowledge in 2011 to 2.03 times that of 2003, with an annual growth rate of 9.49%. The frequency of new product and process innovations improved at an annual growth rate of 15.64% and 15.66%, respectively. Busan exhibited steady growth in sales between 2006 and 2011 at a rate of 9.86%. Profits showed a decline between 2009 and 2010, but general growth was at an average rate of 12.19% per year.

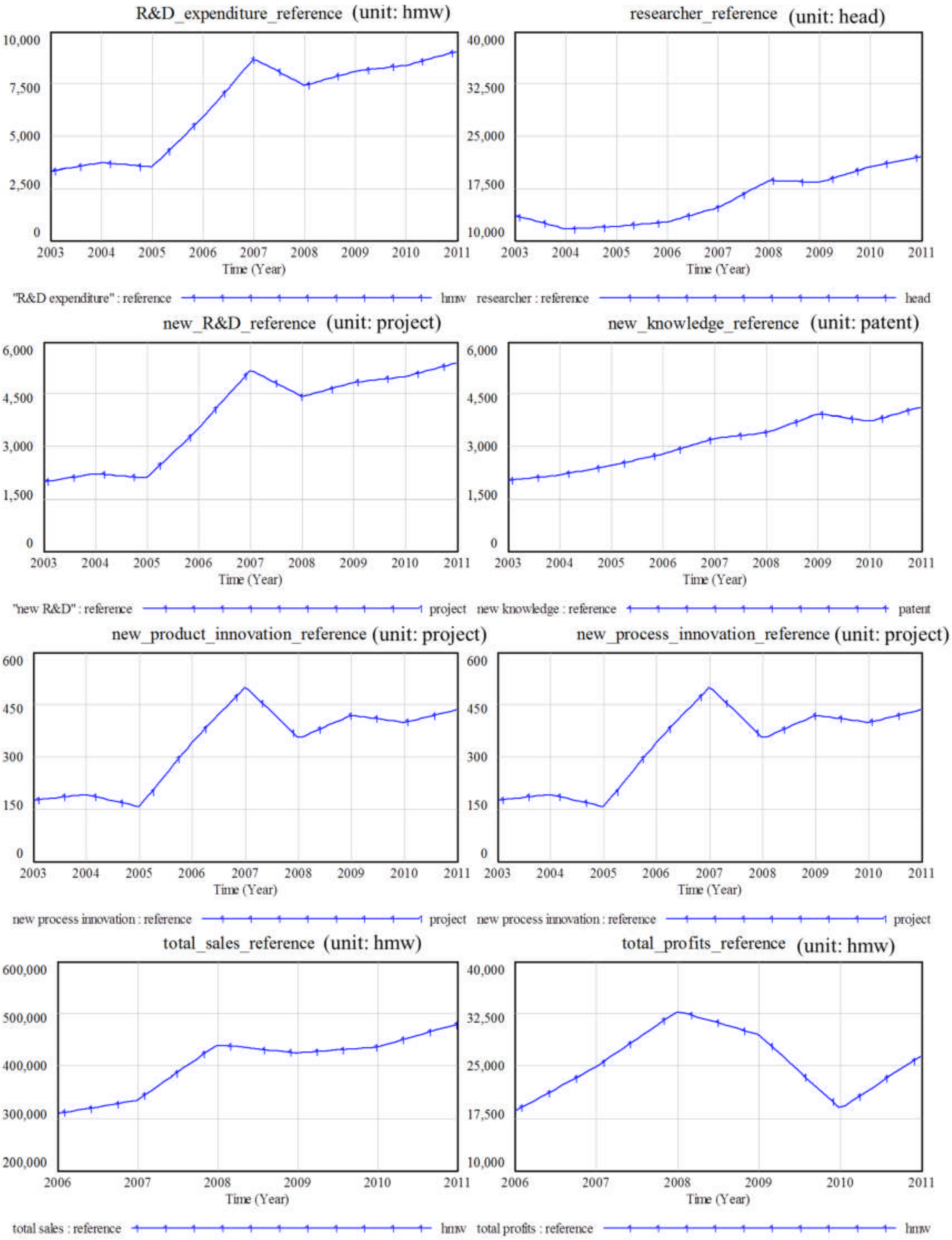


Figure 28. Reference data, 2003–2011[15]

---

[15] The term ‘hmw’ is short for hundred million Won; Won is the Korean currency unit; and data on sales and profits were available only for the years between 2006 and 2011.

Busan appears to enjoy regional development, according to the overall uptrends found in partial competitiveness indices. In the 1980s, Busan's economy peaked on the strength of its manufacturing industry. Since the fiscal crisis of 1997, however, Busan has lost key industries, including footwear manufacturing (Lim, 2000). As a result, the city has been suffering from a decaying regional economy. According to Korean Statistical Information Service (KOSIS) statistics, while Busan's R&D expenditure increased from 1.73% to 1.82% (relative to nation-wide R&D expenditure for the period 2000−2011), the number of researchers decreased from 4.66% to 4.16%. Additionally, the number of R&D organisations dropped from 4.32% in 2000 to 4.18% in 2011. Busan's GRDP also dropped from 5.65% to 5.01% during the same period. In order for this post-industrial city to achieve long-term growth despite this decline, it will have to shift to innovation-based development (Duke et al., 2006). To overcome economic recession and promote decentralisation and rebalancing policies, this study attempts to define what policies Busan should implement to achieve robust development of regional competitiveness.

5.5.2. Model formulation

This study develops a simulation model that contains the above eight partial competitiveness factors and core variables regarding potential policy interventions, as illustrated in Figure 29.[16]

---

[16] For equations in the model, see Appendix C.

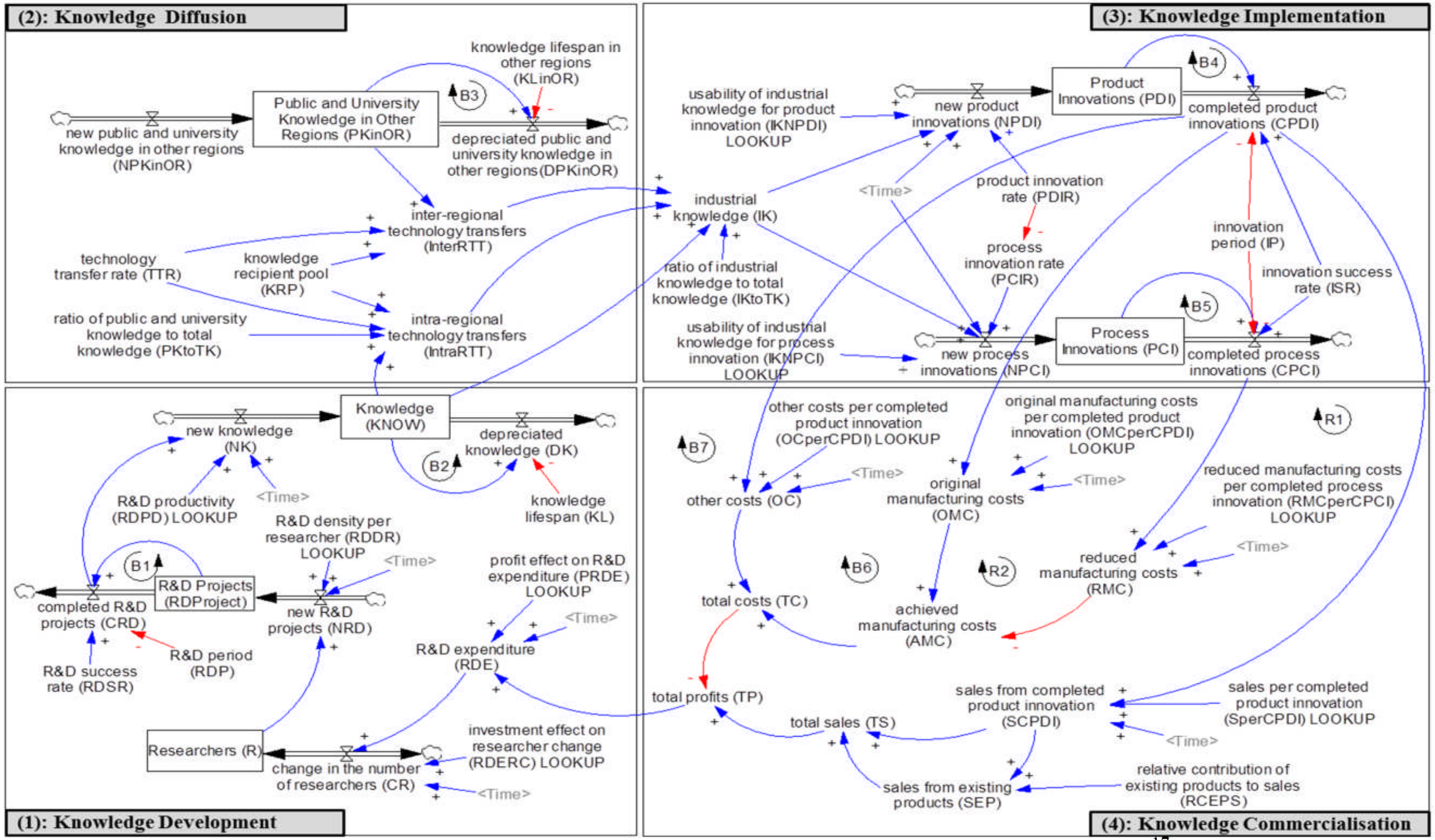


Figure 29. A system dynamics model of the knowledge-based innovation process[17]

---

[17] For the definitions of variables, see Appendix C.

The system dynamics model, summarised in Table 15, entails four core feedbacks (R1, R2, B6 and B7) that represent the main structures determining the dynamics of regional competitiveness.

Table 15. Key feedback structures of the model

Loop	Explanation
(R1) Product innovation-centred loop	R&D expenditure (RDE) enables researchers (CR and R) to conduct R&D (NRD, RDProject, and CRD) that produces knowledge (NK and KNOW). Industrial knowledge (IK) stimulates product innovations (NPDI and PDI). Successful product innovations (CPDI) generate sales (SCPDI and TS) and profits (TP) that boost R&D expenditure (RDE) for sequential R&D still more. Through this process, an innovation process shapes self-reinforcing behaviour over time.
(R2) Process innovation-centred loop	This loop counters two balancing loops (B6 and B7) in the knowledge-based innovation process. Industrial knowledge (IK), attained via R&D (NRD, RDProject, and CRD), is applied to process innovation projects (NPCI, PCI, and CPCI) that reduce manufacturing costs (RMC and AMC) and lower total costs (TC). In turn, it increases profits (TP) that boost R&D expenditure (RDE) still more.
(B6) Manufacturing costs-centred loop	Product innovations (NPDI, PDI, and CPDI) cause manufacturing costs (OMC) and other costs (OC) that raise total costs (TC), lessening profits (TP). In turn, the reduced R&D expenditure (RDE) declines researchers (CR and R) allocated to R&D (NRD, RDProject, and CRD). The inactive R&D reduces knowledge (NK, KNOW, and IK) and thus leads to less effort in product and process innovations (NPDI [NPCI], PDI [PCI], and CPDI [CPCI]). As a result, these two loops erode self-reinforcing phenomena formed by Loop R1.
(B7) Other costs-centred loop	

The competitiveness modes of capacity−capability−performance and other determinant variables are interrelated across the knowledge boundaries.

(1) Knowledge development. R&D expenditure (RDE) is derived from knowledge commercialisation (Barry, 2005; Katz, 2006; Scherer, 2001). Financial

capacity is used to employ researchers (RDERC, CR and R) who are allocated to new R&D projects (RDDR and NRD) to produce new knowledge (NK). R&D productivity (RDPD) is an essential consideration in the estimation of the amount of new knowledge in the knowledge production process (Chen and Guan, 2012; Wang and Huang, 2007). Success rate (RDSR) and time period (RDP) determine the beginning and the completion of R&D processes (CRD) (Lopolito et al., 2013; Maier, 1998). Because of the dynamic changes of new and completed R&D projects, the stock of R&D projects (RDProject) is also dynamic over time. Accumulated knowledge (KNOW) stimulates inter-organisational technology transfers (IntraRTT and InterRTT) in knowledge diffusion and new product/process innovations (NPDI and NPCI) for industrial firms in knowledge implementation. Knowledge lifespan (KL) is a consideration in knowledge accumulation, because the value of innovation-related knowledge depreciates over time (DK) (Park et al., 2006).

(2) Knowledge diffusion. Knowledge diffusion is an ancillary channel that provides new public and university knowledge for innovation practices in knowledge implementation. This boundary concerns technology transfer from the university and government sectors to industry (Caldera and Debande, 2010) in two contexts: intra-regional (IntraRTT) and inter-regional (InterRTT) (Simmie, 2003).[18] The extent of the potential regional knowledge recipient pool (KRP) is represented by the density

---

[18] In this study, the system dynamics model does not include other regions in the endogenous feedback structure because the focus of the analysis is confined to Busan. Further, this study does not consider technology transfers between industrial firms, because Busan's industry is mainly occupied by small- and medium-sized firms with medium-level technologies that usually do not require scientific and technological knowledge generated from other regions (interviews with industrial firms and the Small and Medium Business Administration [SMBA]).

of innovating firms localised within a region. The success rate of technology transfer (TTR) is critical to knowledge diffusion (Owen-Smith and Powell, 2001). These segments determine the frequency of technology transfer.

(3) Knowledge implementation. Using industrial knowledge (IK) generated from knowledge development and knowledge diffusion, this boundary relates product innovations (NPDI) and process innovations (NPCI) to economic earnings in knowledge commercialisation. Successful innovation (CPDI and CPCI) includes sequential activities such as production, marketing and other commercialising projects that create economic value in the marketplace (Dvir and Pasher, 2004; Maier, 1998; Smith and Barfield, 1996). Both the product innovation rate (PDIR) and process innovation rate (PCIR) change over time (Abernathy and Utterback, 1978). The ratio of new product (and process) innovation to industrial knowledge (IKNPDI and IKNPCI) determines the usability of industrial knowledge in multiple projects for product (and process) innovations. Additionally, the extent of success (ISR) and the innovation period (IP) is a determining factor with respect to the adoption of innovations in the marketplace (Kessler and Chakrabarti, 1996).

(4) Knowledge commercialisation. This boundary represents the economic effects of product and process innovations completed (CPDI and CPCI) in knowledge implementation. Activities following successful product innovations create costs (OC and OMC) that increase financial burdens. In contrast, the sales of (new) products/services (SCPDI) represent the direct benefit of product innovations (Chen and Guan, 2012; Smolny, 1998; Zhang and Li, 2010). Existing products/services, which are not new or improved, are also an important source of

sales (SEP). Process innovations are linked to product innovations (Adner and Levinthal, 2001) that achieve cost-efficient manufacturing processes (AMC) (Porter, 1980). Process innovations rely on the success and failure of product innovations and, thus, the success rate (ISR) is associated with both product innovations and process innovations (interviews with MoST).[19] In addition, the period of process innovation (IP) appears to be identical to the period of product innovation in the regional context (interviews with industrial firms and SMBA).[20] Profits (TP) are the difference between sales (TS) and costs (TC) (i.e. profits = sales − costs). This relationship estimates the economic effects of innovations (e.g. Galanakis, 2006; Lee and von Tunzelmann, 2005). Profits are a significant consideration in maintaining financial capacity that facilitates R&D in knowledge development (PRDE) (Scherer, 2001).

To quantify the model, this study collected data from on-line and off-line reports released by the Korean government and research institutes. Region-wide yearly data for some variables were limited. To overcome this limitation, this study adopted proxy measures (e.g. technology transfer rate, TTR) by estimating mean values drawn from regional or national survey results produced by the government and research institutes. Additionally, interviews provided quantifiable data (e.g.

---

[19] MoST is the acronym for the Ministry of Science and Technology. It is also known as the Ministry of Education, and Science and Technology (2008–2012), and the Ministry of Science, ICT, and Future Planning (2013–present). Theoretically, the implementation of process innovations requires a certain time lag after product innovations (Abernathy and Utterback, 1978). However, the mixture of multiple industries located in a macro-level territory (e.g. a region) reduces the time lag between product innovation and process innovation.

[20] Product innovation and process innovation occur simultaneously in the concept of concurrent engineering in a meso-level territory.

R&D period, RDP) that are not reported in the formal documents. Following data collection, the key variables, equations, parameters and initial conditions of the simulation model are defined. In the analysis, time units are yearly and the time span for the analysis is from 2003 to 2011. The quantified model is simulated to determine the policy effect on the endogenous properties and Busan's regional competitiveness in terms of knowledge boundaries and competitiveness modes.

5.5.3. Testing

To verify model reproducibility that refers to the degree of regenerating the same or similar behaviours in the innovation process, simulated data are compared with reference data for the period 2003 to 2011.

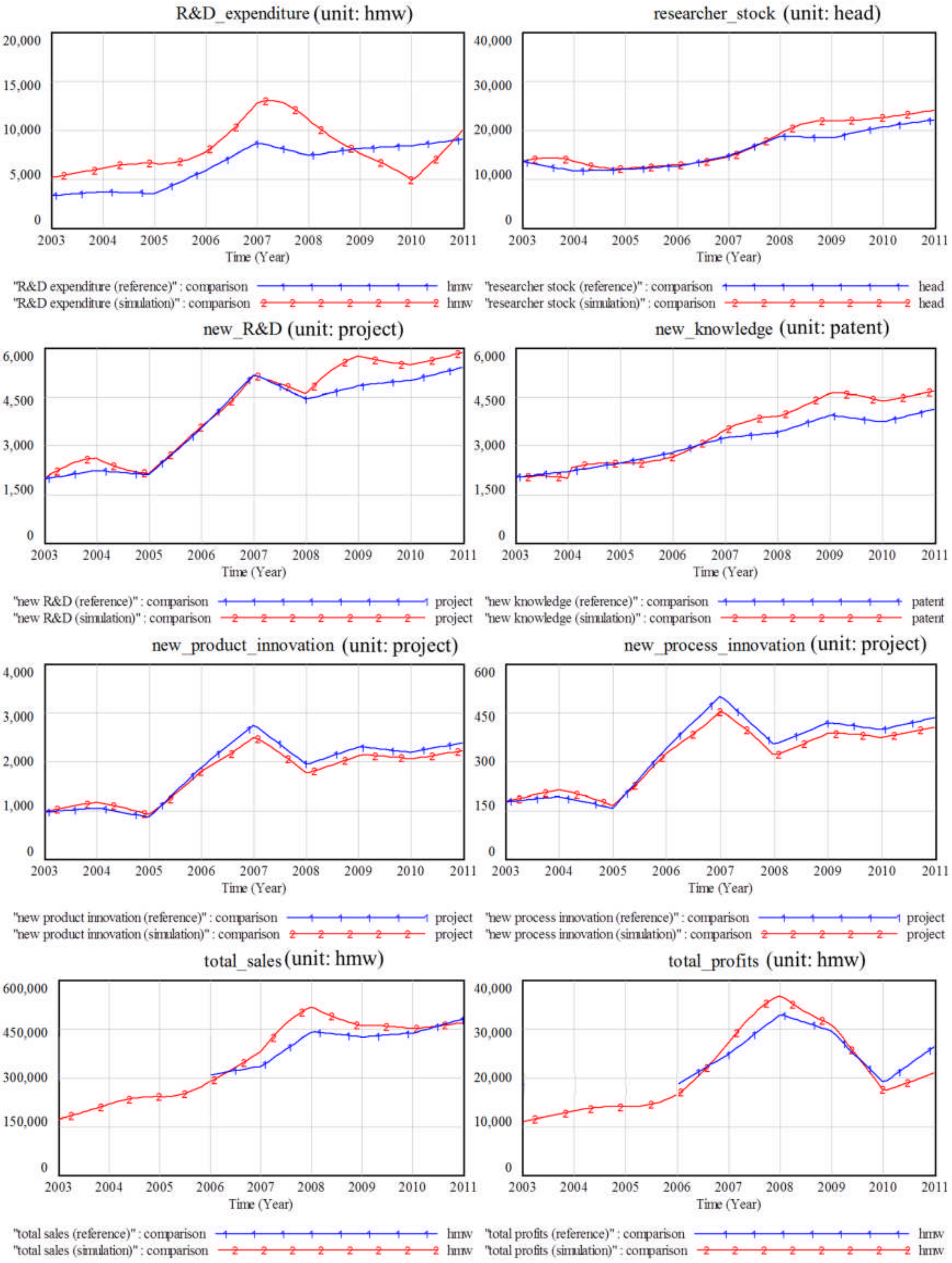


Figure 30. A simulation−reference comparison, 2003–2011

Figure 30 shows that the simulated data demonstrated trends similar to the reference data, despite there being no identical point-by-point data. A behaviour reproduction test measuring the coefficient of determination (R^2) and Theil's Inequality Statistics were used to confirm the robustness of the model. R^2 measures the covariance between two time series (Sterman, 2000). R^2 is close to 1 when the model outputs fit the actual series on a 1−0 scale. Theil's Inequality Statistics (Theil, 1966) consider the unequal mean (U^m), unequal variation (U^s) and unequal covariation (U^c). The same mean between the simulated and the actual series results in U^m of 0, the same trend between the two series results in U^s of 0 and the same values point-by-point result in U^c of 0.

Table 16. Results of a model fit test and a comparison in normalised competitiveness indices

Competitiveness variable	R^2	Theil's Inequality			Normalised competitiveness	
		U^m	U^s	U^c	Reference data	Simulated data
R&D expenditure	0.300	0.294	0.019	0.687	0.358	0.362
Researcher	0.790***	0.424	0.099	0.477	0.383	0.392
New R&D project	0.890***	0.407	0.076	0.517	0.351	0.351
New knowledge	0.945***	0.447	0.397	0.156	0.349	0.348
New product innovation	0.990***	0.363	0.458	0.179	0.345	0.343
New process innovation	0.990***	0.368	0.456	0.176	0.341	0.339
Total sales	0.720**	0.121	0.442	0.437	0.993	0.993
Total profits	0.869***	0.003	0.700	0.298	0.409	0.402

**significant at the 0.05 level; ***significant at the 0.01 level

Some competitiveness indices present simulation−reference dissimilarity in mean value (e.g. U^m is 0.447 for new knowledge), trend (e.g. U^s is 0.458 for new product innovation) and time lag (e.g. U^c is 0.687 for R&D expenditure). However, Table 16 shows that all but R&D expenditure are highly significant with respect to R^2. In addition, normalised competitiveness indices between the reference data and simulated data are similar. This similarity is confirmed by Kendall's coefficient of concordance test (Conover, 1980), which finds a 100% correlation between the reference data and the simulation data.[21] Consequently, the model has acceptable reproducibility to articulate partial indices of regional competitiveness for the period 2003 to 2011.

In a structural test, the core feedback structures of the model described in Table 15 are commonly found in the literature concerning innovation processes (e.g. Galanakis, 2006; Lee and von Tunzelmann, 2005), and they have been validated by the 33 interviewees, who had access to the model. Thus, it is concluded that the structure reflects knowledge-based innovation processes observed in general settings. Further, the model operates properly under extreme conditions. For example, the profit effect on R&D expenditure (PRDE) when the value of zero drops the change in the number of researchers (CR) to zero, and other competitiveness indices showed the same results as the original simulation. It can be concluded that the system dynamics model, based on these multiple tests, is sufficiently accurate to reflect a knowledge-based regional innovation process and, therefore, the policy tests can be conducted using this reliable simulation model.

---

[21] A non-parametric method to examine correlations among multiple variables based on a small sample's ranking.

5.5.4. Policy formulation and evaluation

The sensitivity test (Tank-Nielsen, 1980) is used to evaluate potential policy effects on the regional competitiveness of Busan's knowledge-based innovation process.

5.5.4.1. Test assumptions

The sensitivity test in this study includes two considerations. First, the test excludes particular controlling factors that are impractical to adjust. R&D productivity (RDPD) is associated with quality of R&D personnel that is difficult to improve in practice; thus, the sensitivity test does not consider this issue. Further, ratio of public and university knowledge to total knowledge (PKtoTK), ratio of industrial knowledge to total knowledge (IKtoTK), and technology transfer rate (TTR) tend to depend on infrastructural sufficiency. Infrastructural establishment and/or expansion usually accompany political resistance between government and local interest groups. Therefore, adjusting these parameters is unlikely to be practical. Further, knowledge lifespan in other regions (KLinOR) was not a concern in the sensitivity test because this parameter is external to Busan, which is the focus of this study. In addition to knowledge lifespan (KL), the system dynamics model did not detail a mechanism of market responses to (new) products/services.[22] Thus, the sensitivity test did not consider the adjustments of all variables related to knowledge

---

[22] In general, governments tend to allow companies and customers to make their transaction decisons in the marketplace at their own pace (Battisti, 2008).

commercialisation. Table 17 suggests 11 controlling factors used for the policy test.

The second consideration is related to the maximum parameter change of policy interventions (see the fifth column in Table 17). For example, it is not realistic to permanently alter profit effect on R&D expenditure (PRDE) (e.g. a 100% rise every year). The adoption of the maximum change is based on the assumption that the system can re-implement the maximised level of routines conducted in the past. To set the maximum parameter change, historical data were used. Longitudinally, the maximum change in PRDE was approximately 20% between 2010 and 2011 during the period from 2003 to 2011. By calculating the mean value of regional competitiveness improved by an incremental 1% increase in PRDE up to 20%, the effect of the PRDE adjustment was evaluated. This logic was similarly applied toinvestment effect on researcher change (RDERC), R&D density per researcher (RDDR), usability of industrial knowledge for product innovation (IKNPDI), and usability of industrial knowledge for process innovation (IKNPCI). With respect to R&D period (RDP), product innovation rate (PDIR), process innovation rate (PCIR), and innovation period (IP), the maximum changes were estimated until singular interventions resulted in one or more negative competitiveness index. This assumption is based on the intuitive purpose of policy instruments, which is to positively influence regional competitiveness. If the intensity of a particular policy leads to the presence of negative numbers in any competitiveness index (e.g. when R&D period [RDP] is reduced by 17 months, the value for new knowledge is −2,729 for 2004), then the utility of the sole policy is in effect before its negative effect (e.g. until RDP is reduced by 16 months). For the R&D success rate (RDSR) and innovation success rate (ISR) adjustments, the maximum changes were defined by the distance to 100%. For example, RDSR is approximately 74% in the simulation model, and the attainable maximum change is 26%.

Table 17. Controlling factors for the sensitivity test

Knowledge boundary	Controlling factor	Inclusion	Reason for exclusion	Maximum change	Reference for defining the maximum change
Knowledge development	profit effect on R&D expenditure (PRDE)	Yes	–	+20%	Largest change in historical data
	investment effect on researcher change (RDERC)	Yes	–	+119%	Largest change in historical data
	R&D density per researcher (RDDR)	Yes	–	+59%	Largest change in historical data
	R&D period (RDP)	Yes	–	−16 months	Until a negative value is evident
	R&D success rate (RDSR)	Yes	–	+26%	Difference to 100%
	R&D productivity (RDPD)	No	Quality-dependent	–	–
	knowledge lifespan (KL)	No	Market-dependent	–	–
Knowledge diffusion	ratio of public and university knowledge to total knowledge (PKtoTK)	No	Infrastructure-dependent	–	–
	technology transfer rate (TTR)	No	Infrastructure-dependent	–	–
	knowledge lifespan in other regions (KLinOR)	No	Out of Busan	–	–
Knowledge implementation	ratio of industrial knowledge to total knowledge (IKtoTK)	No	Infrastructure-dependent	–	–
	usability of industrial knowledge for product innovation (IKNPDI)	Yes	–	+73%	Largest change in historical data
	usability of industrial knowledge for process innovation (IKNPCI)	Yes	–	+73%	Largest change in historical data
	product innovation rate (PDIR)	Yes	–	+6%	Until a negative value is evident
	process innovation rate (PCIR)	Yes	–	+54%	Until a negative value is evident
	innovation period (IP)	Yes	–	−4 months	Until a negative value is evident
	innovation success rate (ISR)	Yes	–	+64%	Difference to 100%
Knowledge commercialisation	sales per completed product innovation (SperCPDI)	No	Market-dependent	–	–
	relative contribution of existing products to sales (RCEPS)	No	Market-dependent	–	–
	original manufacturing costs per completed product innovation (OMCperCPDI)	No	Market-dependent	–	–
	reduced manufacturing costs per completed process innovation (RMCperCPCI)	No	Market-dependent	–	–
	other costs per completed product innovation (OCperCPDI)	No	Market-dependent	–	–

5.5.4.2. Test results

Table 18 presents the improved amount and time-based growth of the core competitiveness indices. The profit effect on R&D expenditure (PRDE), investment effect on researcher change (RDERC), and R&D density per researcher (RDDR) adjustments influence all competitiveness indices, whereas the R&D period (RDP), R&D success rate (RDSR), innovation period (IP), and innovation success rate (ISR) adjustments generate improvement in all indices, but are accasionally negative for time-based growth in R&D expenditure, new knowledge, total sales, and/or total profits. The usability of industrial knowledge for product innovation (IKNPDI), usability of industrial knowledge for process innovation (IKNPCI), product innovation rate (PDIR), and process innovation rate (PCIR) adjustments occasionally deteriorate average change or time-based growth, or both.

Table 18. Policy effects: Average change and time-based growth for 2003−2011

Controlling factor	R&D expenditure (hmw)		Researcher (head)		New R&D (project)		New knowledge (patent)	
	Average change	Time-based growth	Average change	Time-based growth	Average change	Time-based growth	Average change	Time-based growth
profit effect on R&D expenditure (PRDE)	+215.37	+112.88	+122.29	+345.02	+30.36	+84.19	+12.53	+50.00
investment effect on researcher change (RDERC)	+61.17	+24.97	+1,190.77	+190.41	+299.14	+46.46	+156.28	+32.07
R&D density per researcher (RDDR)	+25.77	+72.13	+13.52	+38.26	+48.18	+50.80	+32.12	+56.12
R&D period (RDP)	+220.52	+343.97	+146.21	+411.45	+36.91	+100.39	+119.44	−1,040.71
R&D success rate (RDSR)	+29.09	+44.27	+19.71	+54.74	+4.95	+13.36	+18.44	−6.10
usability of industrial knowledge for product innovation (IKNPDI)	−21.89	−81.18	+2.55	−8.69	+0.63	−2.12	+0.62	+1.16
usability of industrial knowledge for process innovation (IKNPCI)	+89.18	+170.21	+24.34	+109.73	+6.10	+26.78	+1.12	+13.31
product innovation rate (PDIR)	−619.83	−1,302.84	−157.88	−681.12	−39.55	−166.19	−6.65	−75.57
process innovation rate (PCIR)	+564.45	+1,070.27	+146.11	+621.02	+36.63	+151.53	+5.99	+72.06
innovation period (IP)	+9,983.69	−1,115.86	+22,173.73	+1,814.54	+5,341.10	+442.75	+4,119.72	+341.25
innovation success rate (ISR)	+44.52	−126.66	+125.04	+191.95	+31.21	+46.84	+20.49	+38.49

Controlling factor	New product innovation (project)		New process innovation (project)		Total sales (hmw)		Total profits (hmw)	
	Average change	Time-based growth	Average change	Time-based growth	Average change	Time-based growth	Average change	Time-based growth
profit effect on R&D expenditure (PRDE)	+1.60	+6.50	+0.29	+1.18	+173.78	+456.77	+9.76	+20.45
investment effect on researcher change (RDERC)	+29.13	+8.19	+5.30	+1.49	+3,418.02	+1,156.42	+173.33	+51.91
R&D density per researcher (RDDR)	+8.94	+20.07	+1.63	+3.65	+1,356.63	+3,340.81	+74.74	+149.97
R&D period (RDP)	+53.42	+105.86	+9.72	+19.27	+10,012.19	+15,931.53	+588.04	+715.11
R&D success rate (RDSR)	+7.39	+9.98	+1.35	+1.82	+1,378.02	+2,051.58	+80.70	+92.05
usability of industrial knowledge for product innovation (IKNPDI)	+17.55	+19.71	+0.03	+0.05	+3,282.74	+4,541.45	−55.25	−168.77
usability of industrial knowledge for process innovation (IKNPCI)	−0.34	+0.72	+3.04	+3.69	−72.66	−144.61	+236.48	+353.86
product innovation rate (PDIR)	+23.03	+13.55	−20.18	−15.36	+4,373.22	+6,993.55	−1,644.13	−2,708.61
process innovation rate (PCIR)	−21.33	−14.66	+18.44	+16.12	−4,021.21	−6,014.08	+1,482.91	+2,225.10
innovation period (IP)	+1,890.35	+103.40	+344.11	+18.82	+441,217.62	−31,772.38	+25,928.43	−2,391.80
innovation success rate (ISR)	+4.97	+13.49	+0.90	+2.46	+1,891.84	−4,064.24	+108.82	−270.41

5.6. Discussion: Policy implications

Based on the results, Figure 31 discriminates policies into three groups: (1) highly effective interventions are marked by positive effects on both improvement and time-based growth, (2) moderately effective interventions increase the improvement of partial competitiveness indices but lead to downtrends in time-based growth for certain indices and (3) ineffective interventions reduce improvement and time-based growth in multiple competitiveness indices.

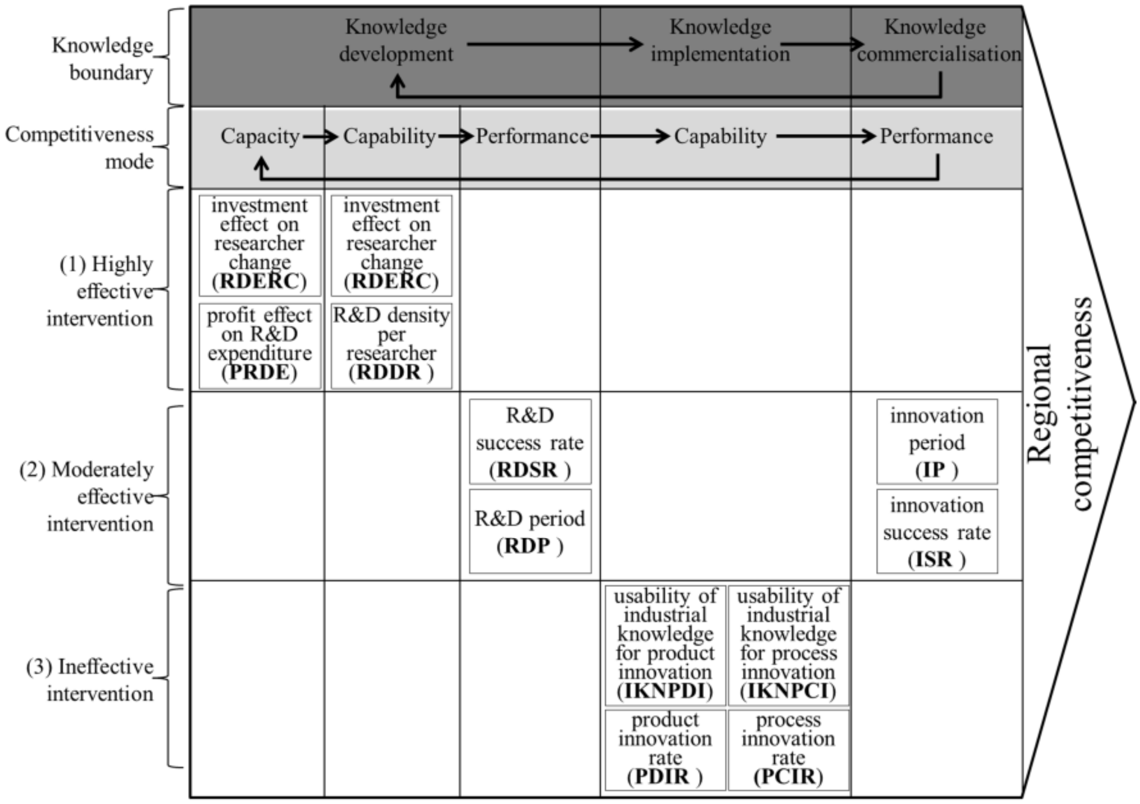


Figure 31. A classification of policies in the knowledge-based innovation process[23]

---

[23] For graphical details, see Appendix D.

With respect to system dynamics model structures (see Figure 29) based on a conceptual framework (see Figure 25) for knowledge development, profit effect on R&D expenditure (PRDE) and investment effect on researcher change (RDERC) are determinants of capacity that is related to financial and human resources, investment effect on researcher change (RDERC) and R&D density per researcher (RDDR) determine R&D capability, and R&D period (RDP) and R&D success rate (RDSR) address R&D performance. In knowledge commercialisation, innovation period (IP) and innovation success rate (ISR) are related to the financial performance of innovations. Based on the direct linkages, specific adjustments are incorporated into policy implications for the sustainable development of regional competitiveness.

5.6.1. Policy implications from capacity adjustment

Figure 32 compares the adjustments of profit effect on R&D expenditure (PRDE) and investment effect on researcher change (RDERC) in terms of the effect on competitiveness indices from static and dynamic perspectives.[24] The positive effect of these two adjustments implies that the capacity of financial and human resources for R&D is essential to regional competitiveness. This interpretation is consistent with the general perception that technological development is important to regional growth (Braczyk et al., 1998; Buesa et al., 2010; Cooke and Memedovic, 2003).

---

[24] Because indices have different units of measurement, the analysis results shown in Table 18 are normalised to compare policy effects in terms of the average change and time-based growth of regional competitiveness. Hereafter, Figures 32–35 display normalised values.

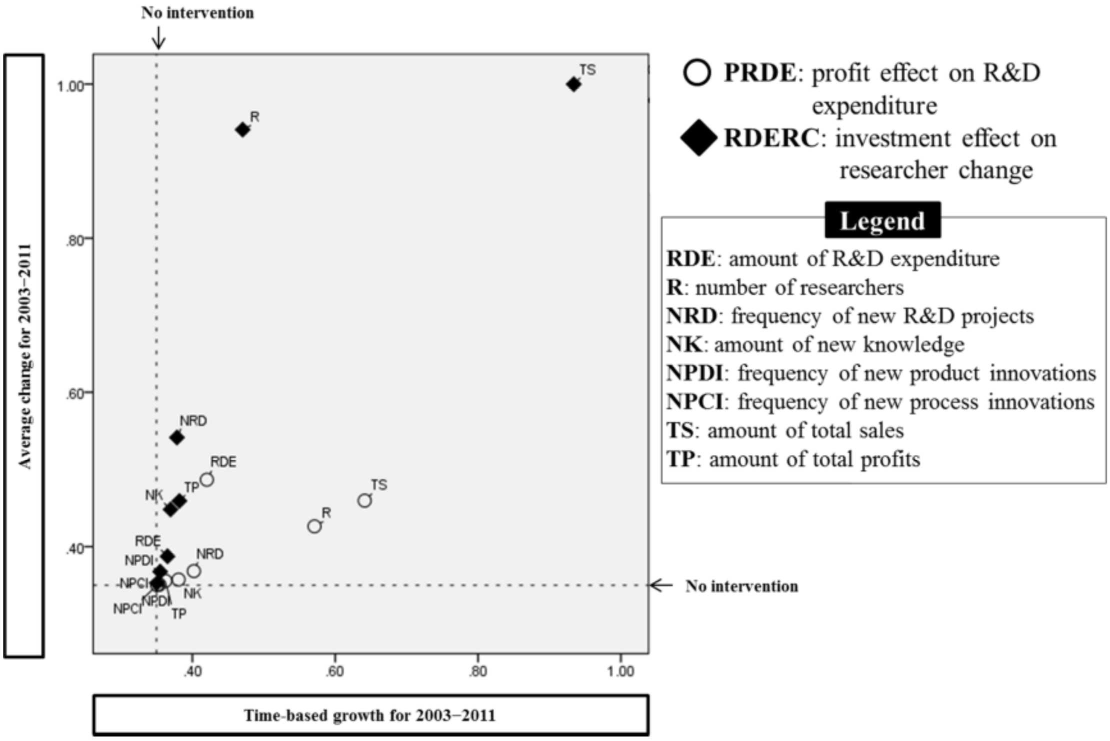


Figure 32. Results of capacity adjustment

However, in comparison, the investment effect on researcher change (RDERC) adjustment has a greater effect than the profit effect on R&D expenditure (PRDE) adjustment. That is, the adjustment of R&D expenditure alone cannot lead to satisfactory regional innovation. In fact, researchers are actual performers engaged in R&D and their contribution to the production of scientific and technological knowledge is irreplaceable. The KOSIS statistics report that the average annual increase in the number of researchers is 6.3%, which is less than half the amount of R&D expenditure (13.4%) in Busan during 2003–2011. The slower growth in R&D personnel indicates that human resource capacity, rather than financial capacity, has more room to contribute to the sustainable development of regional competitiveness. Thus, with respect to innovation policy, capacity adjustment will improve the regional competitiveness of Busan only when the increase in R&D expenditures sufficiently induces investment in the hiring of additional researchers.

5.6.2. Policy implications from capability adjustment

Figure 33 shows that the investment effect on researcher change (RDERC) and R&D density per researcher (RDDR) represent capability-attached factors that belong to knowledge development and are effective for improving regional competitiveness. In contrast, the usability of industrial knowledge for product innovation (IKNPDI), usability of industrial knowledge for process innovation (IKNPCI), product innovation rate (PDIR), and process innovation rate (PCIR) are capability factors belonging to knowledge implementation and are considered ineffective. This stark difference concludes that capability-related controlling factors of knowledge development are significant policy considerations when promoting regional competitiveness, but those related to knowledge implementation are not.

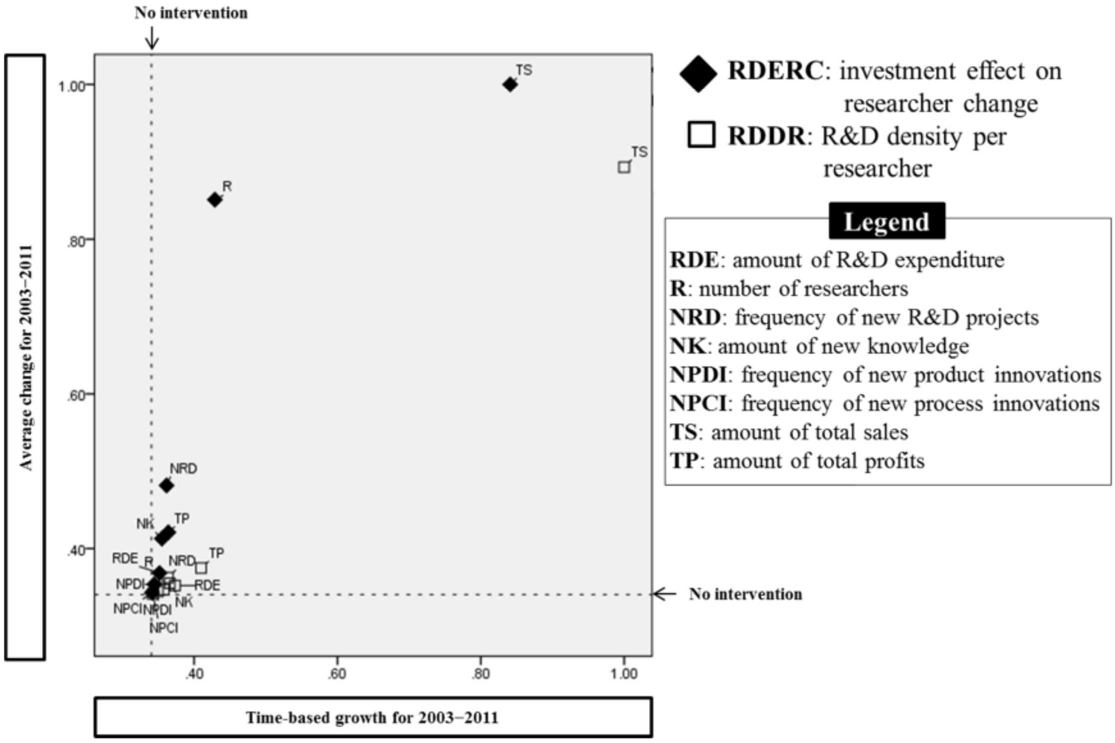


Figure 33. Results of capability adjustment

Similar to the comparative results for capacity adjustment (see Figure 32), Figure 33 also stresses the importance of R&D human resources. In comparison with the R&D density per researcher (RDDR) adjustment, the investment effect on researcher change (RDERC) adjustment generally results in greater improvement in the competitiveness indices of Busan. Although the RDDR adjustment is positive, particularly for the size of sales, its consequence seems unsatisfactory for other indices. RDERC reflects the size of the available expert pool for new R&D projects, whereas RDDR refers to the number of newly emerging R&D projects that are undertaken by a single researcher. The RDDR adjustment should facilitate an expert pool system that enables researchers to be engaged in multiple R&D projects. This, in turn, creates additional knowledge and leads to product/process innovations that achieve superior earnings in the innovation process. However, the RDERC adjustment conflicts with the RDDR adjustment. Specifically, the former increases the number of researchers, while the latter includes either an increase in the frequency of new R&D or a decrease in the number of researchers. For policy, this contradiction highlights the necessity of an optimal adjustment that upsizes the R&D human resource pool on a regional scale and encourages researchers to have multi-player functions. While the former focuses on the quantity of R&D researchers, the latter focuses on the quality of R&D researchers.

5.6.3. Policy implications from performance adjustment

Figure 34 shows that the innovation period (IP) adjustment, in comparison with the R&D period (RDP) adjustment, positively influences financial performance, including sales and profits, to a greater extent, although with decreasing growth (−31,772.38 in sales and −2,391.80 in profits; see Table 18) between the years 2003 and 2011. The RDP adjustment has a satisfactory effect mainly on sales, but not on other indices. The analysis result supports the fact that rapid response to innovation market competition enhances regional competitiveness. The successful competition of speed in product and process innovations allows industrial firms to survive or lead in an aggressive environment by retaining existing customers or attracting new customers. Thus, concurring with Lee and von Tunzelmann (2005), shortening the lead time of IP should be a policy focus.

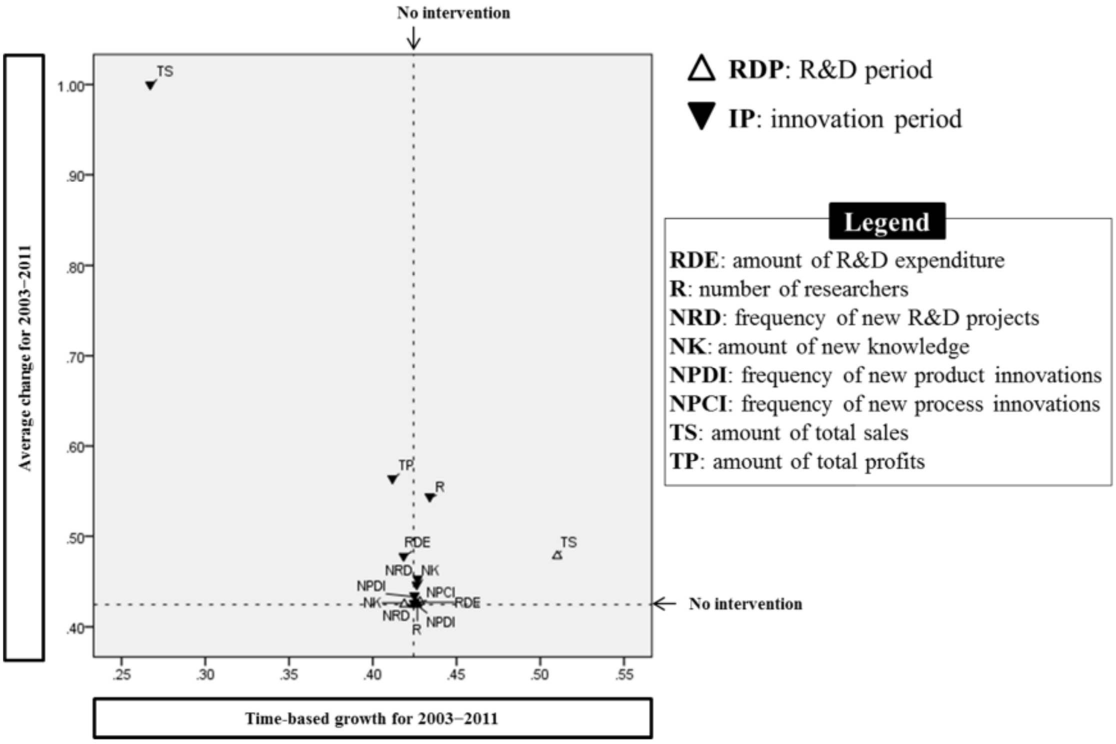


Figure 34. Results of time-related performance adjustment

Compared with the ISR adjustment, Figure 35 reveals that the R&D success rate (RDSR) adjustment has greater influence on regional competitiveness improvements. Table 18 shows that the slightly negative effect of the RDSR adjustment is found only in time-based growth of new knowledge (−6.10). In Figure 35, whereas all competitiveness indices with the exception of sales cluster around an intersecting point that presents no intervention, the innovation success rate (ISR) adjustment excessively decreases the time-based growth in sales (−4,064.24; see Table 18). RDSR is approximately 0.738 (73.8%) and ISR is 0.357 (35.7%) in the reference data. Although ISR has more room for improvement (an additional 64.3% to reach 100%), the analysis result recommends that policy focus on the R&D success rate for knowledge development is required, rather than policy to encourage the innovation success rate in knowledge implementation.

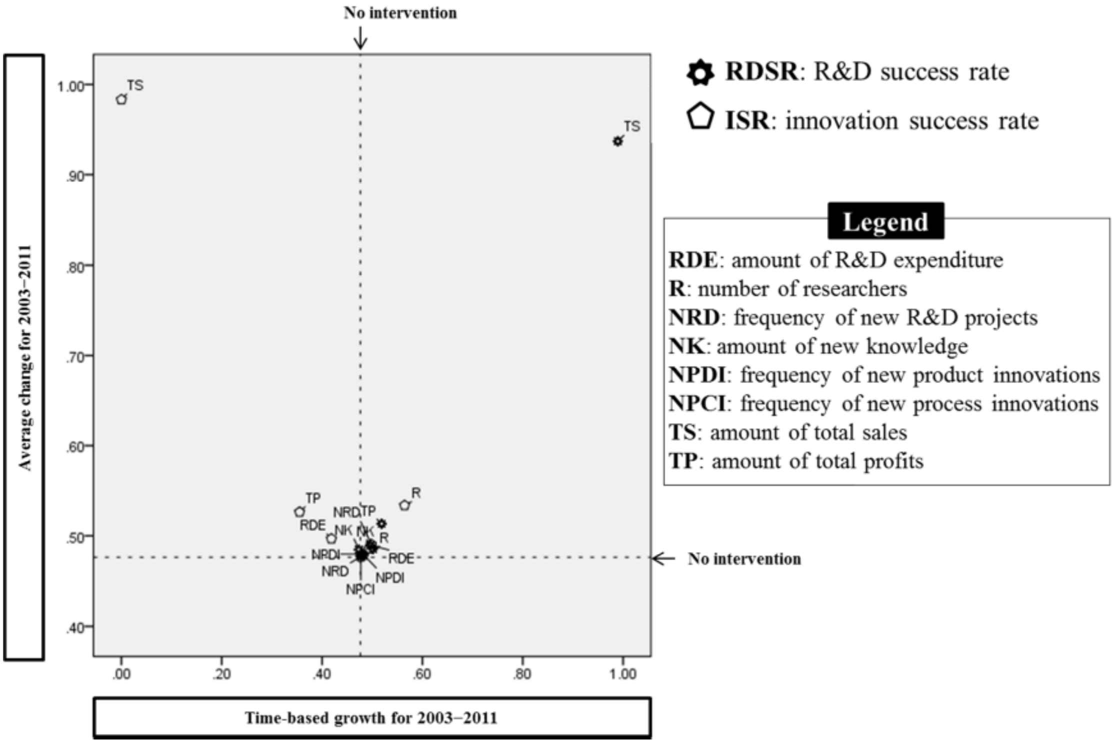


Figure 35. Results of success-related performance adjustment

A comparison between Figures 34 and 35 provides interesting implications for policy focus. Although all the above-suggested four adjustments (R&D period [RDP], innovation period [IP], R&D success rate [RDSR], and innovation success rate [ISR]) are assumed to be effective, the success rate for knowledge development and lead time for knowledge commercialisation are more decisive concerning regional competitiveness improvements. Consequently, in terms of performance-related adjustment, the effective aggregate policy portfolio should improve the success rate in knowledge development and shorten the innovation-related period for knowledge commercialisation.

5.6.4. Policy implications from system structures

Structuring the knowledge-based innovation process provides policy implications for Busan's regional innovation. The graphs displayed in Figure 28 indicate that Busan is characterised by continuous growth in multiple variables that constitute regional competitiveness. Referring to the feedback structures illustrated in Figure 29, the sustainable uptrends can be attributed to the governance of two reinforcing loops (R1: product innovation-centred loop and R2: process innovation-centred loop) over two balancing loops (B6: manufacturing costs-centred loop and B7: other costs-centred loop). Thus, a full understanding of the complex feedback mechanism frames policies. These policies strengthen the governance of reinforcing feedback loops and simultaneously weaken the control of balancing feedback loops over the operation of the established regional innovation process. From the above results (see Sections 5.6.1.–5.6.3.), R&D human resources, time and success rate are core parameters for the sustainable development of Busan's regional competitiveness:

- Hiring human resources is linked to R&D-related capacities and capabilities that are highly effective in improving regional competitiveness.
- Shortening lead time in product/process innovation and increasing R&D success rate constitute an aggregate policy portfolio that is a catalyst to regional competitiveness.

Additionally, consistent with Jervis (1997), the quantified regional innovation process leads policymakers to intuitively understand the changes in a sub-system's elements that affect the properties of other elements in other subboundaries and the entire innovation system. The sensitivity test demonstrated that the effects of all policies do not remain in particular knowledge boundaries and competitiveness modes, but are influential throughout the entire innovation process. That is, a specific system problem can be resolved by adjusting distant parts of the process. The negative effect of the usability of industrial knowledge for product innovation (IKNPDI), usability of industrial knowledge for process innovation (IKNPCI), product innovation rate (PDIR), and process innovation rate (PCIR) adjustments on certain competitiveness indices provides warning signs with respect to counterintuitive policymaking results (Lee and von Tunzelmann, 2005; Marcus, 1981; Sterman, 2000). For example, general perception implies that the greater the number of product innovations, the higher the sales and, ultimately, the higher the profits. However, the analysis result shows that the IKNPDI adjustment reduces the average (−55.25) and time-based growth (−168.77) of profits.

While the results seem counterintuitive, the main reason is the large percentage of small firms in Busan (Duke et al., 2006). Relative to large firms, small and medium-sized enterprises (SMEs) suffer from limited capacity to access financial and human resources. Because of insufficient internal funds, SMEs lack the ability to lead industrial expansion and achieve financial sufficiency for sequential R&D (Tether, 1998). As a result, they are incapable of self-sustaining their innovation processes and tend to rely on government funds for R&D projects. Although government aid can support the R&D investment and product innovation of SMEs, the economic gains of these SMEs depends on their existing capacity in merchandise manufacturing and in investor-customer market transactions. Given Busan’s limited system ability, solely increasing R&D expenditure and product innovation may not achieve the desired levels of regional competitiveness and financial stability.

From a systems perspective, it is necessary to stimulate the reinforcing loop R2 (process innovation-centred loop) in order to offset the additional costs created by increased product innovations in the balancing loops B6 (manufacturing costs-centred loop) and B7 (other costs-centred loop). To this end, aid from central and local governments for localised SMEs should focus on multifaceted leverage points, including increasing funds expected to directly encourage the creation of new or improved products and services in the knowledge implementation boundary and reducing production, delivery, and marketing costs incurred from the innovation process.

Based on the points above, policymakers are recommended to obtain systemic insight into feedback structures endogenous to the innovation process, and develop innovation policies that intensify reinforcing feedback loops for SME-dominant competitiveness on the regional scale.

5.6.5. Generalisation of the research

Busan, as a single case study, does not provide a one-size-fits-all finding that can be generalised throughout Korea. This single experiment is unlikely to share similar findings with international cases because of different innovation conditions set by different countries.

In social science, however, the generalisation from a single case can be supported by a strategic selection of the case (Platt, 1992; Ragin and Becker, 1992). As previously mentioned, Busan is a leading region in the southeast economic zone of Korea as well as in the nation (Duke et al., 2006). In addition, Busan is seen as the most likely place for long-term R&D efficiency in Korea (Han et al., forthcoming 2015). It is a good example representing the competitive ability to build a long-term knowledge base that stimulates the regional innovation process. As a result, Busan can provide practical implications for sustainable regional innovation in regional and nation-wide contexts.

Although Busan cannot represent findings in different contexts, this study's approach of analysing regional diversity (i.e. Busan's context displayed in Figure 28), regional structure (i.e. Busan's interwoven feedback loops displayed in Table 15), and regional behaviour (i.e. Busan's regional competitiveness displayed in Figure 30 and Table 18) can help explain the sustainable operation of innovation processes for encouraging regional competitiveness in other domestic and international examples. In particular, Korea is characterised by SME prevalence throughout the country, such that all regions share similar characteristics to Busan in this respect. Korea is also characterised by localised national approaches to regional development (Asheim and Isaksen, 1997). Thus, the conceptual models (see Figures 25 and 26), simplified innovation processes (see Figure 29), and analysis principles and procedures using system dynamics are good examples for other Korean cases in innovation governance. The structure of the simplified system dynamics model also shows a high similarity to other cases found in existing quantitative (e.g. Taiwan, see Lee and von Tunzelmann, 2005) and qualitative studies (e.g. a normative innovation system; see Galanakis, 2006) on meso- and macro innovation systems. The meta narrative of this study may therefore have high applicability to other countries, such as China, where the strong governance of national initiatives leads to regional development towards state-led industrialisation.

5.7. Conclusion

This study highlighted the increasing interest in policy effects on regional competitiveness in the field of innovation policy through evaluating the regional innovation process of Busan, South Korea. This study defined regional competitiveness as a set of capacities, capabilities and performances that are embedded across knowledge boundaries of development–implementation–commercialisation. Additionally, the study identified the reinforcing and balancing feedback structures of knowledge-based innovation processes at a regional level. Methodologically, by means of a system-based method, this study contributed to knowledge evaluating policy effects on the dynamic nature of regional competitiveness. The system-based method helped to confirm cross-boundary and counterintuitive consequences of policymaking. Through the interpretations of systemic structures and dynamic regional innovation, this study offered a precedent for future research that seeks to articulate multi-dimensional regional competitiveness and the policy effects.

In spite of these contributions, this study has limitations that are relevant to the direction of future research. The analysis used a small-sized city model and did not include potential external factors (e.g. foreign direct investment). The consideration of significant external aspects may provide additional insight into the operation of a territorial innovation system in an open economy. Conversely, a more specific design of region-specific characteristics, such as industrial configuration, could generate a nuanced understanding of multiple policies. Second, this study examined only one city, Busan; therefore, the research findings cannot be generalised to other cases. Different regions are likely to present different dynamic patterns in regional competitiveness. A cross-regional comparison could expose regional diversity under different conditions that trigger different policy suggestions to improve regional competitiveness. Finally, as innovation policies require an integrated approach with multiple initiatives (Lee and von Tunzelmann, 2005), a more sophisticated model may develop diverse policy portfolios. Together with the current study, such future research is expected to expand the knowledge on the dynamic phenomena of regions in terms of the innovation ecosystem, its interactions with policies and the development of regional competitiveness in the evolutionary innovation process.

CHAPTER 6. CONCLUSION OF THE THESIS

This chapter briefly reviews the research presented in this thesis throughout the three academic papers. In addition, it summarises the papers' major findings, and explores the contributions of knowledge to the regional innovation field. Finally, this chapter presents the limitations of this thesis that open novel avenues for future studies.

6.1. A Brief retrospection

This thesis investigated 'regional diversity', 'regional structure', and 'regional behaviour', to address an open question '*How do regions fulfil their territorial innovation potential and become competitive based on science and technology from a systems perspective?*' The inquiry was decomposed into three sub-questions. First, *which regions are competitive in terms of R&D efficiency?* (Research Question 1); second, *how do regional innovation systems operate in the resource−function−performance structure?* (Research Question 2); and third, *how does regional competitiveness behave over time, and what policy(ies) can help or hinder regional competitiveness?* (Research Question 3)

To answer these questions, this thesis used quantitative and qualitative operational research tools, including data envelopment analysis, the Malmquist productivity index, systems thinking (causal loop diagram), and system dynamics (stock and flow diagram). Following a three-paper scheme, this thesis addressed '*An Analysis of Regional Innovation Processes Using Operational Research Tools: The Case of South Korea*'. The scope of this thesis covered city- and province-based routines, Schumpeterian innovation, and the resource–function–performance structure.

6.2. Key findings and policy implications

Paper 1 aimed to classify Korean regions using data envelopment analysis from a static perspective and the Malmquist productivity index from a dynamic perspective. The results designated Busan as the most competitive region in terms of R&D efficiency between 2005 and 2009. Busan demonstrated a significant increase in regional R&D efficiency and was close to the frontier set by best practices. Paper 2 employed systems thinking to illustrate a causal loop diagram for identifying the cause and effect relationships in Korea's triple helix system, focusing especially on Busan. From the qualitative analysis, Paper 2 confirmed that Korea's regional innovation system presents a feedback process composed of interrelated domains including knowledge development, knowledge diffusion, and knowledge deployment. By simplifying the causal loop diagram, Paper 3 modelled a stock and flow diagram for Busan's regional innovation process that enables simulations to uncover the dynamics of regional competitiveness and the effect of policy alternatives. The test results demonstrated that the adjustment of R&D human resources is more important than that of R&D expenditures in promoting Busan's regional competitiveness. Further, for regional competitiveness, improving the success rate for knowledge development is an effective policy intervention point, whereas reducing lead-time for knowledge commercialisation is a key intervention.

From the three papers, this thesis found common policy implications. Paper 1 (regional R&D efficiency) and Paper 3 (regional competitiveness) indicated that increasing R&D expenditures does not guarantee excellence in knowledge production and regional competitiveness. In Paper 1, the time-dependent change in industrial R&D expenditures had a positive impact on the technical efficiency change index (the catch-up effect of each region), a key determinant of improvements to regional R&D productivity change. However, from the regional perspective (taking universities, industries, and government research institutes together), abundant financial resources do not necessarily lead to high static or dynamic regional R&D efficiency scores, as seen in the cases of Seoul, Gyeonggi, and Daejeon. As compared with improvements in R&D human resources, Paper 3 showed that increasing R&D expenditures was relatively less effective in improving the average change and time-based growth in multiple regional competitiveness indices in the case of Busan’s ongoing regional innovation process.

Paper 2 (regional structure) and Paper 3 (regional competitiveness) found counterintuitive consequences of policy interventions. Paper 2 concluded that specific policies generate positive results in the short-term, but lead to other systemic problems either in the same or other parts of the system in the long-run. Similarly, Paper 3 provided empirical evidence that actions do not necessarily create the intended results. An example, demonstrating the idea that more product innovation leads to more economic gains, upended knowledge commonly held to be true. The results of Papers 2 and 3 give clear warning signs of counterintuitive public decision-making, as demonstrated in Table 14 in Chapter 4 and Table 18 in Chapter 5. Therefore, policymakers should interpret policy effects based on an interwoven structure of reinforcing and balancing feedback loops that comprise a regional innovation process.

6.3. Key contributions

This thesis contributed theoretical, methodological, and practical knowledge to the regional innovation field.

6.3.1. Theoretical contributions

This thesis expanded measurement approaches to regional R&D efficiency by combining a static view (Charnes et al., 1994) and a dynamic view (Färe et al., 1994) (see Paper 1). This composite investigation enabled more robust regional classification based on efficiency scores.

Further, this thesis contributed to a theoretical advance over the existing triple helix studies that have mainly focused on the trilateral collaboration of universities, industries, and government research institutes (e.g. Eom and Lee, 2010; Etzkowitz and Leydesdorff, 2000; Kwon et al., 2012; Leydesdorff and Fritsch, 2006; Leydesdorff and Meyer, 2006; Leydesdorff et al., 2006; Meyer et al., 2003; Park and Leydesdorff, 2010; Park et al., 2005; Shapiro, 2007) (see Paper 2). This thesis encompassed the intra-sphere circle and linked it to the inter-sphere circle established among three key knowledge-producing spheres (universities, industries, and government research institutes). This improved the understanding of the mechanism of an inclusive knowledge-based innovation process based on the triple helix framework in the Korean context.

Using computer-based simulations, Paper 3 contributed a quantification of the regional innovation systems, which are seen as conceptual relative to theories of industry-specific innovation systems (SCBRI, 2005). In doing so, this thesis applied causality-based relations in the resource-function-performance structure to an observation of dynamic regional competitiveness and the effects of policy. Based on the resource−function−performance structure, the interpretation of counterintuitive policy effects illustrated the need for systemic insight into complex and evolutionary reinforcing and balancing feedback loops in the innovation process.

6.3.2. Methodological contributions

This thesis employed operational research tools (i.e. data envelopment analysis, Malmquist productivity index, causal loop diagram, and system dynamics) to analyse regional innovation systems. This methodological approach supported the applicability and utility of operational research tools in the meso-level innovation context, in line with the benefits of operational research tools held by Lee et al. (2008). Specifically, this thesis incorporated each tool appropriately into the specific system problems to be resolved under the umbrella term ‘innovation’. The data envelopment analysis addressed the static patterns of regional R&D efficiency, whereas the Malmquist productivity index identified the changes in it (see Paper 1).

While these two linear programming techniques provided comparisons in R&D efficiency between different regions, the causal loop diagram and system dynamics explained the reasons behind the success or failure of regional innovation/competitiveness. The causal loop diagram offered a systems perspective based on the perception of actors performing key tasks in the knowledge-based innovation systems (see Paper 2). By means of system dynamics based on modelling and quantitative data, this thesis accounted for the issue of complexity and dynamics in the regional innovation context, seldom sought to employ suitable methodologies, or methods (see Paper 3). Consequently, the four operational research tools could be integrated into a unique multi-methodological framework to understand regional innovation systems.

6.3.3. Practical contributions

The theoretical and methodological framework developed in this thesis provided analytic evidence for rational decision-making. Although this thesis was limited to Korea (and Busan for Paper 3) and the results were restricted to the policies regarding innovation within this one country (and a city), the sequential analysis procedure taken in this thesis – evaluating regional R&D efficiency, modelling a regional structure of the innovation process, and analysing policy effects on regional competitiveness − appears applicable to other cases for ‘meta narratives’ related to the management of sustainable (regional) innovation systems.

Firstly, the dynamic attributes of regional R&D efficiency provided rational indicators yielding relative regional rankings by reflecting immediate and long-term achievements within a given time period (see Paper 1). In addition, the two dimensions contributed to a novel regional assignment within a quadrant matrix that may offer a visualisation of regional positions for policymakers who do not have much knowledge of operational research with complex mathematic models.

Secondly, the causal loop diagram provided a big picture for stakeholders within the triple helix so they can better understand the dynamics of their operating environment (see Paper 2). As a result, policymakers may be able to understand the conflicts between the intended and unintended effects of specific (regional) innovation initiatives and the conflicts around the influential boundary such as whether only one segment falls within a specific measure’s orbit or all spheres do.

Lastly, the quantification of dynamic regional competitiveness may be useful to support legislation of innovation policies by demonstrating the expected and unexpected effects of various policy interventions (see Paper 3). In doing so, the scientific evidence (results of the sensitivity test) can help policymakers to consider the multifaceted impacts of their decisions.

6.4. Limitations of the thesis and future research

This section discusses theoretical, methodological, and practical limitations that offer research directions for future studies.

6.4.1. Theoretical limitations and future research

This thesis conceived the regional innovation process as feedback phenomena; however, the evaluation of regional R&D efficiency adopted a linear approach starting with inputs and finishing with outputs (see Paper 1). Although the linear perspective is still useful to analyse systemic operational performance such as system efficiency (Hollanders and Celikel-Esser, 2007), it would be worthwhile to develop a novel measurement method that reflects the feedback phenomena of innovation including knowledge development, knowledge diffusion, knowledge implementation, and knowledge commercialisation.

In addition, a typical triple helix paradigm theoretically refers to the relations of university−industry−government (Etzkowitz, 2008; Etzkowitz and Leydesdorff, 2000). However, the Korean example in this thesis used a triple helix that did not include government roles (see Paper 2); rather, it was focused on the role of government research institutes. This limitation was attributed to insufficient information on region-wide policies related to feedback between the triple helix and government policies. To integrate the typical triple helix from a policy perspective, it would be interesting to expand the triple helix to a quadruple helix that comprises universities, industries, government research institutes, and government bodies.

Along with a structure that consists of linkages among activities, the term ‘system’ implies interactions that refer to inter-organisational relations (Nelson, 1993). However, as the research focus was on the system structure that comprises a regional innovation process, this thesis did not investigate the interaction attributes within the system investigated in several other studies (e.g. Eom and Lee, 2010; Etzkowitz and Leydesdorff, 2000; Kwon et al., 2012; Leydesdorff and Fritsch, 2006; Leydesdorff and Meyer, 2006; Leydesdorff et al., 2006; Meyer et al., 2003; Park and Leydesdorff, 2010; Park et al., 2005; Shapiro, 2007) (see Paper 3). While interactions in the literature are largely interpreted as relations (e.g. frequency of collaboration), an analysis of interactions is associated with micro-level decision-making. Thus, in order to fully understand the term ‘system’, it would be useful to examine how individual decisions affect the behavioural dynamics of regional competitiveness. In addition, this approach would be useful in analysing a multi-layered regional innovation system that covers the micro- and macro-level.

Throughout the three papers, attention was paid to innovation related activities carried out within the context of intra-regional boundaries that were designated as administrative cities and provinces. Along with endogenous characteristics attached to each region, exogenous sources also provide knowledge that affects innovation processes and economic development (Bottazzi and Dindo, 2013; Fritsch and Franke, 2004; Greunz, 2005). Accordingly, inter-regional interactions, knowledge flows, and dependence on exogenous externalities between neighbouring regions should be considered when analysing the regional dynamics of innovation for future research. These discourses will help illuminate different perspectives on the operation of regional innovation and clarify the corresponding findings on regional diversity, regional structure and behaviour, R&D efficiency, triple helix mechanisms, and regional competitiveness.

6.4.2. Methodological limitations and future research

The regional R&D efficiency evaluation used short-term data covering only five years, from 2005 to 2009 (see Paper 1), which may not illustrate stagnation in R&D efficiency and its change between adjacent years. Therefore, a longer timeframe is suggested to evaluate the implications of longer-term planning for regional innovation on the dynamics of R&D efficiency. In addition, for a research process using system dynamics, a causal loop diagram is the basis for developing a system dynamics model for empirical simulations (Fowler, 2003; Sterman, 2000). However, owing to the lack of region-wide data related to the triple helix, the thesis developed a simple model of the knowledge-based innovation process for analysing policy effects on regional competitiveness (see Paper 3). Future research gathering the triple helix related data on regional innovation allowing a quantification of the dynamic behaviours of the triple helix system offers a promising possibility for future research.

6.4.3. Practical limitations and future research

The analysis of regional R&D efficiency did not account for the details of influential factors (e.g. regional distribution of R&D actors and R&D stages, industrial structure, quality of outputs, partner accessibility, demographic changes, and industrial shifts) on regional R&D efficiency and its time-dependent change (see Paper 1). A more sophisticated investigation of region-specific causes would help to identify multiple policy measures that contribute to improvements in regional R&D efficiency and its productivity change. On the study of regional R&D efficiency, this thesis was restricted to an intra-national comparison focusing on Korea. A cross-country analysis comparing Korean regions with those of OECD members may illustrate the position of Korean regions on the supranational scale. In addition, the triple helix model could not be adopted immediately by other countries because system structures differ by country (see Paper 2). Hence, it would be interesting to compare Korean regions with other nations' regions to capture Korea's unique regional innovation structure on an international scale.

In fact, different regions are likely to present different dynamic patterns in regional competitiveness. However, this thesis investigated only one city, Busan, and thus the empirical findings cannot simply be applied to other cases (see Paper 3). A cross-regional comparison could expose regional diversity under different conditions that require different policy suggestions to improve regional competitiveness. Further, the simplified system dynamics model did not include the potential external factors such as foreign direct investment (see Paper 3). Accounting for significant external factors may provide additional insight into the operation of a territorial innovation system in an open economy. More to the issue of policy, this thesis mainly focused on producing a simplified model of the knowledge-based innovation process that broadly consists of knowledge development, knowledge diffusion, and knowledge deployment (implementation and commercialisation) (see Paper 3). Therefore, a more detailed model could generate a nuanced understanding of multiple policy portfolios. In terms of developing policy recommendations, a scenario planning approach could be used to consider how external environments of the future would turn out. Scenario planning usually generates between two and four strategic options (O'Brien, 2004). Using this approach provides decision-makers with a better understanding of the range of uncertainty in the potential outcomes, enabling multiple decisions to respond to changes they may face in the future. As a result, individual innovation stakeholders could access information specific to their interests − e.g. systemic behaviours related to basic research from a university scientist's perspective.

6.4.4. Summary of future research

Based on the thesis' limitations outlined above, future studies may contribute to advances in knowledge with respect to the objects of research, as follows.

- Regional innovation efficiency:
    - To employ a longer-term timeframe in evaluating the dynamic R&D efficiency of regions
    - To develop a new method that reflects feedback phenomena of efficiency in a series of knowledge-based innovation processes ranging from knowledge development, knowledge diffusion, and knowledge implementation, to knowledge commercialisation

- Regional triple helix:
    - To expand the triple helix to include universities, industries, public research institutes, and government bodies
    - To quantify triple helix behaviours for capturing the region-wide dynamics of intra- and inter-sphere circles among universities, industries, and government research institutes
- Regional open innovation:
    - To examine dynamic interactions between micro-level decisions and regional competitiveness
    - To analyse a multi-layered regional innovation system on both the micro- and macro-levels
    - To conduct a cross-country analysis in terms of regional efficiency, regional structure, and regional competitiveness
    - To consider inter-regional spillovers of knowledge in analysing regional innovation phenomena
- Regional innovation policy:
    - To specify region-wide data for identifying multiple policy measures and portfolios
    - To employ a scenario planning approach for analysing dynamic future environments

Along with this thesis, these avenues of future research offer perspectives that can help to articulate the fundamental, essential natures of regional innovation systems, including regional diversity, regional structure, and regional behaviour.

REFERENCES

Abernathy, W.J. and Utterback, J.M. (1978) ‘Patterns of industrial innovation’, *Technology Review*, 80(7), 40–47.

Acs, Z.J., Anselin, L. and Varga, A. (2002) ‘Patents and innovation counts as measures of regional production of new knowledge’, *Research Policy*, 31(7), 1069–1085.

Adams, J.D. and Griliches, Z. (2000) ‘Research productivity in a system of universities’, in Encaoua D., ed., *The Economics and Econometrics of Innovation*, Boston: Kluwer.

Adner, R. and Levinthal, D. (2001) ‘Demand heterogeneity and technology evolution: implications for product and process innovation’, *Management Science*, 47(5), 611–628.

Agrawal, A. and Henderson, R. (2002) ‘Putting patents in context: exploring knowledge transfer from MIT’, *Management Science*, 48(1), 44–60.

Agrawal, S., Subramanian, K.R. and Kapoor, S. (2010) ‘Operations research−Contemporary role in managerial decision making’, *International Journal of Research and Reviews in Applied Sciences*, 3(2), 200-208.

Aigner, D., Lovell, C.A.K. and Schmidt, P. (1977) ‘Formulation and estimation of stochastic frontier production function models’, *Journal of Econometrics*, 6(1), 21–37.

Almond, G.A. and Powell, G.B. (1967) *Comparative Politics: A Developmental Approach*, Boston: Little, Brown and Company.

Amit, R. and Schoemaker, P.J.H. (1993) ‘Strategic assets and organizational rent’, *Strategic Management Journal*, 14(1), 33–46.

Andersen, E.S. and Lundvall, B.-Å. (1988) ‘Small national innovation systems facing technological revolutions: an analytical framework’, in Freeman, C. and Lundvall, B.-Å., eds., *Small Countries Facing the Technological Revolution*, London: Pinter.

Andersen, P. and Petersen, N.C. (1993) ‘A procedure for ranking efficient units in data envelopment analysis’, *Management Science*, 39(10), 1261–1264.

Andersson, M. and Karlsson, C. (2004) ‘Regional innovation systems in small and medium-sized regions’, in Johansson, B., Karlsson, C. and Stough, R. R., eds., *The Emerging Digital Economy: Entrepreneurship, Clusters and Policy*, Berlin: Springer-Verlag.

Andersson, T. (1998) ‘Managing a systems approach to technology and innovation policy’, *STI Review*, 22(1), 9–29.

Annoni, P. and Kozovska, K. (2010) *EU Regional Competitiveness Index*, Luxembourg: European Commission.

Archibugi, D. and Lundvall, B.-Å. (2001) *The Globalizing Learning Economy*, Oxford: Oxford University Press.

Archibugi, D., Howells, J. and Michie, J. (1999) *Innovation Systems in a Global Economy*, Cambridge: Cambridge University Press.

Asheim, B.T. (2001) ‘Learning regions as development coalitions: partnership as governance in European workfare states?’, *Concepts and Transformation*, 6(1), 73−101.

Asheim, B.T. and Coenen, L. (2005a) ‘Contextualizing regional innovation systems in a globalising learning economy: on knowledge bases and institutional frameworks’, *The Journal of Technology Transfer*, 31(1), 163–173.

Asheim, B.T. and Coenen, L. (2005b) ‘Knowledge bases and regional innovation systems: comparing Nordic clusters’, *Research Policy*, 34(8), 1173–1190.

Asheim, B.T. and Gertler, M. (2005) ‘The geography of innovation: regional innovation systems’, in Fagerberg, J., Nowery, D. and Nelson, R.R., eds., *The Oxford Handbook of Innovation*, Oxford: Oxford University Press.

Asheim, B.T. and Isaksen, A. (1997) ‘Location, agglomeration and innovation: towards regional innovation systems in Norway?’, *European Planning Studies*, 5(3), 299–330.

Audretsch, D.B. (1998) ‘Agglomeration and the location of innovative activity’, *Oxford Review of Economic Policy*, 14(2), 18–29.

Autio, E. (1998) ‘Evaluation of RTD in regional systems of innovation’, *European Planning Studies*, 6(2), 131–140.

Aydalot, P. (1986) *Milieux Innovateurs en Europe*, Paris: GREMI.

Bai, J. (2013) ‘On regional innovation efficiency: evidence from panel data of China's different provinces’, *Regional Studies*, 47(5), 773–788.

Banker, R.D., Charnes, A. and Cooper, W. W. (1984) ‘Some models for estimating technical and scale inefficiencies in data envelopment analysis’, *Management Science*, 30(9), 1078–1092.

Banker, R.D., Charnes, A., Cooper, W.W., Swarts, J. and Thomas, D.A. (1989) ‘An introduction to data envelopment analysis with some of its models and their uses’, *Research in Governmental and Nonprofit Accounting*, 5, 125–163.

Barry, F. (2005) ‘FDI, transfer pricing and the measurement of R&D intensity’, *Research Policy*, 34(5), 673–681.

Bathelt, H. (2003) ‘Geographies of production: growth regimes in spatial perspectives 1 ─ Innovation, institutions and social systems, *Progress in Human Geography*, 27(6), 789−904.

Bathelt, H., Malmberg, A. and Maskell, P. (2004) ‘Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation’, *Progress in Human Geography*, 28(1), 31–56.

Battisti, G. (2008) ‘Innovations and the economics of new technology spreading within and across users: gaps and way forward’, *Journal of Cleaner Production*, 16(1), S22–S31.

BBC news. ‘South Korea Opens 'Mini Capital' in Sejong City’, [online], available: http://www.bbc.co.uk/news/world-asia-18670195, [last accessed in April, 2014].

Bell, M. and Albu, M. (1999) ‘Knowledge systems and technological dynamism in industrial clusters in developing countries’, *World Development*, 27(9), 1715–1734.

Beneito, P. (2006) ‘The innovative performance of in-house and contracted R&D in terms of patents and utility models’, *Research Policy*, 35(4), 502–517.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) ‘Analyzing the functional dynamics of technological innovation systems: a scheme of analysis’, *Research Policy*, 37(3), 407–429.

Berger, A. and Humphrey, D. (1997) *Efficiency of financial institutions: International survey and directions for future research*, Pennsylvania: Wharton School Center for Financial Institutions.

Berkhout, A.J., Hartmann, L., van der Duin, P.A. and Ortt, J.R. (2006) 'Innovating the innovation process', *International Journal of Technology Management*, 34 (3/4), 390–404.

Betz, F. (1993) *Strategic Technology Management*, New York: McGraw-Hill.

Binz, C., Truffer, B. and Coenen, L. (2014) 'Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology', *Research Policy*, 43(1), 138–155.

Bleda, M. and del Río, P. (2013) 'The market failure and the systemic failure rationales in technological innovation systems', *Research Policy*, 42(5), 1039–1052.

Boschma, R. (2004) Competitiveness of regions from an evolutionary perspective, *Regional Studies*, 38(9), 1001−1014.

Boschma, R. and Iammarino, S. (2009) 'Related variety, trade linkages, and regional growth in Italy', *Economic geography*, 85(3), 289−311.

Bosco, M.G. and Brugnoli, A. (2010) 'Regional efficiency, innovation and productivity', *Regional Studies Association Annual International Conference*, Pécs, Hungary.

Bottazzi, G. and Dindo, P. (2013) 'Global knowledge: how technological openness affects output, spatial inequality, and welfare levels', *Journal of Regional Science*, 53(4), 631–655.

Braczyk, H.-J., Cooke, P. and Heidenreich, M. (1998) *Regional Innovation Systems: The Role of Governances in a Globalized World*, London: UCL Press.

Branstetter, L. (2006) ‘Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan’s FDI in the United States’, *Journal of International Economics*, 68(2), 325–344.

Brown, M.G. and Svenson, R.A. (1998) ‘Measuring R&D productivity’, *Research Technology Management*, 41(6), 30–35.

Budd, L. and Hirmis, A. (2004) ‘Conceptual Framework for Regional Competitiveness’, *Regional Studies*, 38(9), 1015−1028.

Buesa, M., Heijs, J. and Baumert, T. (2010) ‘The determinants of regional innovation in Europe: A combined factorial and regression knowledge production function approach’, *Research Policy*, 39(6), 722–735.

Buesa, M., Heijs, J., Pellitero, M.M. and Baumert, T. (2006) ‘Regional systems of innovation and the knowledge production function: the Spanish case’, *Technovation*, 26(4), 463–472.

Cairncross, F. (1997) *The Death of Distance*, Cambridge: Harvard Business School Press.

Caldera, A. and Debande, O. (2010) ‘Performance of Spanish universities in technology transfer: an empirical analysis’, *Research Policy*, 39(9), 1160–1173.

Camagni, R. (1991) ‘Local ‘milieu’, uncertainty and innovation networks: Towards a new dynamic theory of economic space’, in Camagni, R., Ed., *Innovation Networks: Spatial Perspectives*, London and New York: GREMI/ Belhaven Printer.

Capra, F. (1996) *The Web of Life: A New Scientific Understanding of Living Systems*, New York: Anchor Books.

Carlsson, B. and Jacobsson, S. (1997) 'In search of useful public policies: key lessons and issues for policy makers', in Carlsson, B., ed., *Technological Systems and Industrial Dynamics*, Dordrecht: Kluwer Academic Publishers.

Carlsson, B. and Stankiewicz, R. (1995) 'On the nature, function and composition of technological systems', in Carlsson, B., ed., *Technological Systems and Economic Performance: The Case of Factory Automation*, Dordrecht: Kluwer.

Carlsson, B., Jacobsson, S., Holmén, M. and Rickne, A. (2002) 'Innovation systems: Analytical and methodological issues', *Research Policy*, 31(2), 233–245.

Castellacci, F. and Natera, J.M. (2013) 'The dynamics of national innovation systems: a panel cointegration analysis of the coevolution between innovative capability and absorptive capacity', *Research Policy*, 42(3), 579–594.

Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982) 'The economic theory of index numbers and the measurement of input, output, and productivity', *Econometrica*, 50(6), 1393–1414.

Chaminade, C., Intarakumnerd, P. and Sapprasert, K. (2012) 'Measuring systemic problems in national innovation systems. An application to Thailand', *Research Policy*, 41(8), 1476–1488

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) 'Measuring the efficiency of decision making units', *European Journal of Operational Research*, 2(6), 429–444.

Charnes, A., Cooper, W.W., Lewin, A.Y. and Seiford, L.M. (1994) *Data Envelopment Analysis: Theory, Methodology, and Applications*, Boston: Kluwer.

Chen, K. and Guan, J. (2012) 'Measuring the efficiency of China's regional innovation systems: application of network data envelopment analysis (DEA)', *Regional Studies*, 46(3), 355–377.

Cherchye, L. and Abeele, P.V. (2005) 'On research efficiency: a micro-analysis of Dutch university research in economics and business management', *Research Policy*, 34(4), 495–516.

Chung, S. (2002) 'Building a national innovation system through regional innovation systems', *Technovation*, 22(8), 485–491.

Clark, G.L., Feldman, M.P. and Gertler, M.S. (2000) *The Oxford Handbook of Economic Geography*, Oxford: Oxford University Press.

Cohen, W.M. and Levinthal, D.A. (1989) 'Innovation and learning: the two faces of R&D', *The Economic Journal*, 99(397), 569–596.

Cohen, W.M., Florida, R., Randazzese, L. and Walsh, J. (1998) 'Industry and the academy: uneasy partners in the cause of technological advance', in Noll, R., ed., *Challenges to the Research University*, Washington, D.C.: Brookings Institution.

Conover, W.J. (1980) *Practical Non-Parametric Statistics*, New York: John Wiley and Sons.

Cooke, P. (1998) 'Introduction: origins of the concept', in Braczyk, H. -J., Cooke, P. and Heidenreich, M., eds., *Regional Innovation Systems*, London: UCL Press.

Cooke, P. (2001) ‘Regional innovation systems, clusters, and the knowledge economy’, *Industrial and Corporate Change*, 10(4), 945–974.

Cooke, P. and Memedovic, O. (2003) *Strategies for Regional Innovation Systems: Learning Transfer and Applications*, Vienna: United Nations Industrial Development Organisation.

Cooke, P. and Schienstock, G. (2000) ‘Structural competitiveness and learning regions’, *Enterprise and Innovation Management Studies*, 1(3), 265–280.

Cooke, P., Boekholt, P. and Tödtling, F. (2000) *The Governance of Innovation in Europe: Regional Perspectives on Global Competitiveness*, London: Pinter.

Cooke, P., Roper, S. and Wylie, P. (2001) *Developing Regional Innovation Strategy for Northern Ireland*, Belfast: Northern Ireland Economic Council.

Cooke, P., Uranga, M.G. and Etxebarria, G. (1997) ‘Regional innovation systems: institutional and organisational dimensions’, *Research Policy*, 26(4-5), 475–491.

Cooper, W., Seiford, L. and Tone, K. (2007) ‘Efficiency change over time’, in Cooper, W., Seiford, L. and Tone, K., eds., *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software*, New York: Springer Science+Business Media.

Cruz-Cázares, C., Bayona-Sáez, C. and García-Marco, T. (2013) ‘You can’t manage right what you can’t measure well: technological innovation efficiency’, *Research Policy*, 42(6-7), 1239–1250.

Dawkins, C.J. (2003) ‘Regional Development Theory: conceptual Foundations, Classic Works, and Recent Developments’, *Journal of Planning Literature*, 18(2), 131–172.

Dean, B.V. (1958) ‘Application of operations research to managerial decision making’, *Administrative Science Quarterly*, 3(3), 412–428.

Debackere, K. and Veugelers, R. (2005) ‘The role of academic technology transfer organizations in improving industry science links’, *Research Policy*, 34(3), 321–342.

Denzin, N. (2006) *Sociological Methods: A Sourcebook*, New Brunswick: Aldine Transaction.

Diez, M.A. (2001) ‘The evaluation of regional innovation and cluster policies: towards a participatory approach’, *European Planning Studies*, 9(7), 907−923.

Dijkstra, L., Annoni, P. and Kozovska, K. (2011) ‘A new regional competitiveness index: theory, methods and findings’, *European Union Regional Policy Working Papers*, n. 02/2011.

Dodgson, M., Hughes, A., Foster, J. and Metcalfe, S. (2011) ‘Systems thinking, market failure, and the development of innovation policy: the case of Australia’, *Research Policy*, 40(9), 1145–1156.

Doloreux, D. (2003) ‘Regional innovation systems in the periphery: the case of the Beauce in Quebec (Canada)’, *International Journal of Innovation Management*, 7(1), 67-94.

Doloreux, D. and Parto, S. (2004) *Regional Innovation Systems: A Critical Synthesis*, Maastricht: INTECH United Nations University, Institute for New Technologies.

Doloreux, D. and Parto, S. (2005) ‘Regional innovation systems: current discourse and unresolved issues’, *Technology in Society*, 27(2), 133–153.

Dosi, G. (1988) ‘The nature of the innovative process’, in Dosi, G, Freeman, C., Nelson, R.R, Silverberg, G. and Soete, L.L., eds., *Technical Change and Economic Theory*, London and New York, Frances Pinter.

Duke, C., Etzkowitz, H., Rhee, B. and Kitagawa, F. (2006) *Supporting the Contribution of Higher Education Institutions to Regional Development−Peer Review Report: Busan, Republic of Korea*, Paris: The Organisation for Economic Co-operation and Development.

Dvir, R. and Pasher, E. (2004) ‘Innovation engines for knowledge cities: an innovation ecology perspective’, *Journal of Knowledge Management*, 8(5), 16–27.

Dyson, R.G., Allen, R., Camanho, A.S., Podinovski, V.V., Sarrico, C.S. and Shale, E.A. (2001) ‘Pitfalls and protocols in DEA’, *European Journal of Operational Research*, 132(2), 245–259.

EC (2013) ‘European Competitiveness Report 2013: Towards Knowledge Driven Reindustrialisation’, [online], available: http://www.ivm.vu.nl/en/Images/Systematic%20instruments_tcm53-282777.pdf, [last accessed in March, 2014].

ECOS. ‘Economic Statistics System’, [online], available: http://ecos.bok.or.kr/, [last accessed in January, 2014].

Edquist, C. (1994) ‘Technology policy−The interaction between governments and markets’, in Aichholzer, G. and Schienstock, G., eds., *Technology Policy-Towards and Integration of Social and Ecological Concerns*, Berlin: Walter de Gruyter.

Edquist, C. (1997) *Systems of Innovation. Technologies, Institutions and Organizations*, London: Pinter.

Edquist, C. (2001*a*) 'Innovation policy: A systemic approach', in Archibugi, D. and Lundvall, B.-Å., eds., *The Globalizing Learning Economy*, Oxford: Oxford University Press.

Edquist, C. (2001*b*) 'Innovation systems and innovation policy: the state of the art', in *Presented in the Nelson-Winter Conference*, Aalborg, Denmark, June 12–15.

Edquist, C. and Hommen, L. (1999) 'Systems of innovation: theory and policy for the demand side', *Technology in Society*, 21(1), 63−79.

Edquist, C. and Johnson, B. (1997) 'Institutions and organizations in systems of innovation', in Edquist, C., ed., *Systems of Innovation: Technologies, Institutions and Organizations*, London: Pinter.

Edquist, C. and Lundvall, B.-Å. (1993) 'Comparing the Danish and Swedish systems of innovation', in Nelson, R.R., ed., *National Innovation Systems*, New York: Oxford University Press.

Edquist, C., Hommen, L., Johnson, B., Lemola, T., Malerba, F., Reiss, T. and Smith, K. (1998) *The ISE Policy Statement—The Innovation Policy Implications of the 'Innovations Systems and European Integration'*, Linko¨ping: Linko¨ping University.

Eom, B.-Y. and Lee. K. (2010) 'Determinants of industry–academy linkages and, their impact on firm performance: the case of Korea as a latecomer in knowledge industrialization', *Research Policy*, 39(5), 625–639.

Etzkowitz, H. (2008) *The Triple Helix: University-industry-government Innovation in Action*, New York: Routledge.

Etzkowitz, H. and Leydesdorff, L. (2000) ‘The dynamics of innovation: from national systems and “Mode 2” to a triple helix of university–industry–government relations’, *Research Policy*, 29(2), 109–123.

EU (2006) ‘Evaluating the Effectiveness of European ICT RTD and Innovation Systems’, [online], available: http://ec.europa.eu/dgs/information_society/evaluation/studies/s2005_03/index_en.htm, [last accessed in September, 2012].

EU (2012) *Regional Innovation Scoreboard 2012*, Brussels: European Union.

Evangelista, R., Iammarino, S., Mastrostefano, V. and Silvani, A. (2001) ‘Measuring the regional dimension of innovation. Lessons from the Italian innovation survey’, *Technovation*, 21(11), 733-745.

Evangelista, R., Iammarino, S., Mastrostefano, V. and Silvani, A. (2002) ‘Looking for regional systems of innovation: evidence from the Italian innovation survey’, *Regional Studies*, 36(2), 173–186.

Färe, R., Grosskopf, S., Norris, M. and Zhang, Z. (1994) ‘Productivity growth, technical progress, and efficiency change in industrialized countries’, *The American Economic Review*, 84(1), 66–83.

Feldman, M.P. (1994) *The Geography of Innovation. Economics of Science, Technology and Innovation*, Dordrecht: Kluwer Academic Publishers.

Feldman, M.P., Feller, I., Bercovitz, J. and Burton, R. (2002) ‘Equity and the technology transfer strategies of American research universities’, *Management Science*, 48(1), 105–121.

Florida, R. (1995) ‘Toward the learning region’, *Futures*, 27(5), 527–536.

Fonseca, J. (2002) *Complexity and Innovation in Organizations*, London and New York: Routledge.

Ford, D.N. and Sterman, J.D. (1998) ‘Dynamic modeling of product development processes’, *System Dynamics Review*, 14(1), 31–68.

Forrester, J.W. (1961) *Industrial Dynamics*, Cambridge: MIT Press.

Forrester, J.W. (1971) ‘Counterintuitive behavior of social systems’, *Technology Review*, 73(3), 52–68.

Forrester, J.W. (1994) ‘System dynamics, systems thinking, and soft OR’, *System Dynamics Review*, 10(2), 245–256.

Foster, L., Haltiwanger, J. and Syverson, C. (2008) ‘Reallocation, firm turnover, and efficiency: selection on productivity or profitability?’, *American Economic Review*, 98(1), 394–425.

Fowler, A. (2003) ‘Systems modelling, simulation, and the dynamics of strategy’, *Journal of Business Research*, 56(2), 135–144.

Freeman, C. (1987) *Technology Policy and Economic Performance: Lessons from Japan*, London: Printer.

Freeman, C. (1995) ‘The national system of innovation in historical perspective’, *Cambridge Journal of Economics*, 19(1), 5–24.

Frenz, M. and Ietto-Gillies, G. (2009) ‘The impact on innovation performance of different sources of knowledge: evidence from the UK Community Innovation Survey’, *Research Policy*, 38(7), 1125–1135.

Fritsch, M. (2002) 'Measuring the quality of regional innovation systems: a knowledge production function approach', *International Regional Science Review*, 25(1), 86–101.

Fritsch, M. and Franke, G. (2004) 'Innovation, regional knowledge spillovers and R&D cooperation', *Research Policy*, 33(2), 245–255.

Fritsch, M. and Slavtchev, V. (2011) 'Determinants of the efficiency of regional innovation systems', *Regional Studies*, 45(7), 905–918.

Furman, J.L., Porter, M.E. and Stern, S. (2002) 'The determinants of national innovative capacity', *Research Policy*, 31(6), 899–933.

Galanakis, K. (2006) 'Innovation process. Make sense using systems thinking', *Technovation*, 26(11), 1222–1232.

Gertler, M. and Wolfe, D. (1998) 'Dynamics of the regional innovation system in Ontario', in de la Mothe, J. and Paquet, G., eds., *Local and Regional Systems of Innovation*, Amsterdam: Kluwer Academic Publishers.

Giuliani, E. and Bell, M. (2005) 'The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster', *Research Policy*, 34(1), 47−68.

Godin, B. and Gingras, Y. (2000) 'The place of universities in the system of knowledge production', *Research Policy*, 29(2), 273–278.

Goto, A. and Suzuki, K. (1989) 'R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries', *Review of Economics and Statistics*, 71(4), 555–564.

Graham, S. (1998) ‘The end of geography or the explosion of place? Conceptualizing space’, place and information technology’, *Progress in Human Geography*, 22(2), 165–185.

Greenhut, M.L. (1956) *Plant Location in Theory and Practice*, Chapel Hill: University of North Carolina Press.

Greig, J.M. (2002) ‘The end of geography?: globalization, communications, and culture in the international system’, *Journal of Conflict Resolution*, 46(2), 225–243.

Greunz, L. (2005) ‘Intra- and Inter-regional knowledge spillovers: evidence from European regions’, *European Planning Studies*, 13(3), 449-473.

Grifell-Tatjé, E. and Lovell, C.A.K. (1995) ‘A note on the Malmquist productivity index’, *Economics Letters*, 47(2), 169–175.

Griliches, Z. (1990) ‘Patent statistics as economic indicators: a survey’, *Journal of Economic Literature*, 28(4), 1661–1707.

Grimm, V. and Railsback, S.F. (2005) *Individual-based Modeling and Ecology*, New Jersey: Princeton University Press.

Guan, J. and Chen, K. (2010) ‘Measuring the innovation production process: a cross-region empirical study of China’s high-tech innovations’, *Technovation*, 30(5-6), 348–358.

Guellec, D. and van Pottelsberghe de la Potterie, B. (2003) ‘The impact of public R&D expenditure on business R&D’, *Economics of Innovation and New Technologies*, 12(3), 225−244.

Guellec, D. and van Pottelsberghe de la Potterie, B. (2004) ‘From R&D to productivity growth: do the institutional settings and the source of funds of R&D matter?’, *Oxford Bulletin of Economics and Statistics*, 66(3), 353–378.

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010) *Multivariate Data Analysis [7th ed.]*, New Jersey: Prentice Hall.

Halseth, G., Markey, S. and Bruce, D. (2010) *The Next Rural Economies: Constructing Rural Place in a Global Economy*, Oxfordshire: Cabi Press.

Han, U., Asmild, M. and Kunc, M. (forthcoming 2015) ‘Regional R&D efficiency in Korea from static and dynamic perspectives’, *Regional Studies*, DOI:10.1080/00343404.2014.984670.

Hashimoto, A. and Haneda, S. (2008) ‘Measuring the change in R&D efficiency of the Japanese pharmaceutical industry’, *Research Policy*, 37(10), 1829–1836.

Hekkert, M.P, Negro, S., Heimeriks, G. and Harmsen, R. (2011) *Technological Innovation System Analysis: A Manual for Analysts*, Utrecht: Utrecht University, Faculty of Geoscience.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S. and Smits, R.E.H.M. (2007) ‘Functions of innovation systems: a new approach for analysing technological change’, *Technological Forecasting and Social Change*, 74(4), 413–432.

Henderson, R. and Cockburn, I. (1996) ‘Scale, scope and spillovers: the determinants of research Productivity in drug discovery’, *RAND Journal of Economics*, 27(1), 32–59.

Herstad, S.J. and Brekke, T. (2012) ‘Globalization, modes of innovation and regional knowledge diffusion infrastructures’, *European Planning Studies*, 20(10), 1603−1625.

Hessels, L.K. and van Lente, H. (2008) ‘Re-thinking new knowledge production: A literature review and a research agenda’, *Research Policy*, 37(4), 740–760.

Hollanders, H. and Celikel-Esser, F. (2007) *Measuring Innovation Efficiency*, Brussels: European Commission.

Hommen, L. and Edquist, C. (2008) 'Globalization and innovation policy', in Edquist, C. and Hommen, L., eds., *Small Country Innovation Systems: Globalization, Change and Policy in Asia and Europe*, Cheltenham: Edward Elgar.

Hoover, E. M. (1937) *Location Theory and the Shoe and Leather Industries*, Cambridge: Harvard University Press.

Howell, J. (1999) ‘Regional systems of innovation?’, in Archibugi, D., Howells, J. and Michie, J., eds., *Innovation Policy in a Global Economy*, Cambridge: Cambridge University Press.

Iammarino, S. (2011) ‘Regional innovation and diversity’, in Cooke, P., Asheim, B., Boschma, R., Martin, R., Schwartz, D. and Tödtling, F., eds., *Handbook of Regional Innovation and Growth*, Cheltenham: Edward Elgar.

Intarakumnerd, P. and Chaoroenporn, P. (2013) ‘The roles of intermediaries and the development of their capabilities in sectoral innovation systems: a case study of Thailand’, *Asian Journal of Technology Innovation*, 21(2), 99−114.

Iona, A., Leonida, L. and Battisti, G. (2008), ‘The relationship between innovation and firm performance: evidence from semi-parametric approaches’, *Review of Economics and Statistics*, 90(1), 168−174.

Isaksen, A. (2001) ‘Building regional innovation systems: is endogenous industrial development possible in the global economy?’, *Canadian Journal of Regional Science*, 24(1), 101–120.

Isard, W. (1956) *Location and Space-economy: A General Theory relating to Industrial Location, Market Areas, Land Use, Trade, and Urban Structure*, New York: Wiley.

Jackson, M.C. (2003) *System Thinking: Creative Holism for Managers*, Chichester: John Wiley and Sons.

Jervis, R. (1997) *System Effects: Complexity in Political and Social Life*, New Jersey: Princeton University Press.

Jiménez-Sáez, F., Zabala-Iturriagagoitia, J.M., Zofío, J.L. and Castro-Martínez, E. (2011) ‘Evaluating research efficiency within national R&D programmes’, *Research Policy,* 40(2), 230–241.

Johnson, A. (1998) *Functions in Innovation System Approaches*, Unpublished working paper, Göteborg: Department of Industrial Dynamics, Chalmers University of Technology.

Johnson, B. and Gregersen, B. (1995) ‘System of innovation and economic integration’, *Journal of Industry Studies*, 2(2), 1–18.

Juma, C. (2012) ‘Innovation and the Wealth of Regions’, Technology+Policy [online], available: http://www.technologyandpolicy.org/2012/03/14/innovation-and-the-wealth-of-regions/#.UXAJLrWsiSo [last accessed in April, 2013].

Juniper, J. (2007) ‘Rethinking regional innovation schemes’, in *State of Australian Cities National Conference*, Adelaide, Australia, 28-30 November, 380–396.

Katz, J.S. (2006) ‘Indicators for complex innovation systems’, *Research Policy*, 35(7), 893–909.

Kessler, E.H. and Chakrabarti, A.K. (1996) ‘Innovation speed: a conceptual model of context, antecedents, and outcomes’, *The Academy of Management Review*, 21(4), 1143–1191.

Kim, D.-H. and Kim, D.H. (1997) ‘A system dynamics model for a mixed-strategy game between police and driver’, *System Dynamics Review*, 13(1), 33–52.

KIPO. 'Korean Intellectual Property Office', [online], available: http://www.kipo.go.kr, [last accessed in December, 2013].

Kitson,M., Martin, R. and Tyler, P. (2004) ‘Regional Competitiveness: an Elusive yet Key Concept?’, *Regional Studie*s, 38(9), 991−999.

Koga, T. (2003) ‘Firm size and R&D tax incentives’, *Technovation*, 23(7), 643−648.

KOSIS. ‘Korean Statistical Information Service’, [online], available: http://kosis.kr/, [last accessed in April, 2014].

Krugman, P. (1991) *Geography and Trade*, Cambridge: MIT Press.

Krugman, P. (2003) *Second Winds for Industrial Regions, The Allander Series: Growth on the Periphery*, Fraser of Allander Institute, University of Strathclyde, 9–44.

Kunc, M. (2010) ‘Revisiting Poter's generic strategies using system dynamics: When taking book's recipes conduces your organization to dysfunctional behavior in a competitive environment’, in Mollona, E., ed., *Computational Analysis of Firms' Organization and Strategic Behavior*, New York: Routledge.

Kwon, K.S., Park, H.W., So, M. and Leydesdorff, L. (2012) ‘Has globalization strengthened South Korea’s national research system? National and international dynamics of the triple helix of scientific co-authorship relationships in South Korea', *Scientometrics*, 90(1), 163–176.

Lach, S. (2002) 'Do R&D subsidies stimulate or displace private R&D? Evidence from Israel', *Journal of Industrial Economics*, 50(4), 369−390.

Lars, S. (2006) *General Systems Theory: Problems, Perspective, Practice*, New Jersey: World Scientific Publishing Company.

Latouche, D. (1998) 'Do regions make a difference? The case of science and technology policies in Quebec', in Braczyk, H.-J., Cooke, P. and Heidenreich, M., eds., *Regional Innovation Systems: The Role of Governances in a Globalized World*, London: UCL Press.

Lee, E., Oh, J.-Y. and Pines, E. (2008) 'Practical Managerial Decision Making Tools: Operations Research', *Journal of Applied Business and Economics*, 8(2), 11–18.

Lee, J.H. (2009) 'Korean regional innovation strategies: Focused on the Gumi mobile cluster', Presented in *UN APCTT workshop on Fostering Innovation through Strengthening of Hi-Tech Clusters*, 9–10 November 2009, Hanoi.

Lee, T.-L. and von Tunzelmann, N. (2005) 'A dynamic analytic approach to national innovation systems: the IC industry in Taiwan', *Research Policy*, 34(4), 425–440.

Leydesdorff, L. and Fritsch, M. (2006) 'Measuring the knowledge base of regional innovation systems in Germany in terms of a Triple Helix dynamics', *Research Policy*, 35(10), 1538–1553.

Leydesdorff, L. and Meyer, M. (2006) ‘Triple helix indicators of knowledge-based innovation systems: introduction to the special issue’, *Research Policy*, 35(10), 1441–1449.

Leydesdorff, L., Dolfsma, W. and van der Panne, G. (2006) ‘Measuring the knowledge base of an economy in terms of triple-helix relations among ‘technology, organization, and territory’. *Research Policy*, 35(2), 181–199.

Lietz, C. A., Langer, C. and Furman, R. (2006) ‘Establishing trustworthiness in social work research: implications from a study regarding spirituality’, *Qualitative Social Work*, 5(4), 441–458.

Lim, J.D. (2000) ‘The restructuring of Pusan’s economy under the current economic crisis’, *Asian Geographer*, 19(1/2), 107–118.

Lissoni, F. (2001) ‘Knowledge codification and the geography of innovation: the case of Brescia mechanical cluster’, *Research Policy*, 30(9), 1479–1500.

Lopolito, A., Morone, P. and Taylor, R. (2013) ‘Emerging innovation niches: an agent based model’, *Research Policy*, 42(6-7), 1225–1238.

Lucas, R.E. (1988) ‘On the mechanics of development planning’, *Journal of Monetary Economics*, 22(1), 3–42.

Lundvall, B.-Å. (1992) *National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning*, London: Pinter.

Lundvall, B.-Å. and Borrás, S. (2005) ‘Science, technology, innovation and knowledge policy’, in Fagerberg, J., Mowery, D. and Nelson, R., eds., *The Oxford Handbook of Innovation*, Oxford: Oxford University Press.

Lundvall, B.-Å.and Johnson, B. (1994) ‘The learning economy’, *Industrial Studies*, 1(2), 23–42.

Maier, F.H. (1998) ‘New product diffusion models in innovation management: a system dynamics perspective’, *System Dynamics Review*, 14(4), 285–308.

Malecki, E. (2004) ‘Jockeying for position: what it means and why it matters to regional development policy when places compete’, *Regional Studies*, 38(9), 1101−1120.

Malecki, E.J. and Oinas, P. (1999) *Making Connections: Technological Learning and Regional Economic Change*, Aldershot: Ashgate.

Malerba, F. (1997) ‘Public policy and industrial dynamics: an evolutionary perspective’, in Edquist, C., ed., *Systems of Innovation: Technologies, Institutions and Organizations*, London: Cassel.

Malmberg, A. and Maskell, P. (1997) ‘Towards an explanation of regional specialization and industrial agglomeration’, *European Planning Studies*, 5(1), 25–41.

Malmquist, S. (1953) ‘Index numbers and indifference surfaces’, *Trabajos de Estadística y de Investigación Operativa*, 4(2), 209–242.

Mandinach, E. and Cline, H. (1994) *Classroom Dynamics: Implementing a Technology-based Learning Environment*, Hillsdale: Erlbaum.

March, J.G. (1991) ‘Exploration and exploitation in organizational learning’, *Organization Science*, 2(1), 71–87.

Marcus, A.A. (1981) ‘Policy uncertainty and technological innovation’, *The Academy of Management Review*, 6(3), 443–448.

Markusen, A. (1987) *Regions: The Economics and Politics of Territory*, Totowa: Rowman and Littlefield.

Marshall, A. [1890] (1961) *Principles of Economics: An Introductory Volume [9th ed.]*, London: Macmillan.

Meadows, D.H. (1980) 'The unavoidable a priori', in Randers, J., ed., *Elements of the System Dynamics Method*, Massachusetts: The MIT Press.

MEST (2010*a*) *Regional S&T Yearbook* [in Korean], Seoul: The Ministry of Education, Science and Technology.

MEST (2010*b*) *Survey of national R&D programmes in Korea* [in Korean], Seoul: The Ministry of Education, Science and Technology.

Metcalfe, J.S. (1995) 'Technology systems and technology policy in an evolutionary framework', *Cambridge Journal of Economics*, 19(1), 25–46.

Metcalfe, J.S. (2005) 'Systems failure and the case for innovation policy', in Matt, M., Llerena, P. and Avadikyan, A., eds., *Innovation Policy in a Knowledge-based Economy: Theory and Practice*, Berlin: Springer.

Meyer, M., Siniläinen, T. and Utecht, J.T. (2003) 'Towards hybrid triple helix indicators: a study of university-related patents and a survey of inventors', *Scientometrics*, 58(2), 321–350.

Meyer-Krahmer, F. (1990) 'Innovationsorientierte regionalpolitik: Ansatz, instrumente, grenzen', in Gramaztki, H.E., Klinger, F. and Nutzinger, H.G., eds., *Wissenschaft, Technik und Arbeit: Innovationen in Ost und West*, Kassel: DeutscherInstitutsVerlag.

Meyer-Stamer, J. (2008) 'Systematic Competitiveness and Local Economic Development', in Bodhanya, S., ed., *Large Scale Systemic Change: Theories, Modelling and Practices*, Duisburg.

Milling, P.M. (2002) ‘Understanding and managing innovation processes’, *System Dynamics Review*, 18(1), 73–86.

Morecroft, J. (2007) *Strategic Modelling and Business Dynamics: A Feedback Systems Approach*, Chichester: John Wiley and Sons.

Morgan, K. (2004) ‘Sustainable regions: Governance, innovation and scale’, *European Planning Studies*, 12(6), 871−889.

Morgan, K. and Nauwelaers, C. (1998) Regional Innovation Strategies: The Challenge for Less Favoured Regions, London: Jessica Kingsley.

Moser, P. (2005) ‘How Do Patent Laws Influence Innovation? Evidence from Nineteenth-Century World's Fairs’, *The American Economic Review*, 95(4), 1214−1236.

MoST *a*, *Regional S&T Yearbook* [in Korean], Seoul: The Ministry of Science and Technology.

MoST *b*, Interviews with two government officials from the Ministry of Science and Technology, in January 2013.

Moulaert, F. and Sekia, F. (2003) ‘Territorial innovation models: a critical survey’, *Regional studies*, 37(3), 289−302.

Muller, E. and Zenker, A. (2001) ‘Business services as actors of knowledge transformation: the role of KIBS in regional and national innovation systems’, *Research Policy*, 30(9), 1501–1516.

Müller, K. (2010) ‘Academic spin-off’s transfer speed—Analyzing the time from leaving university to venture’, *Research Policy*, 39(2), 189–199.

Murmann, J.P. and Frenken, K. (2006) ‘Toward a systematic framework for research on dominant designs, technological innovations, and industrial change’, *Research Policy*, 35(7), 925–952.

Nelson, A.J. (2009) ‘Measuring knowledge spillovers: what patents, licenses and publications reveal about innovation diffusion’, *Research Policy*, 38(6), 994–1005.

Nelson, R.R. (1992) ‘National innovation systems: a retrospective on a study’, *Industrial and Corporate Change*, 1(2), 347–374.

Nelson, R.R. (1993) *National Innovation Systems: A Comparative Analysis*, New York: Oxford University Press.

Nelson, R.R. and Rosenberg, N. (1993) ‘Technological innovation and national systems’, in Nelson, R.R., ed., *National Innovation Systems: a Comparative Analysis*, Oxford: Oxford University Press.

Nelson, R.R. and Winter, S.G. (1982) *An Evolutionary Theory of Economic Change*, Cambridge: Harvard University Press.

Niosi, J. (2010) *Building National and Regional Innovation Systems: Institutions for Economic Development*, Cheltenham: Edward Elgar.

Nonaka, I., Toyama, R. Konno, N. (2000) ‘SECI, ba and leadership: a unified model of dynamic knowledge creation’, *Long Range Planning*, 33(1), 5–34.

North, D.C. (1955) ‘Location theory and regional economic growth’, *The Journal of Political Economy*, 63(3), 243−258.

NTIS. ‘National Science and Technology Information Service’, [online], available: http://www.ntis.go.kr, [last accessed in December, 2013].

O’Brien, F.A. (2004) ‘Scenario planning ─ Lessons for practice from teaching and learning’, *European Journal of Operational Research*, 152(3), 709–722.

O’Brien, R. (1992) *Global Financial Integration: The End of Geography*, New York: Council on Foreign Relations Press.

OECD (1993) *Frascati Manual, Proposed Standard Practice for Surveys of Research and Experimental Development*, Paris: The Organisation for Economic Co-operation and Development.

OECD (1996) *The Knowledge-based Economy*, Paris: The Organisation for Economic Co-operation and Development.

OECD (1997) *National Innovation Systems*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2000) *The Impact of Public R&D Expenditure on Business R&D*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2002) *Frascati Manual methodology*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2006) *Government R&D Funding and Company Behaviour: Measuring Behavioural Additionality*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2008) *OECD Reviews of Regional Innovation: North of England, UK*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2009) *OECD Reviews of Innovation Policy: Korea*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2010) *OECD Territorial Reviews: Guangdong, China 2010*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2011) *OECD Reviews of Regional Innovation: Regions and Innovation Policy*, Paris: The Organisation for Economic Co-operation and Development.

OECD (2012) *OECD Science, Technology and Industry Outlook*, Paris: The Organisation for Economic Co-operation and Development.

OECD Statistics. 'Innovation Indicators', [online], available: http://stats.oecd.org/Index.aspx?datasetcode=REG_DEMO_TL2, [last accessed in March, 2014].

OECD STI e-Outlook. 'The STI country profile of Korea', [online], available: http://www.oecd.org/sti/outlook/e-outlook/sticountryprofiles/korea.htm, [last accessed in June, 2014].

Oh, W.-C. (1996) *The Building of Korean type Economy* [in Korean], Seoul: Kia Economic Research Institute.

Ohmae, K. (1990) *The Borderless World: Power and Strategy in the Interlinked Economy*, London: Collins.

Ohmae, K. (1995) *The End of the Nation-State: The Rise of Regional Economies*, New York: The Free Press.

Olof, E. and Urban, G. (2008) *The Effects of R&D on Regional Invention and Innovation*, Paper no. 2008/03, Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE), Lund University.

Owen-Smith, J. and Powell, W.W. (2001) 'To patent or not: faculty decisions and institutional success at technology transfer', *Journal of Technology Transfer*, 26(1-2), 99–114.

Park, G., Shin, J. and Park, Y. (2006) ‘Measurement of depreciation rate of technological knowledge: technology cycle time approach’, *Journal of Scientific and Industrial Research*, 65(2), 121−127.

Park, H.W. and Leydesdorff, L. (2010) ‘Longitudinal trends in networks of university-industry-government relations in South Korea: the role of programmatic incentives’, *Research Policy*, 39(5), 640–649.

Park, H.W., Hong, H.D. and Leydesdorff, L. (2005) ‘A comparison of the knowledge-based innovation systems in the economies of South Korea and the Netherlands using Triple Helix indicators’, *Scientometrics*, 65(1), 3–27.

Park, S.O. (2001) ‘Regional innovation strategies in the knowledge-based economy’, *GeoJournal*, 53(1), 29–38.

Park, S.O. (2007) 'Regional innovation and cluster policies in Korea', Presented in *Korea-France Workshop on Science & Technology Policies*, 20 September 2007.

Patrick, L. 2002. ‘The economics of knowledge production: funding and structure of university research’, *Research Policy,* 31(4), 654–655.

Piore, M.J. and Sabel, C.F. (1984) *The Second Industrial Divide: Possibilities for Prosperity*, New York: Basic Books.

Platt, J. (1992) ‘“Case study” in American methodological thought’, *Current Sociology*, 40(1), 17−48.

Podinovski, V.V. and Thanassoulis, E. (2007) ‘Improving discrimination in data envelopment analysis: some practical suggestions’, *Journal of Productivity Analysis*, 28(1), 117–126.

Polt, W. and Rojo, J. (2002) ‘Policy instruments’, in Fahrenkrog, G., Polt, W., Rojo, J., Tübke, A. and Zinöcker, K., eds., *RTD Evaluation Toolbox: Assessing the Socio-Economic Impact of RTD-Policies, IPTS Technical Report Series*, Sevilla: European Commission.

Popp, D. (2005) ‘Lessons from patents: using patents to measure technological change in environmental models’, *Ecological Economics*, 54(2-3), 209–226.

Porter, M.E. (1980) *Competitive Strategy*, New York: Free Press.

Porter, M.E. (1990) *The Competitive Advantage of Nations*, New York: Free Press.

Porter, M.E. (1992) *Competitive Advantage: Creating and Sustaining Superior Performance*, London: PA Consulting Group.

Porter, M.E. (1996) ‘Competitive advantage, agglomeration economies and regional policy’, *International Regional Science Review*, 19(1), 85–94.

Porter, M.E. (1998*a*) ‘Clusters and the new economics of competition’, *Harvard Business Review*, 76(6), 77–90.

Porter, M.E. (1998*b*) *On competition. Boston*, Cambridge: Harvard Business School Press.

Porter, M.E. (2003) ‘The economic performance of regions’, *Regional Studies*, 37(6), 545–546.

Porter, M.E. (2006) ‘Q&A with Michael Porter’, Bloomberg Businessweek [online], available: http://www.businessweek.com/magazine/content/06_34/b3998460.htm, [last accessed 14 January 2011].

Ragin, C.C. and Becker, H.S. (1992) *What is a Case? Exploring the Foundations of Social Inquiry*, Cambridge: Cambridge University Press.

Raines, P. (2002) ‘Clusters and prisms’, in Raines, P., ed., *Cluster Development and Policy*, Aldershot: Ashgate.

Ranga, M. and Etzkowitz, H. (2013) ‘Triple helix systems: an analytical framework for innovation policy and practice in the knowledge society’, *Industry and Higher Education,* 27(4), 237–262.

Richardson, G.P. (2011) ‘Reflections on the foundations of system dynamics’, *System Dynamics Review*, 27(3), 219–243.

Rickne, A. (2001) ‘Regional characteristics and performance: evidence from biomaterials firms’, in Carlsson, B., ed., *New Technological Systems in the Bio Industries*, Boston: Kluwer Academic Publishers.

Roessner, D. (2000) ‘Technology transfer’, in Hill, C.T., ed., *Science and Technology Policy in the US, A Time of Change*, London: Longman.

Romer, P.M. (1986) ‘Increasing returns and long-run growth’, *Journal of Political Economy*, 94(5), 1002–1037.

Rosell, C. and Agrawal, A. (2009) ‘Have university knowledge flows narrowed?: evidence from patent data’, *Research Policy*, 38(1), 1–13.

Sarkar, S. (2007) *Innovation, Market Archetype and Outcome: An Integrated Framework*, New York: Physica-Verlag.

Särndal, C.E., Swensson, B. and Wretman, J. (1992) *Model Assisted Survey Sampling*, New York: Springer-Verlag.

Sastry, M.A. (1997) ‘Problems and paradoxes in a model of punctuated organizational change’, *Administrative Science Quarterly*, 42(2), 237–275.

Saxenian, A. (1994) *Regional Advantage: Culture and competition in Silicon Valley and Route 128*, Cambridge: Harvard University Press.

SCBRI (2005) ‘Arrangement and restructure of theories for regional industry vitalisation – A mechanism of new industry creation in a region [in Japanese]’, *Regional Survey Information*, 17(1), Tokyo: Shinkin Central Bank Research Institute.

Scherer, F.M. (2001) ‘The link between gross profitability and the pharmaceutical R&D spending’, *Health Affairs*, 20(5), 216−220.

Schumpeter, J.A. (1934) *The Theory of Economic Development*. London: Oxford University Press.

Schumpeter, J.A. (1975) *Capitalism, Socialism and Democracy*, New York: Harper Torchbooks.

Scott, A.J. (1988) *New Industrial Spaces: Flexible Production Organization and Regional Development in North America and Western Europe*, London: Pion.

Scott, W.R. (1995) *Institutions and Organisations*, California: Sage.

Seidman, I, (1998) *Interviewing as Qualitative Research: A Guide for Researchers in Education and the Social Sciences*, New York: Teachers College Press.

Shane, S. (2004) *Academic Entrepreneurship: University Spinoffs and Wealth Creation*, Cheltenham: Edward Elgar.

Shapiro, M. (2007) ‘The triple helix paradigm in Korea: a test for new forms of capital’, *International Journal of Technology Management and Sustainable Development*, 6(3), 171–191.

Sherman, H.D. (1985) ‘Bank branch operating efficiency: evaluation with data envelopment analysis’, *Journal of Banking and Finance*, 9(2), 297–315.

Simar, L. and Wilson, P. (2000) ‘Statistical inference in nonparametric frontier models: the state of the art’, *Journal of Productivity Analysis*, 13(1), 49–78.

Simmie, J. (2001) *Innovation cities*, London: Spon Press.

Simmie, J. (2003) ‘Innovation and urban regions as national and international nodes for the transfer and sharing of knowledge’, *Regional Studies*, 37(6-7), 607–620.

SMBA, interviews with two government officials from the Small and Medium Business Administration, in January 2013.

Smith, B.L.R. and Barfield, C.E. (1996) *Technology, R&D, and the Economy*, Washington DC: The Brookings Institution.

Smith, K. (2000) ‘Innovation as a systemic phenomenon: rethinking the role of policy’, *Enterprise and Innovation Management Studies*, 1(1), 73–102.

Smits, R. and Kuhlmann, S. (2004) ‘The rise of systemic instruments in innovation policy’, *International Journal of Foresight and Innovation Policy*, 1(1-2), 4–32.

Smolny, W. (1998) ‘Innovations, prices and Employment: a theoretical model and an empirical application for West German manufacturing firms’, *Journal of Industrial Economics*, 46(3), 359−381.

Solow, R.M. (1957) ‘Technical change and the aggregate production function’, *The Review of Economics and Statistics*’, 39(3), 312–320.

Statistics Korea website. ‘Stastics Korea’, [online], available: Statistics Korea http://www.kostat.go.kr/eng/, [last accessed in October, 2011].

STEPI. *Report on the Korean Innovation Survey: Manufacturing Sector and Service Sector* [in Korean], Seoul: Science and Technology Policy Institute.

Sterman, J.D. (2000) *Business Dynamics: Systems Thinking and Modeling for a Complex World*, New York: Irwin/McGraw-Hill.

Stoneman, P. (1983) *The Economic Analysis of Technological Change*, Oxford: Oxford University Press.

Storper, M. (1997) *The Regional World – Territorial Development in a Global Economy*, London: Guilford Press.

Storper, M. and Scott, A.J. (1988) ‘The geographical foundations and social regulation of flexible production complexes’, in Wolch, J. and Dear, M., eds., *The Power of Geography*, London: Allen and Unwin.

Storper, M. and Scott, A.J. (2003) ‘Regions, globalization, development’, *Regional Studies*, 37(6-7), 579−593.

Ström, P. and Nelson, R. (2010) ‘Dynamic regional competitiveness in the creative economy: can peripheral communities have a place?’, *The Service Industries Journal*, 30(4), 497−511.

Suchman, E. (1967) *Evaluative Research: Principles and Practice in Public Service and Social Action Program*, New York: Russell Sage.

Suh, J.H. (2009) ‘Development strategy and evolution of Korea’s innovation system’, in Suh, J.H., ed., *Models for National Technology and Innovation Capacity Development in Turkey*, Seoul: Korea Development Institute, Korea Ministry of Strategy and Finance.

Tank-Nielsen, T. (1980) ‘Sensitivity analysis in system dynamics’, in Randers, J., ed., *Elements of the System Dynamics Method*, Massachusetts: The MIT Press.

Teece, D.J., Pisano, G. and Shuen, A. (1997) ‘Dynamic capabilities and strategic management’, *Strategic Management Journal*, 18(7), 509−533.

Tether, B. S. (1998) ‘Small and large firms: sources of unequal innovations?’, *Research Policy*, 27(7), 725−745.

Theil, H. (1966) *Applied Economic Forecasting*, Amsterdam: North Holland.

Thursby, J.G. and Kemp, S. (2002) ‘Growth and productive efficiency of university intellectual property licensing’, *Research Policy*, 31(1), 109–124.

Tödtling, F. and Trippl, M. (2005) ‘One size fits all? Towards a differentiated regional innovation policy approach’, *Research Policy*, 34(8), 1203–1219.

Trappey, A. J. C. and Chiang, T.-A. (2008) ‘A DEA benchmarking methodology for project planning and management of new product development under decentralized profit-center business model’, *Advanced Engineering Informatics*, 22(4), 438–444.

Tsao, J.Y., Boyack, K.W., Coltrin, M.E., Turnley, J.G. and Gauster, W.B. (2008) ‘Galileo's stream: a framework for understanding knowledge production’, *Research Policy*, 37(2), 330–352.

Turok, I. (2004) ‘Cities, regions and competitiveness’, *Regional Studies*, 38(9), 1069−1083.

van der Duin, P. Ortt, R. and Kok, M. (2007) ‘The cyclic innovation model: a new challenge for a regional approach to innovation systems?’, *European Planning Studies*, (15)2, 195–215.

van der Wal, S., Scheffer, M. and Thonon, I. (2007) *Exploring Successful Regional Innovation Systems in Europe*, The Hague: Technopolicy Network.

van Geenhuizen, M. and Soetanto, D.P. (2008) ‘Science parks: what they are and how they need to be evaluated’, *International Journal of Foresight and Innovation Policy*, 4(1-2), 90−111.

van Geenhuizen, M. and Soetanto, D.P. (2009) ‘Academic spin-offs at different ages: a case study in search of key obstacles to growth’, *Technovation*, 29(10), 671−681.

Vedovello, C. (1997) ‘Science parks and university-industry interaction: geographical proximity between the agents as a driving force’, *Technovation*, 17(9), 491–502, 530-531.

Wang, E.C. and Huang, W. (2007) ‘Relative efficiency of R&D activities: a cross-country study accounting for environmental factors in the DEA approach’, *Research Policy*, 36(2), 260–273.

Weber, A. (1929) *Theory of the Location of Industries*, Chicago: University of Chicago Press.

Weber, M.K. and Rohracher, H. (2012) ‘Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive ‘failures’ framework’, *Research Policy*, 41(6), 1037−1047.

Weck, M. and Blomqvist, K. (2008) ‘The role of inter-organizational relationships in the development of patents: a knowledge-based approach’, *Research Policy*, 37(8), 1329–1336.

Weiss, R.S. (1994) *Learning from Strangers: The Art and Method of Qualitative Interview Studies*, New York: Free Press.

Wiig, H. (1995) *An Empirical Study of the Innovation System in Finnmark*, Oslo: STEP-Group.

Woolthuis, R.K., Lankhuizen, M. and Gilsing, V. (2005) ‘A system failure framework for innovation policy design’, *Technovation*, 25(6), 609–619.

Yam, R.C.M., Lo, W., Tang, E.P.Y. and Lau, A.K.W. (2011) ‘Analysis of sources of innovation, technological innovation capabilities, and performance: an empirical study of Hong Kong manufacturing industries’, *Research Policy*, 40(3), 391–402.

Zabala-Iturriagagoitia, J.M., Voigt, P., Gutiérrez-Gracia, A. and Jiménez-Sáez, F. (2007) ‘Regional innovation systems: how to assess performance’, *Regional Studies,* 41(5), 661–672.

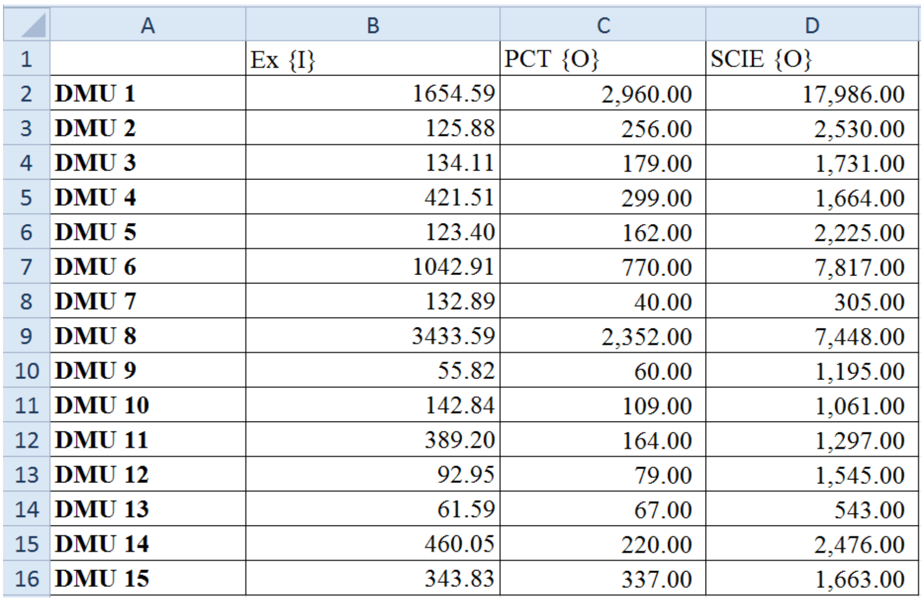
Zhang, Y. and Li, H.Y. (2010) ‘Innovation search of new ventures in a technology cluster: the roles of ties with service intermediaries’, *Strategic Management Journal*, 31(1), 88–109.

Zhu, J. (2009) ‘Super efficiency’, in Zhu, J., ed., *Quantitative Models for Performance Evaluation and Benchmarking: Data Envelopment Analysis with Spreadsheets*, New York: Springer.

APPENDIX A. SCREENSHOTS IN THE REGIONAL R&D EFFICIENCY EVALUATION (PAPER 1)

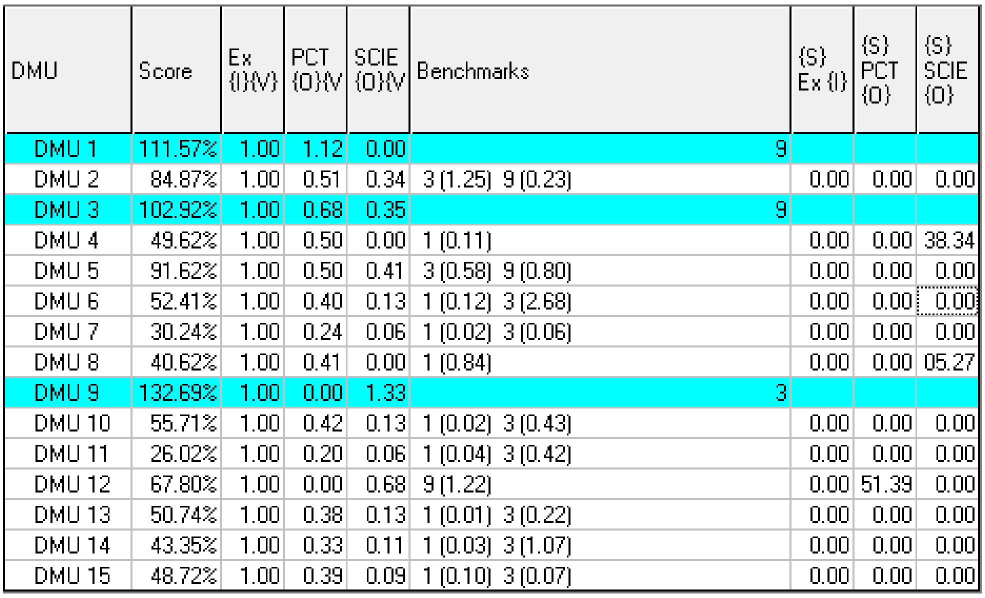
A.1. Static R&D efficiency (super-efficiency)

A.1.1. Data in Microsoft Excel



	A	B	C	D
1		Ex {I}	PCT {O}	SCIE {O}
2	**DMU 1**	1654.59	2,960.00	17,986.00
3	**DMU 2**	125.88	256.00	2,530.00
4	**DMU 3**	134.11	179.00	1,731.00
5	**DMU 4**	421.51	299.00	1,664.00
6	**DMU 5**	123.40	162.00	2,225.00
7	**DMU 6**	1042.91	770.00	7,817.00
8	**DMU 7**	132.89	40.00	305.00
9	**DMU 8**	3433.59	2,352.00	7,448.00
10	**DMU 9**	55.82	60.00	1,195.00
11	**DMU 10**	142.84	109.00	1,061.00
12	**DMU 11**	389.20	164.00	1,297.00
13	**DMU 12**	92.95	79.00	1,545.00
14	**DMU 13**	61.59	67.00	543.00
15	**DMU 14**	460.05	220.00	2,476.00
16	**DMU 15**	343.83	337.00	1,663.00

A.1.2. Results in Efficiency Measurement System (EMS)[25]



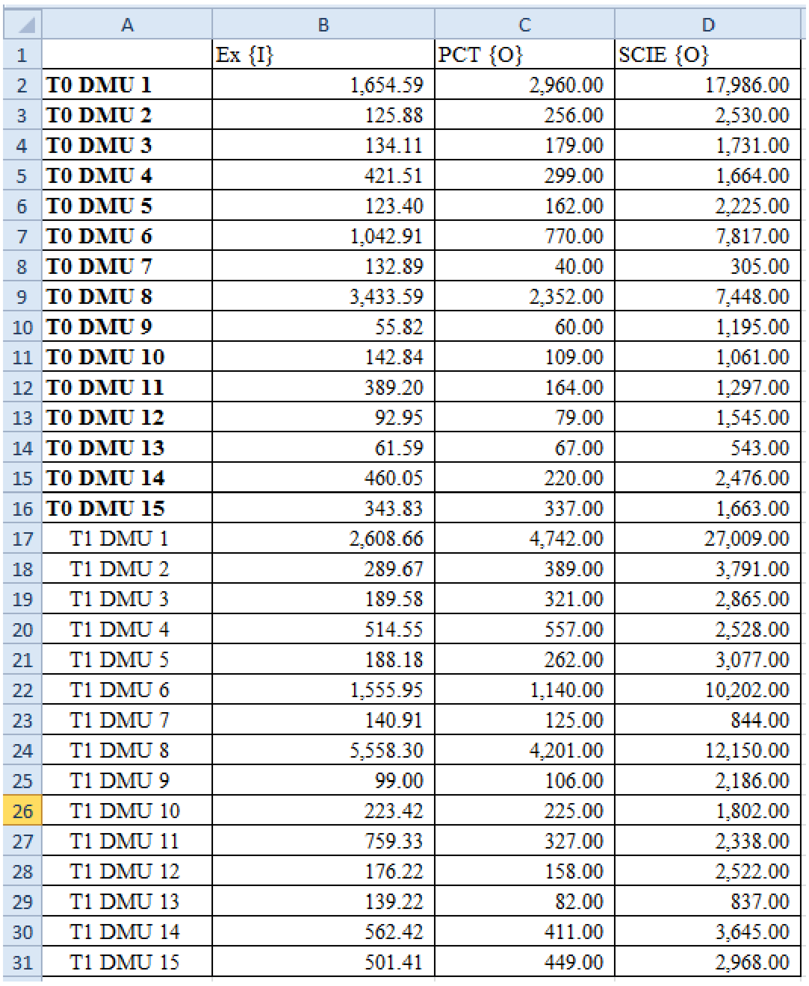
DMU	Score	Ex {I}{V}	PCT {O}{V	SCIE {O}{V	Benchmarks	{S} Ex {I}	{S} PCT {O}	{S} SCIE {O}
DMU 1	111.57%	1.00	1.12	0.00	9			
DMU 2	84.87%	1.00	0.51	0.34	3 (1.25) 9 (0.23)	0.00	0.00	0.00
DMU 3	102.92%	1.00	0.68	0.35	9			
DMU 4	49.62%	1.00	0.50	0.00	1 (0.11)	0.00	0.00	38.34
DMU 5	91.62%	1.00	0.50	0.41	3 (0.58) 9 (0.80)	0.00	0.00	0.00
DMU 6	52.41%	1.00	0.40	0.13	1 (0.12) 3 (2.68)	0.00	0.00	0.00
DMU 7	30.24%	1.00	0.24	0.06	1 (0.02) 3 (0.06)	0.00	0.00	0.00
DMU 8	40.62%	1.00	0.41	0.00	1 (0.84)	0.00	0.00	05.27
DMU 9	132.69%	1.00	0.00	1.33	3			
DMU 10	55.71%	1.00	0.42	0.13	1 (0.02) 3 (0.43)	0.00	0.00	0.00
DMU 11	26.02%	1.00	0.20	0.06	1 (0.04) 3 (0.42)	0.00	0.00	0.00
DMU 12	67.80%	1.00	0.00	0.68	9 (1.22)	0.00	51.39	0.00
DMU 13	50.74%	1.00	0.38	0.13	1 (0.01) 3 (0.22)	0.00	0.00	0.00
DMU 14	43.35%	1.00	0.33	0.11	1 (0.03) 3 (1.07)	0.00	0.00	0.00
DMU 15	48.72%	1.00	0.39	0.09	1 (0.10) 3 (0.07)	0.00	0.00	0.00

---

[25] For details, see ‘EMS: Efficiency Measurement System User’s Manual’ (http://www.scheel-online.de/ems/ems.pdf). For the results, see Table 6 in Chapter 3.

A.2. Dynamic R&D efficiency (productivty change)

A.2.1. Data in Microsoft Excel

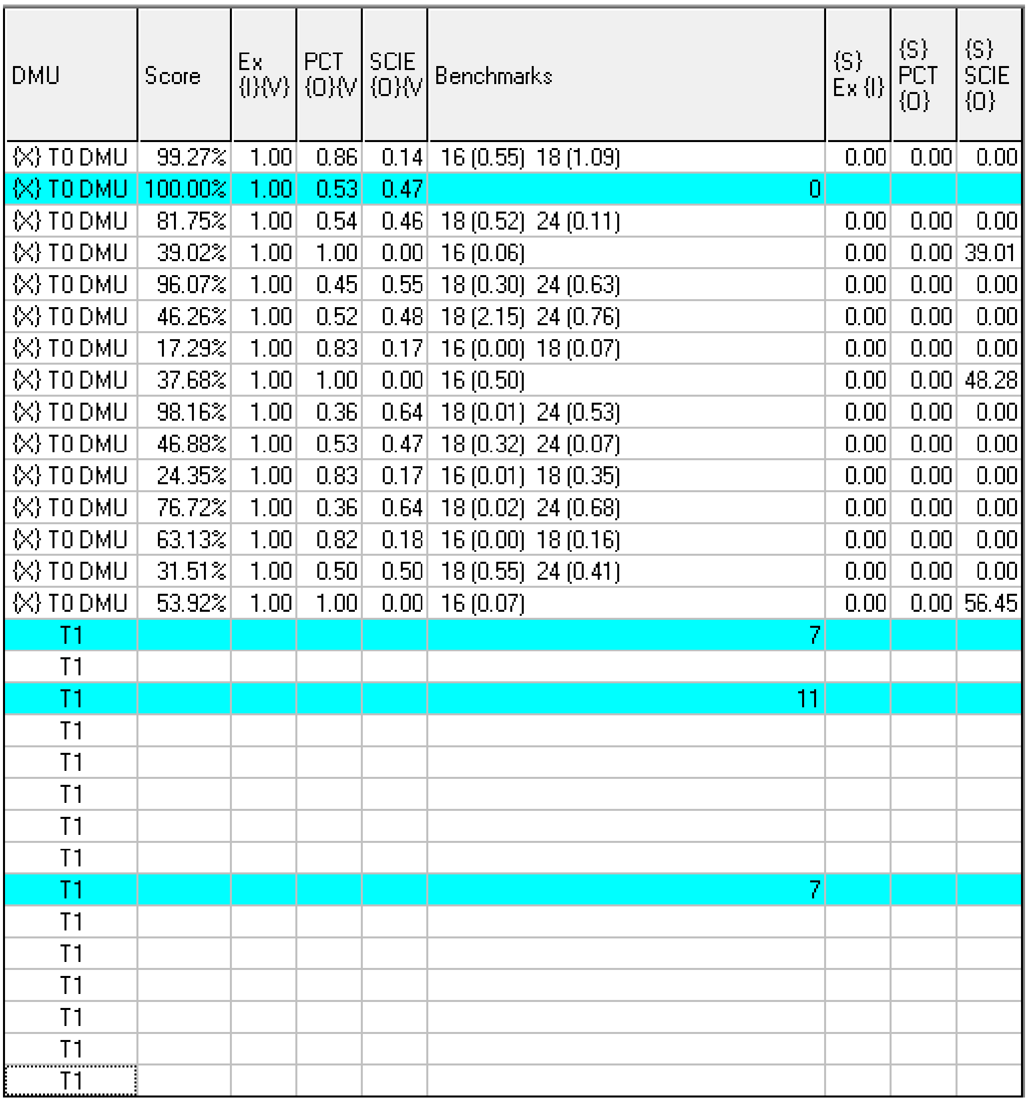


	A	B	C	D
1		Ex {I}	PCT {O}	SCIE {O}
2	**T0 DMU 1**	1,654.59	2,960.00	17,986.00
3	**T0 DMU 2**	125.88	256.00	2,530.00
4	**T0 DMU 3**	134.11	179.00	1,731.00
5	**T0 DMU 4**	421.51	299.00	1,664.00
6	**T0 DMU 5**	123.40	162.00	2,225.00
7	**T0 DMU 6**	1,042.91	770.00	7,817.00
8	**T0 DMU 7**	132.89	40.00	305.00
9	**T0 DMU 8**	3,433.59	2,352.00	7,448.00
10	**T0 DMU 9**	55.82	60.00	1,195.00
11	**T0 DMU 10**	142.84	109.00	1,061.00
12	**T0 DMU 11**	389.20	164.00	1,297.00
13	**T0 DMU 12**	92.95	79.00	1,545.00
14	**T0 DMU 13**	61.59	67.00	543.00
15	**T0 DMU 14**	460.05	220.00	2,476.00
16	**T0 DMU 15**	343.83	337.00	1,663.00
17	T1 DMU 1	2,608.66	4,742.00	27,009.00
18	T1 DMU 2	289.67	389.00	3,791.00
19	T1 DMU 3	189.58	321.00	2,865.00
20	T1 DMU 4	514.55	557.00	2,528.00
21	T1 DMU 5	188.18	262.00	3,077.00
22	T1 DMU 6	1,555.95	1,140.00	10,202.00
23	T1 DMU 7	140.91	125.00	844.00
24	T1 DMU 8	5,558.30	4,201.00	12,150.00
25	T1 DMU 9	99.00	106.00	2,186.00
26	T1 DMU 10	223.42	225.00	1,802.00
27	T1 DMU 11	759.33	327.00	2,338.00
28	T1 DMU 12	176.22	158.00	2,522.00
29	T1 DMU 13	139.22	82.00	837.00
30	T1 DMU 14	562.42	411.00	3,645.00
31	T1 DMU 15	501.41	449.00	2,968.00

A.2.2. Results in EMS

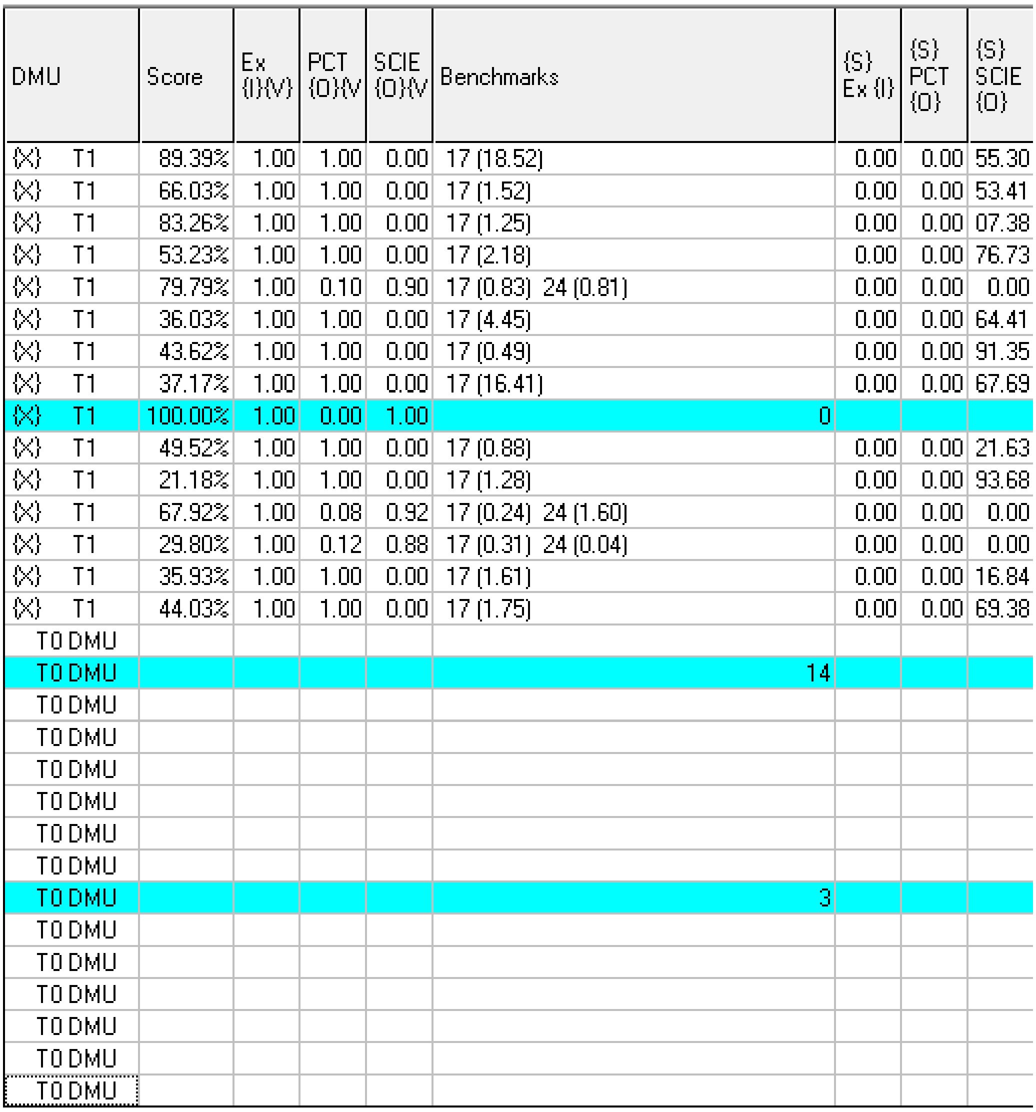
To estimate the time-dependent R&D productivity changes, five steps are necessary.

A.2.2.1. Malmquist-Index yields 1 / D1(x0,y0)



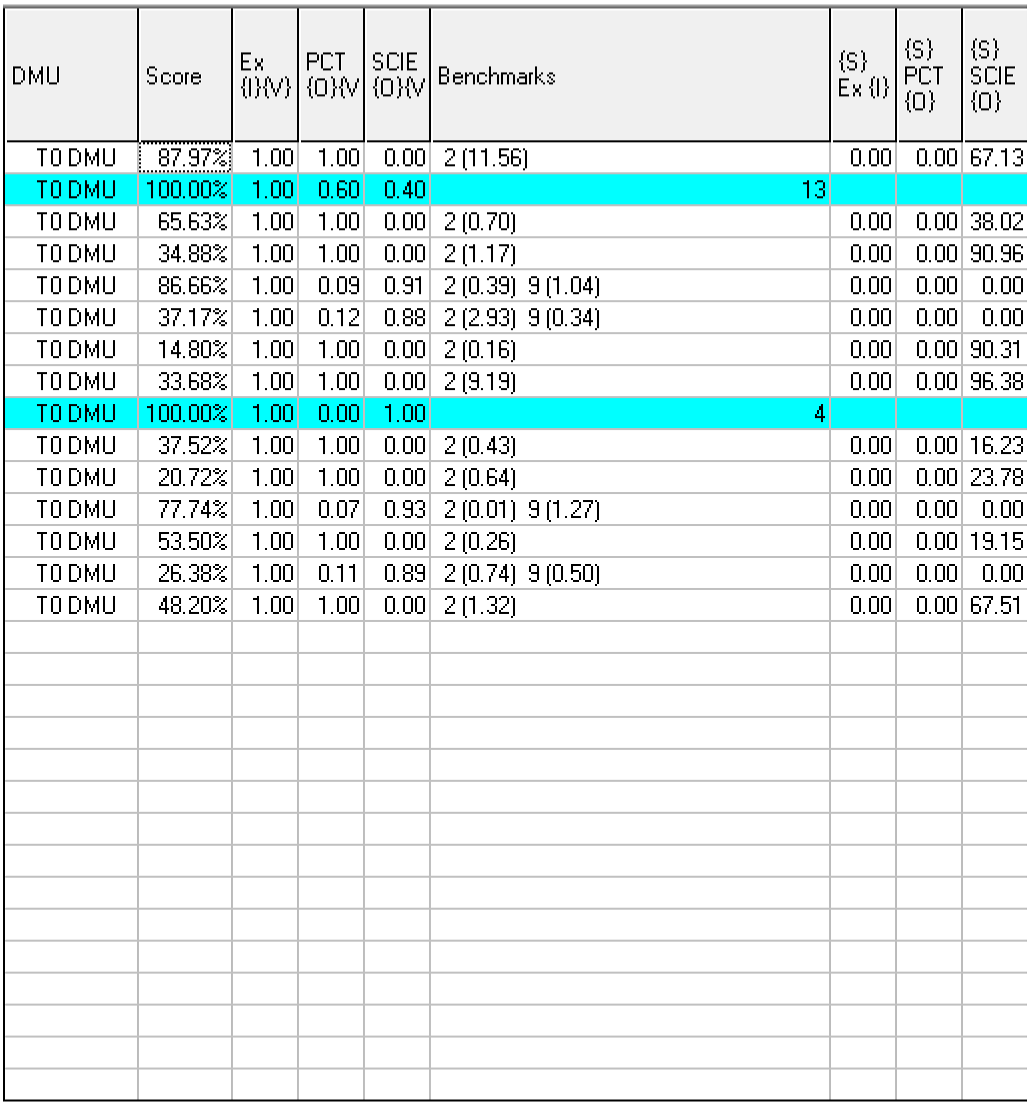
DMU	Score	Ex {I}{V}	PCT {O}{V	SCIE {O}{V	Benchmarks	{S} Ex {I}	{S} PCT {O}	{S} SCIE {O}
{X} T0 DMU	99.27%	1.00	0.86	0.14	16 (0.55) 18 (1.09)	0.00	0.00	0.00
{X} T0 DMU	100.00%	1.00	0.53	0.47	0			
{X} T0 DMU	81.75%	1.00	0.54	0.46	18 (0.52) 24 (0.11)	0.00	0.00	0.00
{X} T0 DMU	39.02%	1.00	1.00	0.00	16 (0.06)	0.00	0.00	39.01
{X} T0 DMU	96.07%	1.00	0.45	0.55	18 (0.30) 24 (0.63)	0.00	0.00	0.00
{X} T0 DMU	46.26%	1.00	0.52	0.48	18 (2.15) 24 (0.76)	0.00	0.00	0.00
{X} T0 DMU	17.29%	1.00	0.83	0.17	16 (0.00) 18 (0.07)	0.00	0.00	0.00
{X} T0 DMU	37.68%	1.00	1.00	0.00	16 (0.50)	0.00	0.00	48.28
{X} T0 DMU	98.16%	1.00	0.36	0.64	18 (0.01) 24 (0.53)	0.00	0.00	0.00
{X} T0 DMU	46.88%	1.00	0.53	0.47	18 (0.32) 24 (0.07)	0.00	0.00	0.00
{X} T0 DMU	24.35%	1.00	0.83	0.17	16 (0.01) 18 (0.35)	0.00	0.00	0.00
{X} T0 DMU	76.72%	1.00	0.36	0.64	18 (0.02) 24 (0.68)	0.00	0.00	0.00
{X} T0 DMU	63.13%	1.00	0.82	0.18	16 (0.00) 18 (0.16)	0.00	0.00	0.00
{X} T0 DMU	31.51%	1.00	0.50	0.50	18 (0.55) 24 (0.41)	0.00	0.00	0.00
{X} T0 DMU	53.92%	1.00	1.00	0.00	16 (0.07)	0.00	0.00	56.45
T1					7			
T1								
T1					11			
T1								
T1								
T1								
T1								
T1								
T1					7			
T1								
T1								
T1								
T1								
T1								
T1								

A.2.2.2. Resort the Data such that now T1 comes before T0 (Malmquist-Index with this order yields 1 / D0(x1,y1))



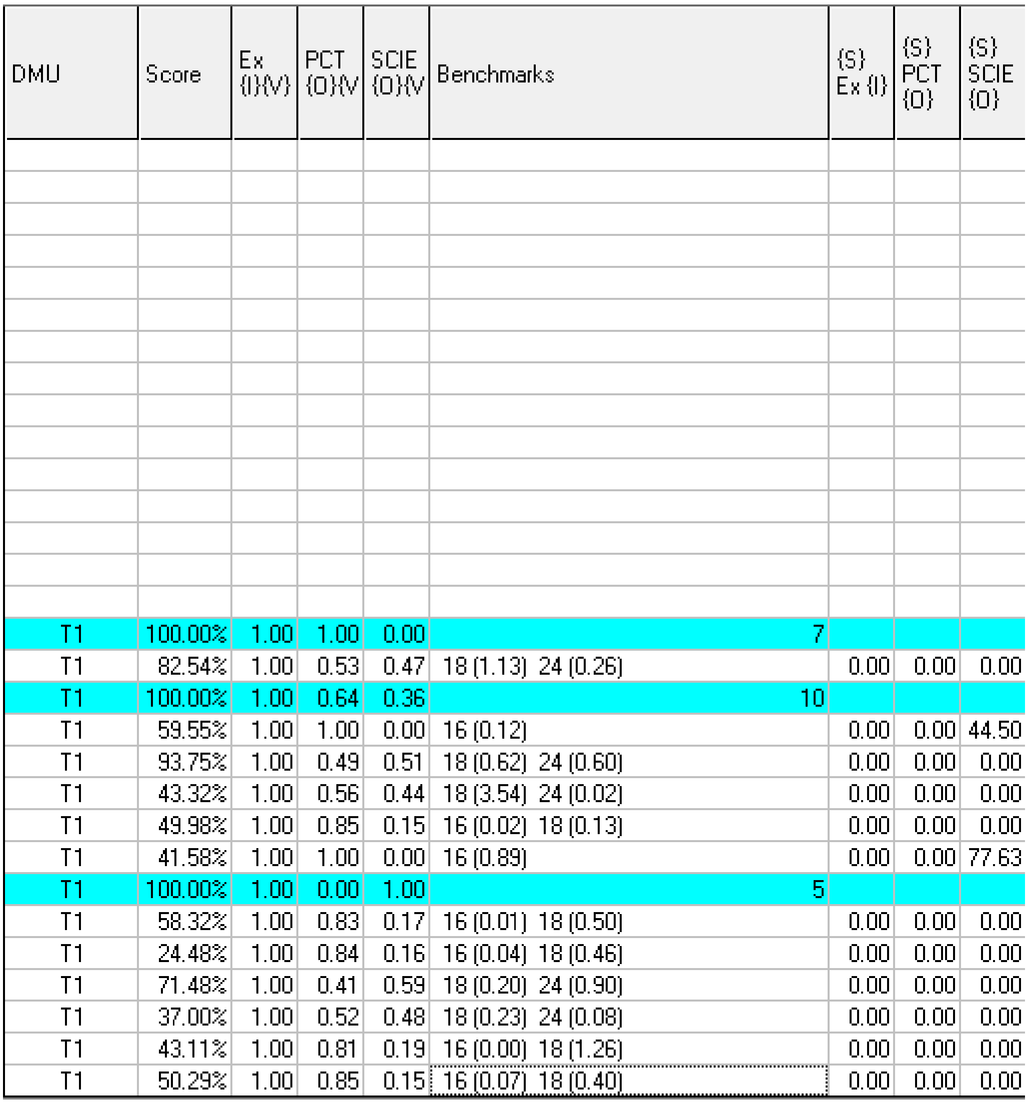
DMU	Score	Ex {I}{V}	PCT {O}{V	SCIE {O}{V	Benchmarks	{S} Ex {I}	{S} PCT {O}	{S} SCIE {O}
{X} T1	89.39%	1.00	1.00	0.00	17 (18.52)	0.00	0.00	55.30
{X} T1	66.03%	1.00	1.00	0.00	17 (1.52)	0.00	0.00	53.41
{X} T1	83.26%	1.00	1.00	0.00	17 (1.25)	0.00	0.00	07.38
{X} T1	53.23%	1.00	1.00	0.00	17 (2.18)	0.00	0.00	76.73
{X} T1	79.79%	1.00	0.10	0.90	17 (0.83) 24 (0.81)	0.00	0.00	0.00
{X} T1	36.03%	1.00	1.00	0.00	17 (4.45)	0.00	0.00	64.41
{X} T1	43.62%	1.00	1.00	0.00	17 (0.49)	0.00	0.00	91.35
{X} T1	37.17%	1.00	1.00	0.00	17 (16.41)	0.00	0.00	67.69
{X} T1	100.00%	1.00	0.00	1.00	0			
{X} T1	49.52%	1.00	1.00	0.00	17 (0.88)	0.00	0.00	21.63
{X} T1	21.18%	1.00	1.00	0.00	17 (1.28)	0.00	0.00	93.68
{X} T1	67.92%	1.00	0.08	0.92	17 (0.24) 24 (1.60)	0.00	0.00	0.00
{X} T1	29.80%	1.00	0.12	0.88	17 (0.31) 24 (0.04)	0.00	0.00	0.00
{X} T1	35.93%	1.00	1.00	0.00	17 (1.61)	0.00	0.00	16.84
{X} T1	44.03%	1.00	1.00	0.00	17 (1.75)	0.00	0.00	69.38
T0 DMU								
T0 DMU					14			
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU					3			
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU								
T0 DMU								

A.2.2.3.Window Analysis with window-width=1 yields 1 / D0(x0,y0)



DMU	Score	Ex {I}{V}	PCT {O}{V	SCIE {O}{V	Benchmarks	{S} Ex {I}	{S} PCT {O}	{S} SCIE {O}
T0 DMU	87.97%	1.00	1.00	0.00	2 (11.56)	0.00	0.00	67.13
T0 DMU	100.00%	1.00	0.60	0.40	13			
T0 DMU	65.63%	1.00	1.00	0.00	2 (0.70)	0.00	0.00	38.02
T0 DMU	34.88%	1.00	1.00	0.00	2 (1.17)	0.00	0.00	90.96
T0 DMU	86.66%	1.00	0.09	0.91	2 (0.39) 9 (1.04)	0.00	0.00	0.00
T0 DMU	37.17%	1.00	0.12	0.88	2 (2.93) 9 (0.34)	0.00	0.00	0.00
T0 DMU	14.80%	1.00	1.00	0.00	2 (0.16)	0.00	0.00	90.31
T0 DMU	33.68%	1.00	1.00	0.00	2 (9.19)	0.00	0.00	96.38
T0 DMU	100.00%	1.00	0.00	1.00	4			
T0 DMU	37.52%	1.00	1.00	0.00	2 (0.43)	0.00	0.00	16.23
T0 DMU	20.72%	1.00	1.00	0.00	2 (0.64)	0.00	0.00	23.78
T0 DMU	77.74%	1.00	0.07	0.93	2 (0.01) 9 (1.27)	0.00	0.00	0.00
T0 DMU	53.50%	1.00	1.00	0.00	2 (0.26)	0.00	0.00	19.15
T0 DMU	26.38%	1.00	0.11	0.89	2 (0.74) 9 (0.50)	0.00	0.00	0.00
T0 DMU	48.20%	1.00	1.00	0.00	2 (1.32)	0.00	0.00	67.51

A.2.2.4.Window Analysis with window-width=1 yields 1 / D1(x1,y1)



DMU	Score	Ex {I}{V}	PCT {O}{V	SCIE {O}{V	Benchmarks	{S} Ex {I}	{S} PCT {O}	{S} SCIE {O}
T1	100.00%	1.00	1.00	0.00	7			
T1	82.54%	1.00	0.53	0.47	18 (1.13) 24 (0.26)	0.00	0.00	0.00
T1	100.00%	1.00	0.64	0.36	10			
T1	59.55%	1.00	1.00	0.00	16 (0.12)	0.00	0.00	44.50
T1	93.75%	1.00	0.49	0.51	18 (0.62) 24 (0.60)	0.00	0.00	0.00
T1	43.32%	1.00	0.56	0.44	18 (3.54) 24 (0.02)	0.00	0.00	0.00
T1	49.98%	1.00	0.85	0.15	16 (0.02) 18 (0.13)	0.00	0.00	0.00
T1	41.58%	1.00	1.00	0.00	16 (0.89)	0.00	0.00	77.63
T1	100.00%	1.00	0.00	1.00	5			
T1	58.32%	1.00	0.83	0.17	16 (0.01) 18 (0.50)	0.00	0.00	0.00
T1	24.48%	1.00	0.84	0.16	16 (0.04) 18 (0.46)	0.00	0.00	0.00
T1	71.48%	1.00	0.41	0.59	18 (0.20) 24 (0.90)	0.00	0.00	0.00
T1	37.00%	1.00	0.52	0.48	18 (0.23) 24 (0.08)	0.00	0.00	0.00
T1	43.11%	1.00	0.81	0.19	16 (0.00) 18 (1.26)	0.00	0.00	0.00
T1	50.29%	1.00	0.85	0.15	16 (0.07) 18 (0.40)	0.00	0.00	0.00

A.2.2.5. Manual computation (or a selfmade Excel macro) yields Malmquist productivity index[26]

- Malmqusit productivity index = Square root of $[(\frac{1}{1/\mathrm{D0(x1,y1)}} / \frac{1}{1/\mathrm{D0(x0,y0)}}) * (\frac{1}{1/\mathrm{D1(x1,y1)}} / \frac{1}{1/\mathrm{D1(x0,y0)}})]$
- Technical efficiency change = $(\frac{1}{1/\mathrm{D1(x1,y1)}})/(\frac{1}{1/\mathrm{D0(x0,y0)}})$
- Technical change = $[\left\{\frac{\frac{1}{1/\mathrm{D0(x1,y1)}}}{\frac{1}{1/\mathrm{D1(x1,y1)}}}\right\} * \left\{\frac{\frac{1}{1/\mathrm{D0(x0,y0)}}}{\frac{1}{1/\mathrm{D1(x0,y0)}}}\right\}]^{1/2}$

---

[26] For the results, see Table 7 in Chapter 3.

APPENDIX B. KEY QUESTIONS IN EXPERT INTERVIEWS (PAPER 2)

B.1. Brief information about the interviews

- Schedule: January – March 2013
- Location: Korea
- Interviewees: 33 researchers, practitioners, and government officials (For details about the interview participants, see Table 11 in Chapter 4)
- Approach:
    - Multi-round interviews ─ Initiation, revision, and confirmation
    - Multi-angled interviews ─ Same questions to different, neighbouring respondents

B.2. Questions used in the interviews

The following tables contain interview questions that were only used in order to describe the knowledge-based, triple helix model used in Korea. To complement insufficient explanations gained from these core questions, more open-ended questions were asked. The key questions are as follows:

Missions	
Education	• Are there academic degree curriculums for scientists and engineers (in universities, industries, and government research institutes)? • If so, how are the programmes operated? • What are the graduates' career paths (to universities, industries, or government research institutes)?
R&D	• What factors (information and materials) trigger R&D? • What are the sources of R&D funds (government, public research institutes, and/or internal funds)? • How is the funding process operated internally and externally? • How is the demand and supply system of research manpower operated? • How are R&D processes operated? • What factors are essential to complete R&D projects? • Who has ownership of intellectual properties (research results) in cases of outsourcing, collaboration, and in-house R&D (researchers, organisations, or clients)? • If researchers want to keep intellectual properties, what do they have to do and how is the formal/informal process operated? • Are R&D processes affected by knowledge obsolescence (positively and negatively)? If so, what factors trigger knowledge obsolescence? • What are the motives to continue R&D investment and what are the criteria used to make a decision to increase or decrease R&D investment?
Business	• What factors are essential to complete product/process innovation projects? • How are product/process innovations operated? • Between product innovation and process innovation, are there significant time delays at a macro level? Are the two types of innovations independent or dependent? If independent (dependent), how are the two conducted separately (together)? • What are the channels (product/ process innovations, spin-offs, technology transfers, etc.) for making money in the marketplace? • What are profit sources for industrial firms (innovations, marketing, existing and new products/services, etc.)?

Hybrid organisation	
Technology transfer office	• What is the process of transferring technologies (patents)? • What are the roles of technology transfer offices (technology inflow and outflow, etc.)? • Which organisations are the recipients of technology transfers (universities, industries, government research institutes, spin-offs, etc.)? • Can researchers hire external technology transfer agencies? • Are there technology transfers between universities and between government research institutes? • Can R&D organisations (or researchers) still use the sold technological knowledge (e.g. patents) for their successive R&D? If not, does it mean that the sellers do not have legal rights to use the knowledge? If they do not retain the rights, what do they have to do for successive R&D? • For technology transfers and to operate technology transfer offices, what is the profit structure based on?
Incubator	• What is the process for establishing incubators? • What are the roles of incubators in formulating spin-off firms? • What are motives (or deterrents) for establishing and expanding incubators (successful/failed spin-offs, institutional support, etc.)? • What are distinct (similar) characteristics of incubators compared to other similar types of agglomerations such as science parks? • What is the profit structure (rental fee, etc.) that is needed in order to operate incubators?
Spin-off	• What factors trigger spin-off formulation (R&D, funds, individual willingness, etc.)? • What is the purpose of establishing spin-offs? • What is the process of formulating spin-offs? • What are the funding sources for formulating and running spin-offs (in-house funds, venture capitalists, etc.)? • Do researchers have to quit their original position to run their own spin-offs?

	• What is the process for technology transfers when formulating spin-off firms? • Who has ownership of technological knowledge that is transferred to spin-off firms (former organisations or spin-off firms)? • Do established spin-off firms have their own knowledge channels apart from the original sources from former organisations? • Where are the locations of the spin-off firms (incubators, science parks, etc.)? • Do spin-offs have sustainable profit structures to keep running their business (and continue R&D)? If so, how is the process operated?
Venture capitalist	• What are the roles/purposes of venture capitalists? • What is the process of establishing venture capitalists? • What types of venture capitalists exist (private, public, etc.)? • What factors make venture capitalists want to keep investing in new business? • When a company that is sponsored by a venture capitalist fails in its business, what does the venture capitalist do to handle the failed company? • What profit structure do venture capitalists use in order to operate?

APPENDIX C. EQUATIONS IN THE SYSTEM DYNAMICS MODEL (PAPER 3)

(1) Knowledge Development

Equation and comment	Unit [data source]
PRDE=[(2007,0)-(2011,1)],(2007,0.47),(2008,0.298),(2009,0.247),(2010,0.284),(2011,0.481)	Hmw/Hmw [KOSIS]
PRDE is the profit effect on R&D expenditure, which is measured by the ratio of the amount of R&D expenditure to the amount of profits. Profits represent financial capacity for conducting R&D projects. This lookup relates profits (TP) in year *t -1* to R&D expenditure (RDE) in year *t*.	
RDE(t)= TP(t-1)*PRDE	Hmw/Year
RDE is the amount of R&D expenditure. This represents the product of profits in year *t -1* (TP) and the profit effect on R&D expenditure (PRDE).	
RDERC=[(2003,-0.6)-(2011,1)],(2003,0.504),(2004,-0.522),(2005,0.102),(2006,0.11),(2007,0.239),(2008,0.527),(2009,-0.03),(2010,0.261),(2011,0.165)	Head/Hmw [KOSIS]
RDERC is the investment effect on researcher change, which is measured by the ratio of a chage in the number of researchers to the amount of R&D expenditure. R&D expenditure facilitates researcher participation in R&D projects. This lookup converts R&D expenditure (RDE) to the change in researchers (CR).	
CR(t)=RDE(t)*RDERC	Head/Year
CR is a change in the number of researchers. This value depends on R&D expenditure (RDE) with the investment effect on researcher change (RDERC).	
$R(t)= R(0)+\int_0^t CR(s)ds$, R(0)=13610	Head
R is the stock of researchers. The research manpower accumulates by the change in researchers (CR) over time. The initial number given by R(0) is 13610.	
RDDR=[(2003,0)-(2011,1)],(2003,0.146),(2004,0.19),(2005,0.175),(2006,0.278),(2007,0.352),(2008,0.237),(2009,0.262),(2010,0.243),(2011,0.244)	Project/Head/Year [KOSIS; NTIS]

RDDR is the R&D density per researcher. This value refers to the degree of D projects conducted by a single researcher. This lookup relates researchers (R) to new R&D projects (NRD).

NRD(t)=R(t)*RDDR Project/Year

NRD is the number of new R&D projects. This value depends on the number of available researchers (R) with the R&D density per researcher (RDDR).

RDP=1.76 Year [KOSIS; MoST *a*]

RDP is the R&D period. This factor determines the frequency of completed R&D projects (CRD), assumed to be 1.76 years.

RDSR=0.738 Dmnl [KOSIS; MoST *a*; NTIS]

RDSR is the R&D success rate. This factor affects the frequency of completed R&D projects (CRD), assumed to be 0.738.

CRD(t)= RDProject(t)*RDSR/RDP Project/Year

CRD is the number of completed R&D projects. This value is the product of R&D stock (RDProject) and R&D success rate (RDSR) divided by R&D period (RDP).

RDProject(t)= RDProject(0)+$\int_0^t [\mathrm{NRD}(s) - \mathrm{CRD}(s)]ds$, RDProject(0)=2510 Project

RDProject is the stock of R&D projects, which represents the aggregated difference between the number of new R&D projects (NRD) and the number of completed R&D projects (CRD) over time. The initial number given by RDProject(0) is 2510.

RDPD=[(2003,0)-(2011,2)],(2003,1.931),(2004,1.322), (2004,1.509),(2006,1.224),(2007,1.199),(2008,1.087), (2009,1.107),(2010,0.934),(2011,0.936) Patent/Project [KIPO; KOSIS]

RDPD is R&D productivity, which represents the number of patents over the number of completed R&D projects (CRD). This lookup relates completed R&D projects (CRD) to new knowledge (NK).

NK(t)=CRD*RDPD Patent/Year

NK is the amount of new knowledge, which represents the average number of new patents produced by a sinlge R&D project. This value is the result of multiplying the number of completed R&D projects (CRD) by the average productivity of individual R&D projects (RDPD).

KL=5.62 Year [STEPI]

KL is the average lifespan of knowledge, assumed to be 5.62 years.

DK(t)=KNOW(t)/KL Patent/Year

DK is the amount of depreciated knowledge (DK), which represents the result of dividing knowledge stock (KNOW) by the knowledge lifespan (KL).

KNOW(t)= KNOW(0)+$\int_0^t [\mathrm{NK}(s) - \mathrm{DK}(s)]ds$, KNOW(0)=4965 Patent

KNOW represents the aggregated difference between the amount of new knowledge (i.e. new patents, NK) and the amount of depreciated knowledge (i.e. depreciated patents, DK) over time. The initial amount given by KNOW(0) is 4965.

(2) Knowledge Diffusion

NPKinOR(t)=NPKinOR(0)+$\int_0^t [\mathrm{NPKinOR}(s)]ds$, Patent/Year [KIPO]

NPKinOR(0)=11300; $\mathrm{NPUKinOR}(s)$=730

NPKinOR is the amount of knowledge (patents) newly produced outside Busan. For simplification, the simulation model represents the yearly mean of increased values ($\mathrm{NPKinOR}(s)$=730) and the initial value (NPKinOR(0)=11300) that composes the amount of new public and university knowledge in other regions (NPKinOR).

KLinOR=5.58 Year [STEPI]

KLinOR is the average lifespan of knowledge (patents) produced outside Busan, assumed to be 5.58 years.

DPKinOR(t)= PKinOR(t)/KLinOR Patent/Year

DPKinOR is the amount of depreciated public and university knowledge (patents) produced outside Busan. This value is calculated by dividing the existing knowledge stock held outside Busan (PKinOR) by lifespan of knowledge produced outside Busan (KLinOR).

PKinOR(t)= PKinOR(0)+$\int_0^t [\mathrm{NPKinOR}(s) - \mathrm{DPKinOR}(s)]ds$, Patent

PKinOR(0)=41404

PKinOR is the stock of public and university knowledge outside Busan. This value is the aggregated difference between the amount of new public and university knowledge produced outside Busan (NPKinOR) and the depreciated amount of knowledge produced outside Busan (DPKinOR) over time. The initial stock given by PKinOR(0) is 41404.

PKtoTK=0.128 Dmnl [KIPO]

PKtoTK is the ratio of the amount of public and university knoweldge to the total mount of knowledge. The public and university sectors provide 12.8% (PKtoTK) of knowledge sources for industrial product/process innovation projects on a national scale.

TTR=0.259 Dmnl [KOSIS]

TTR is technology transfer rate, assumed to be 25.9%.

KRP=0.057 Dmnl [KOSIS]

KRP is the size of knowledge recipient pool. This refers to the ratio of the number of innovating firms localised within Busan relative to the number of innovating firms located outside Busan. This value determines the frequency of technology transfers from the public and university sectors to localised industries in Busan. The average value is 0.057.

InterRTT(t)=PKinOR(t)*TTR*KRP Patent/Year

InterRTT is the amount of interregional technology transfers. This value depends on the amount of public and university knowledge produced outside Busan (PKinOR), the degree of public-industry and university-industry technology transfer rate in Busan (TTR), and the extent of the knowledge recipient pool of Busan (KRP).

IntraRTT(t)=KNOW(t)*PKtoTK*TTR*KRP Patent/Year

IntraRTT is the amount of intraregional technology transfers. This value depends on knowledge stock produced in Busan (KNOW), the ratio of the amount of public and university knowledge to total amount of knowledge produced in Busan (PKtoTK), with the technology transfer rate attached to Busan (TTR) and the extent of the knowledge recipient pool of Busan (KRP).

(3) Knowledge Implementation

IKtoTK=0.872 Dmnl [KIPO]

IKtoTK is the amount of industrial knowledge attached to Busan, which accounts for 87.2% of total knowledge.

IK(t)=InterRTT(t)+IntraRTT(t)+KNOW(t)*IKtoTK Patent/Year

IK is the amount of industrial knowledge. This value is the aggregated public and university knowledge transferred to Busan's industries (IntraRTT and InterRTT) and the amount of knowledge produced in the industry sector calculated by multiplying knowledge stock (KNOW) by the ratio of the amount of industrial knowledge to the total amount of knowledge in Busan (IKtoTK).

PDIR= 0.846 Dmnl [STEPI]

PDIR is the product innovation rate, assumed to be 0.846.

IKNPDI=[(2003,0)-(2011,1)],(2003,0.232),(2004,0.233),(2005,0.152),(2006,0.263),(2007,0.316),(2008,0.188),(2009,0.196),(2010,0.166),(2011,0.164) Project/Patent [KIPO; KOSIS; MoST *a*; NTIS]

IKNPDI refers to the usability of industrial knowledge for new product innovation conducted in Busan. This value represents the number of new product innovation projects conducted based on single industry knowledge. This lookup relates the amount of industrial knowledge (IK) to the number of new product innovations (NPDI).

NPDI(t)=IK(t)*PDIR*IKNPDI Project/Year

NPDI is the number of product innovations. This vale is determined by industrial knowledge (IK), the product innovation rate (PDIR), and the usability of industrial knowledge for new product innovation (IKNPDI).

IP=0.620 Year [KOSIS]

IP is the innovation period, which represents the speed of market launch of new or improved products and/or services. It proximates 0.620 on average.

ISR=0.357 Dmnl [KOSIS]

ISR is the innovation success rate, whichrepresents the possibility of market launch of new or improved products and/or services. The average value is 0.357.

CPDI(t)=PDI(t)*ISR/IP Project/Year

CPDI is the number of completed product innovations. This value represents the product of product innovation stock (PDI) and the innovation success rate (ISR) divided by innovation period (IP).

PDI(t)=PDI(0)+$\int_0^t [\mathrm{NPDI}(s) - \mathrm{CPDI}(s)]ds$, PDI(0)=1153 Project

PDI is product innovation stock. This value represents the aggregated difference between the number of new product innovations (NPDI) and the number of completed product innovations (CPDI) over time. The initial value given by PDI(0) is 1153.

PCIR=1−PDIR Dmnl [STEPI]

PCIR is process innovation rate. This value determines process innovation efforts in the industry sector. Because the sum of the product innovation rate (PDIR) and process innovation rate is 1, this value is the result of subtracting product innovation rate (PDIR) from 1.

IKNPCI=[(2003,0)-(2011,1)],(2003,0.232),(2004,0.233),(2005,0.152),(2006,0.263),(2007,0.316),(2008,0.188),(2009,0.196),(2010,0.166),(2011,0.164) Project/Patent [KIPO; KOSIS; MoST *a*; NTIS]

IKNPCI is the usability of industrial knowledge for new process innovation conducted in Busan. This value represents the number of new process innovation projects conducted based on single industry knowledge. This lookup relates the amount of industrial knowledge (IK) to the number of new process innovations (NPCI).

NPCI(t)=IK(t)*PCIR*IKNPCI Project/Year

NPCI is the number of new process innovations. This value depends on industrial knowledge (IK) with the product of the process innovation rate (PCIR) and the usability of industrial knowledge for process innovation (IKNPCI).

CPCI(t)=PCI(t)*ISR/IP	Project/Year
CPCI is the number of completed process innovations. This value represents the product of process innovation stock (PCI) and innovation success rate (ISR) divided by innovation period (IP).	
$\mathrm{PCI}(t)=\mathrm{PCI}(0)+\int_0^t [\mathrm{NPCI}(s) - \mathrm{CPCI}(s)]\,ds$, PCI(0)=233	Project
PCI is process innovation stock. This value represents the aggregated differences between the number of new process innovations (NPCI) and the number of completed process innovations (CPCI) over time. The initial value given by PCI(0) is 233.	
(4) Knowledge Commercialisation	
SperCPDI=[(2006,0)-(2011,80)],(2006,56.584),(2007,53.363),(2008,62.177),(2009,53.706),(2010,50),(2011,50.334)	Hmw/Project [ECOS; KOSIS; MoST *a*; NTIS; STEPI]
SperCPDI is the amount of sales per a single completed product innovation. This value represents the economic value of individual product innovations. This lookup relates the number of completed product innovations (CPDI) to the amount of sales generated from total number of completed product innovation (SCPDI).	
SCPDI(t)=CPDI(t)*SperCPDI	Hmw/Year
SCPDI is the amount of sales generated from total number of completed product innovations. This value represents the product of the number of completed product innovations (CPDI) and the sales per completed product innovation (SperCPDI).	
RCEPS=3.545	Dmnl [STEPI]
Existing products and/or services create marketplace sales. RCEPS is the relative contribution of existing products to sales, assumed to be 3.545 times the amount of sales generated from total number of completed product innovations (SCPDI).	
SEP(t)=SCPDI(t)*RCEPS	Hmw/Year
SEP is the amount of sales generated from existing products. This value representes the product of the sales from completed product innovations (SCPDI), and the relative contribution of existing products to sales (RCEPS).	
TS(t)=SCPDI(t)+SEP(t)	Hmw/Year
TS is the amount of total sales. This value represents the sum of the total sales generated from the total number of completed product innovations (SCPDI) and the total sales generated from existing products (SEP).	

OMCperCPDI=[(2006,0)-(2011,200)],(2006,188.713),(2007,172.793),(2008,178.206),(2009,178.227),(2010,182.791),(2011,185.268) Hmw/Project [ECOS; KOSIS; STEPI; MoST *a*; NTIS]

OMCperCPDI is the amount of original manufacturing costs which individual successful product innovations lead to. This value represents the extent of costs consumed in the factory production system before the successful adoption of process innovations. This lookup relates completed product innovation (CPDI) to original manufacturing costs (OMC).

OMC(t)=CPDI(t)*OMCperCPDI Hmw

OMC is the amount of original manufacturing costs before the application of process innovations. This value represents the product of the number of completed product innovations (CPDI) and the original manufacturing costs of the individual completed product innovations (OMCperCPDI).

RMCperCPCI=[(2006,0)-(2011,200)],(2006,106.534),(2007,97.443),(2008,100.414),(2009,100.361),(2010,102.874),(2011,104.225) Hmw/Project [ECOS; KOSIS; MoST *a*; NTIS; STEPI]

RMCperCPCI is the amount of reduced manufacturing costs achieved by individual completed process innovations. This lookup relates completed process innovations (CPCI) to reduced manufacturing costs (RMC).

RMC(t)=CPCI(t)*RMCperCPCI Hmw/Year

RMC is the amount of reduced manufacturing costs, which represents economic achievement from successful process innovations. This value is the product of the number of completed process innovations (CPCI) and the extent of manufacturing costs reduced by each completed process innovation (RMCperCPCI).

AMC(t)=OMC(t) −RMC(t) Hmw/Year

AMC is the amount of achieved manufacturing costs. This vaule is the result of the original manufacturing costs (OMC) less the reduced manufacturing costs (RMC).

OCperCPDI=[(2006,0)-(2011,200)],(2006,73.335),(2007,70.248),(2008,102.6),(2009,67.803),(2010,54.504),(2011,52.203) Hmw/Project [ECOS; KOSIS; MoST *a*; NTIS; STEPI]

OCperCPDI is the amount of commercialisation costs (e.g. marketing, packaging, delivery) caused by each completed product innovation, with the exception of manufacturing costs.

OC(t)=CPDI(t)*OCperCPDI Hmw/Year

OC is the total amount of other costs, which represents the product of the total number of completed product innovations (CPDI) and the amount of other costs per completed product innovation (OCperCPDI).

TC(t)=AMC(t)+OC(t) Hmw/Year

TC is the total amount of costs, which is the sum of the total amount of achieved manufacturing costs (AMC) plus the total amount of other costs (OC).

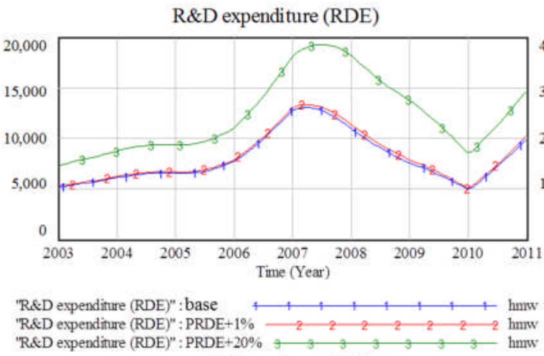
TP(t)=TS(t) −TC(t) Hmw/Year

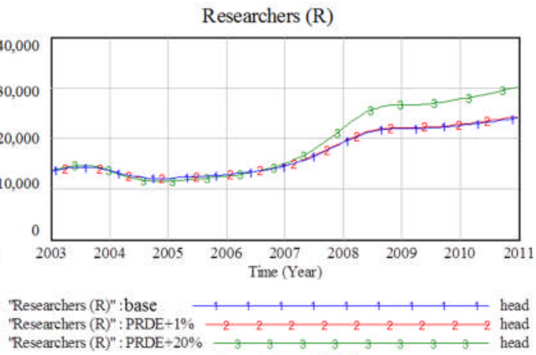
TP is the total amount of profits, which is the difference between total sales (TS) and total costs (TC).

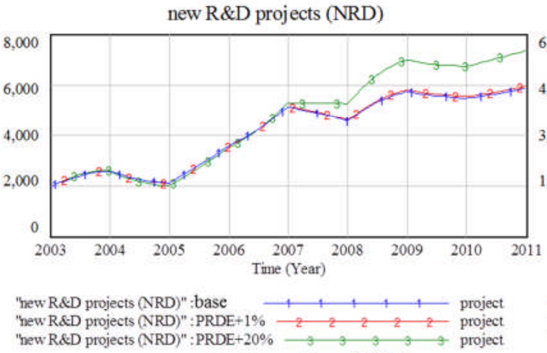
APPENDIX D. RESULTS OF POLICY TEST (PAPER 3)

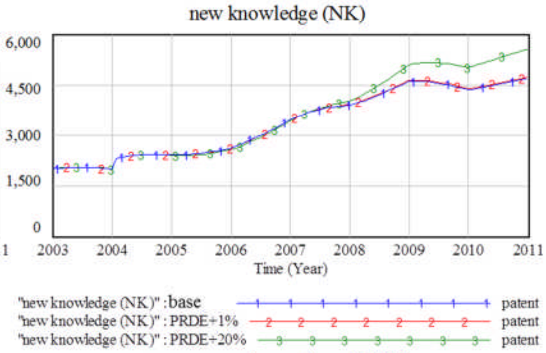
To simplify graphical displays, the following figures from Appendix *D.1.PRDE* to Appendix *D.11. ISR* show only the results of minimum (e.g. a 1% increase in R&D expenditures) and maximum (e.g. a 20% increase in R&D expenditures) parameter changes made by each potential interpretation. The ranges of attainable changes in parameters can be found in Table 17 (see Chapter 5).

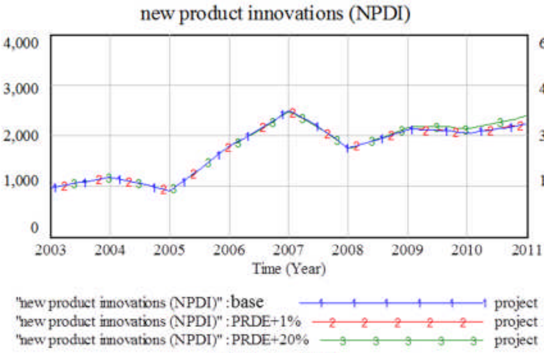
D.1. PRDE (profit effect on R&D expenditure)

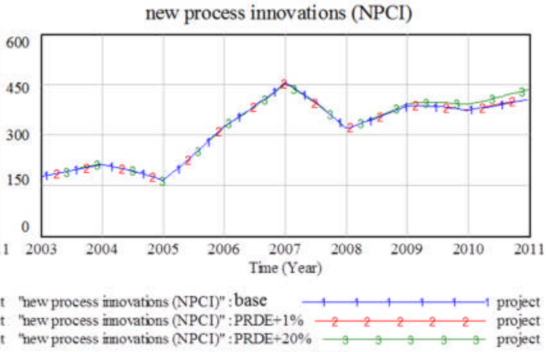


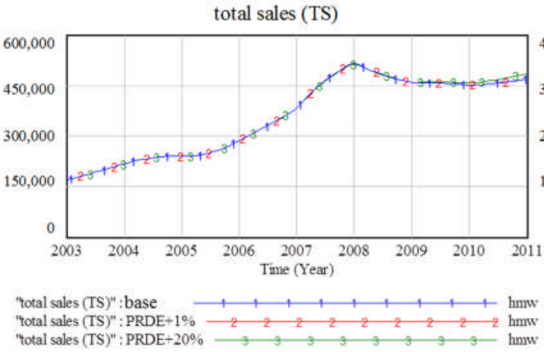


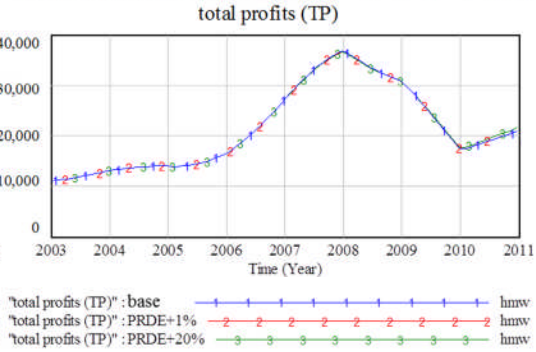






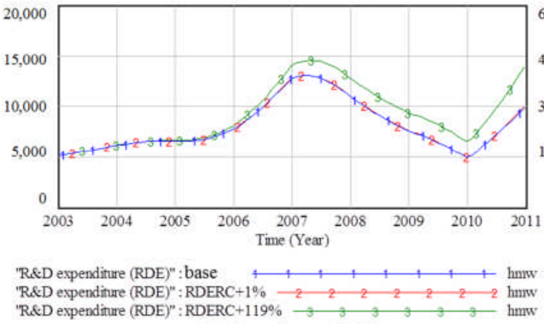




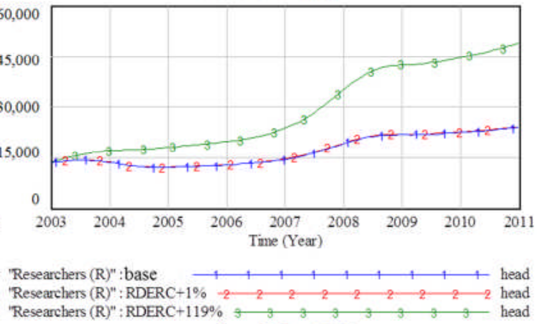


D.2. RDERC (investment effect on researcher change)

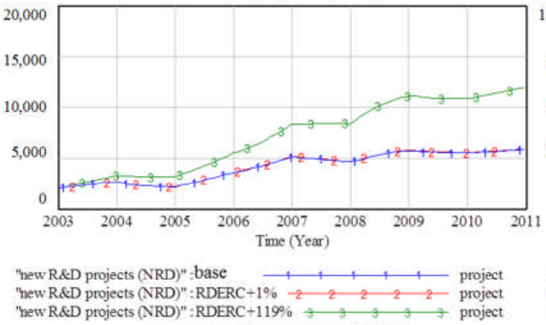
R&D expenditure (RDE)



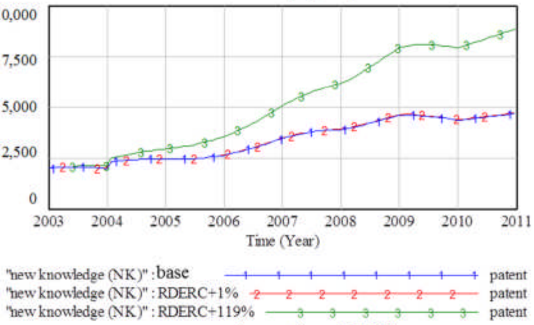
Researchers (R)



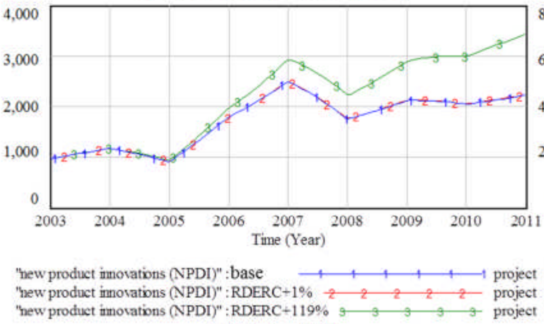
new R&D projects (NRD)



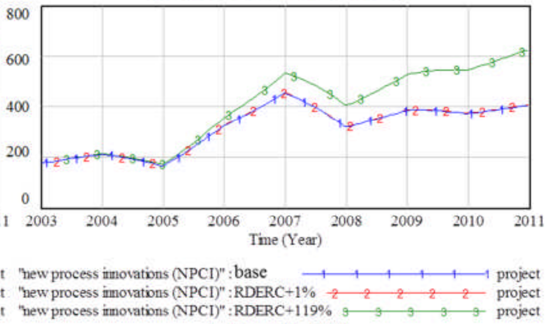
new knowledge (NK)



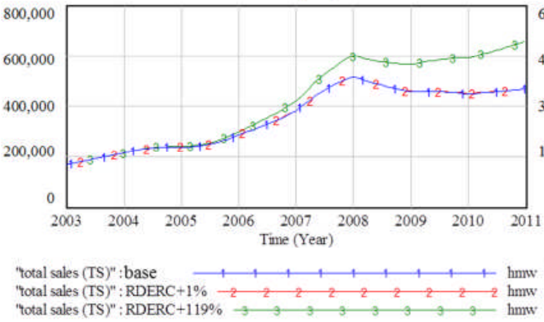
new product innovations (NPDI)



new process innovations (NPCI)

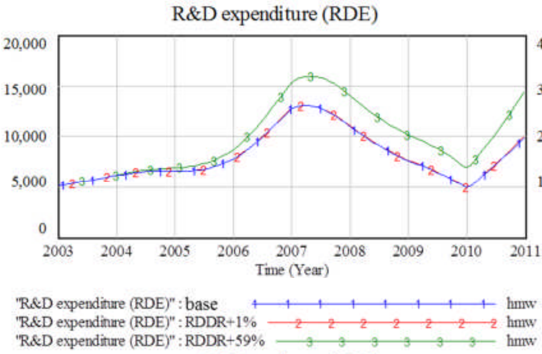


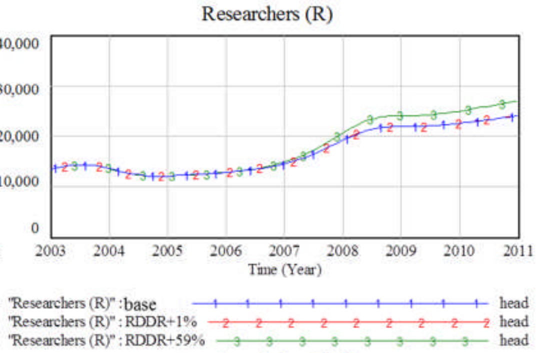
total sales (TS)

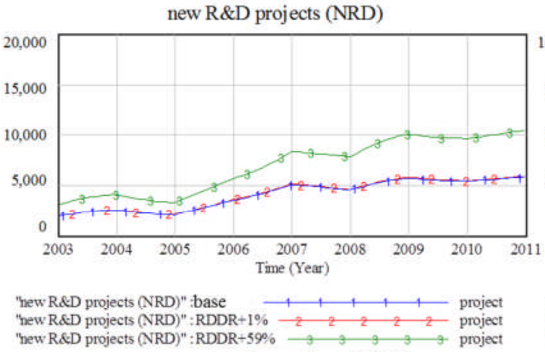


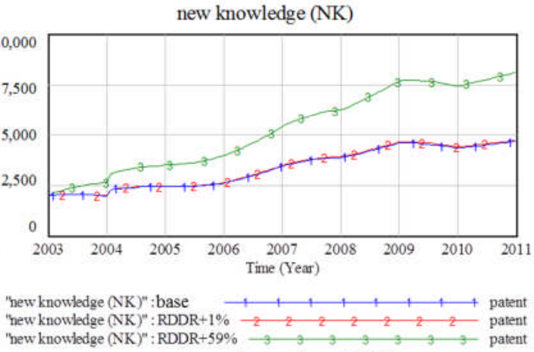
total profits (TP)

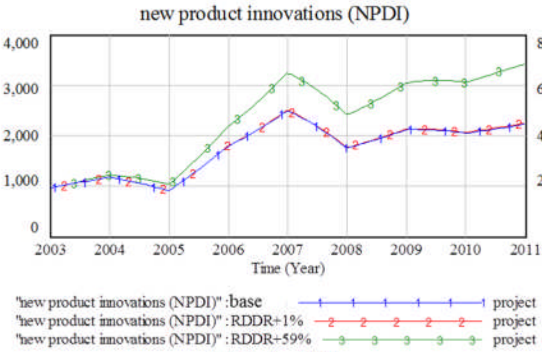
D.3. RDDR (R&D density per researcher)

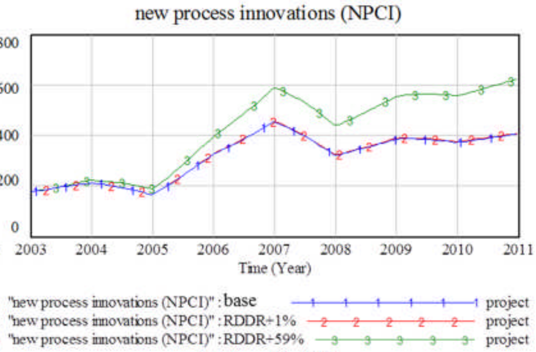

R&D expenditure (RDE)

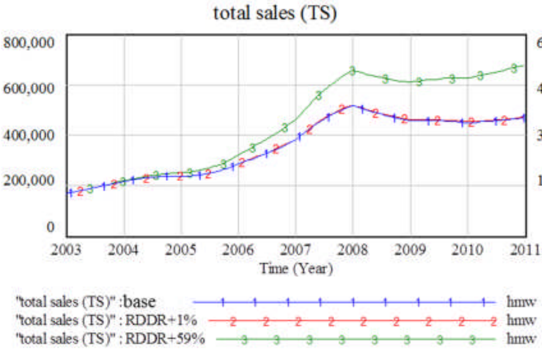

Researchers (R)

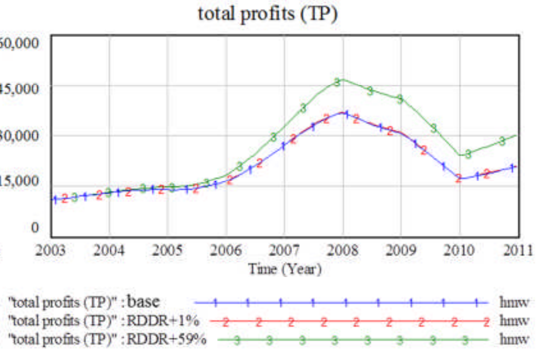

new R&D projects (NRD)


new knowledge (NK)


new product innovations (NPDI)

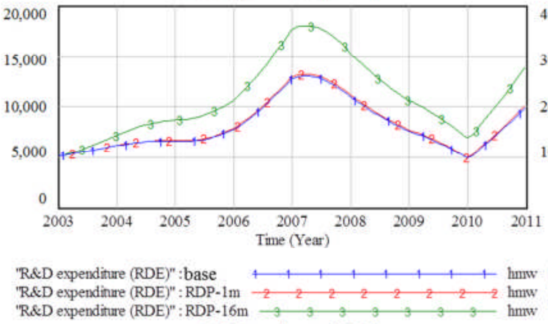

new process innovations (NPCI)


total sales (TS)

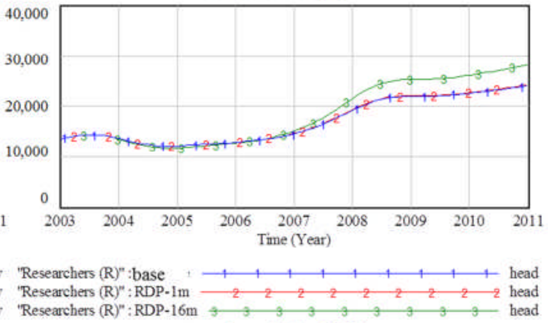

total profits (TP)

D.4. RDP (R&D period)

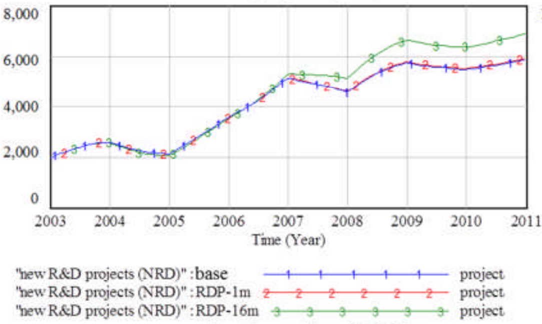
R&D expenditure (RDE)



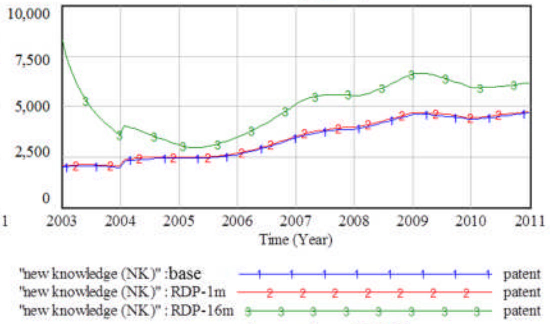
Researchers (R)



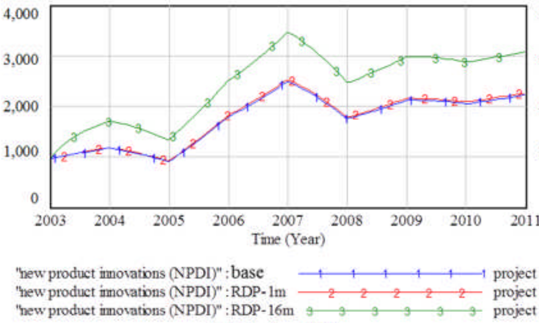
new R&D projects (NRD)



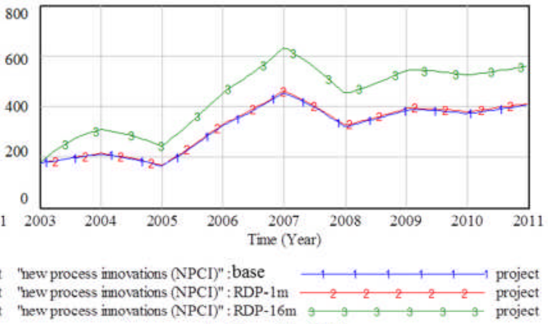
new knowledge (NK)



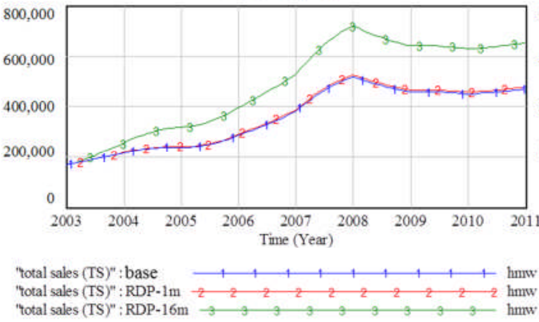
new product innovations (NPDI)



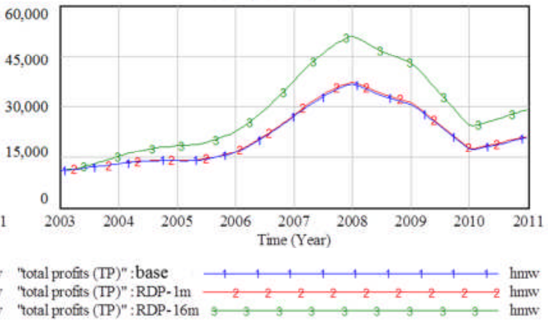
new process innovations (NPCI)



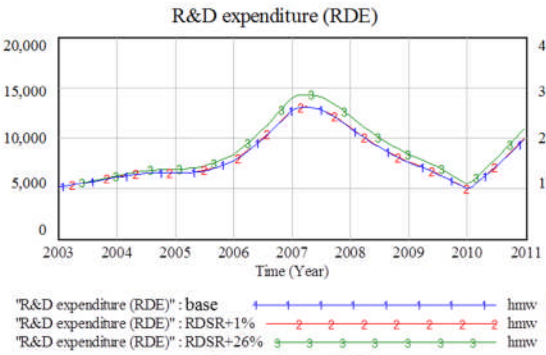
total sales (TS)

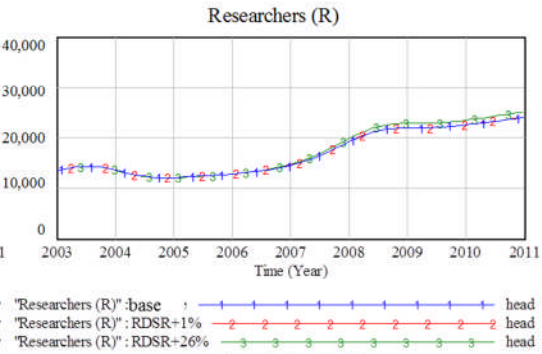


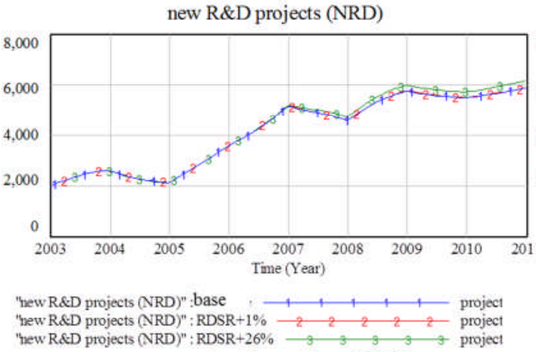
total profits (TP)

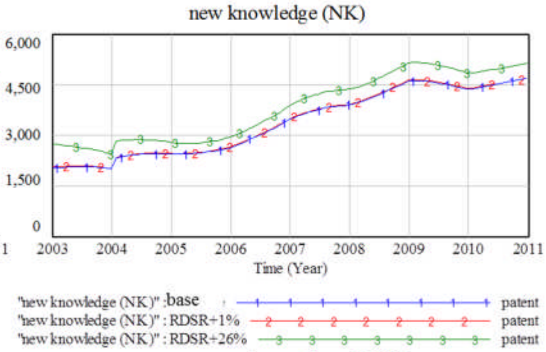


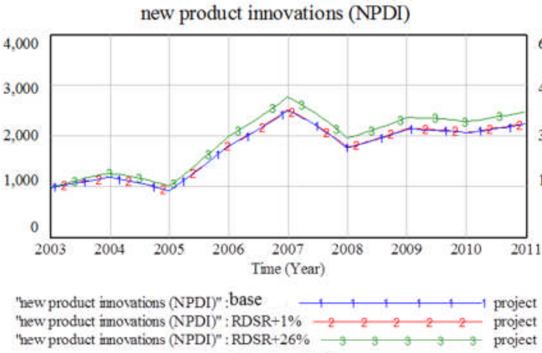
D.5. RDSR (R&D success rate)

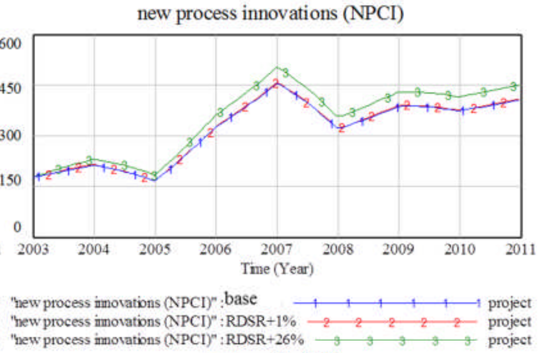


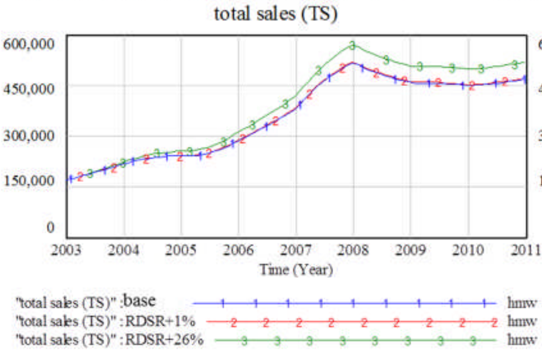


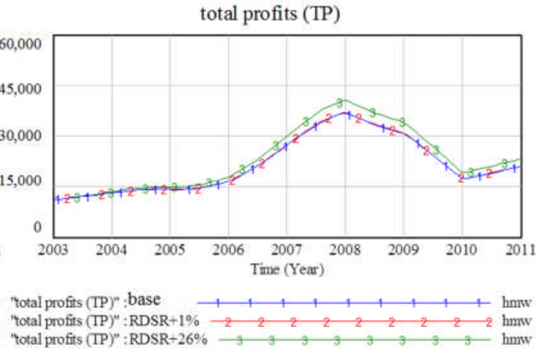




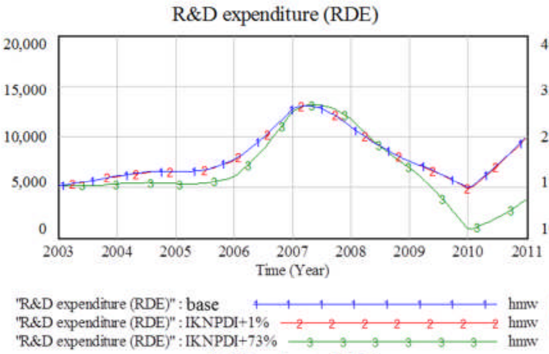


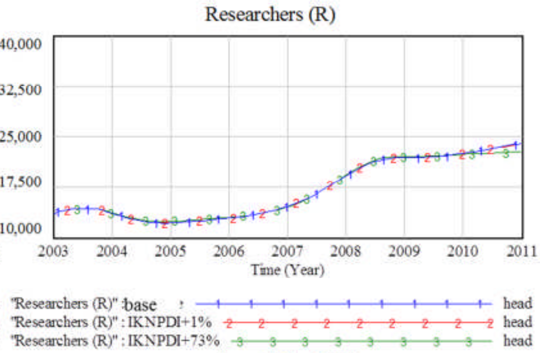


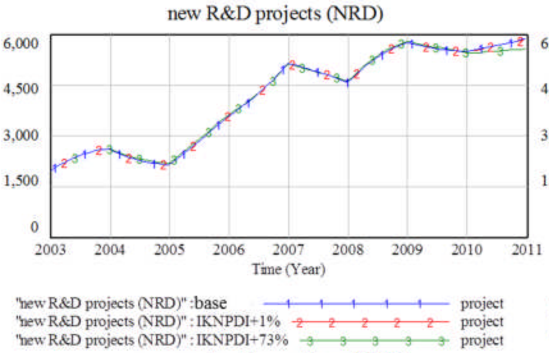


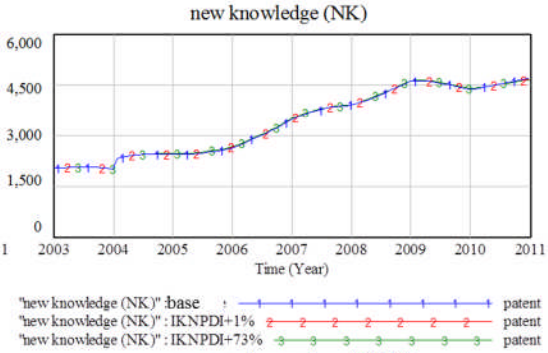


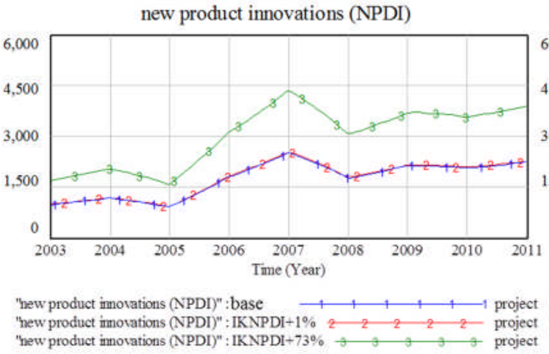
D.6. IKNPDI (usability of industrial knowledge for product innovation)

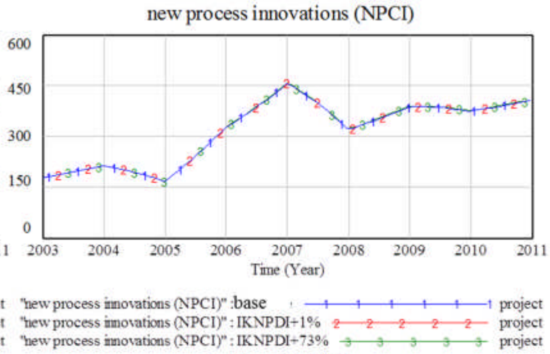


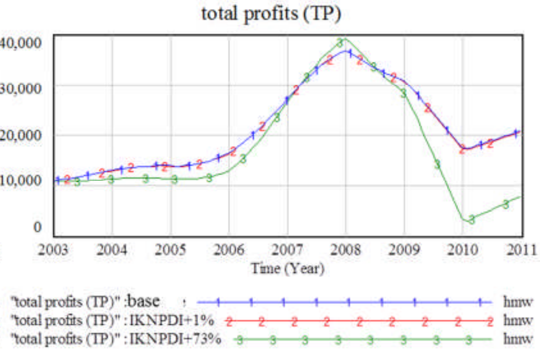




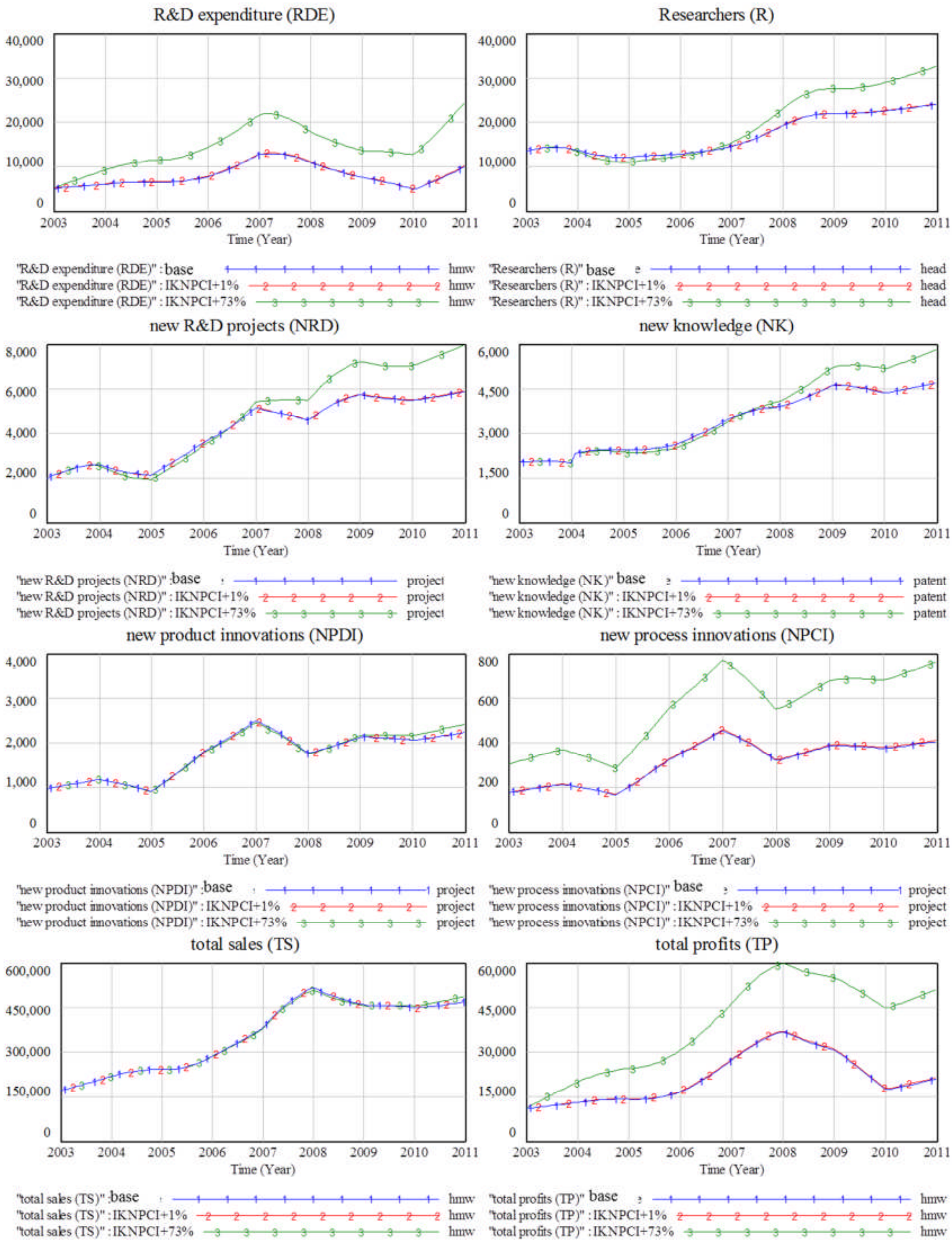




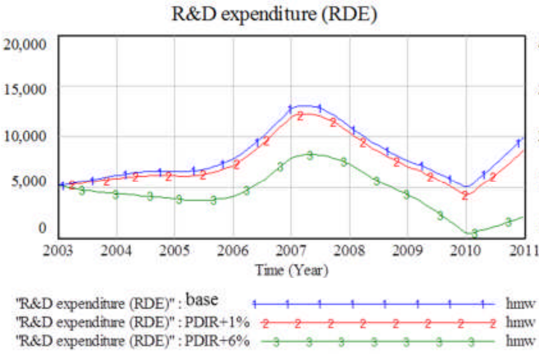


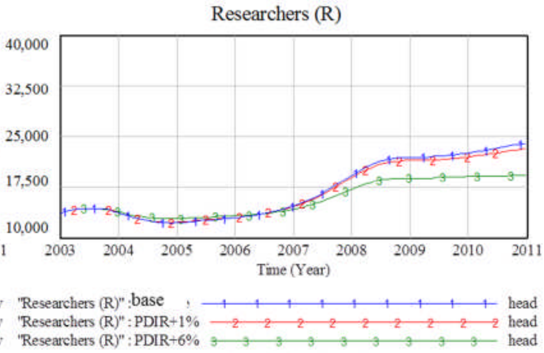


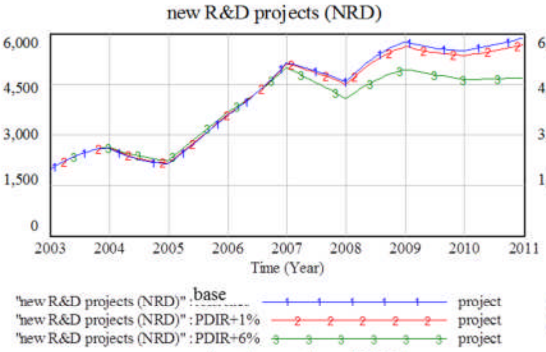
D.7. IKNPCI (usability of industrial knowledge for process innovation)

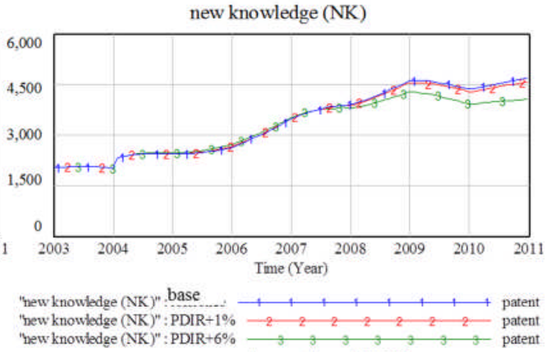


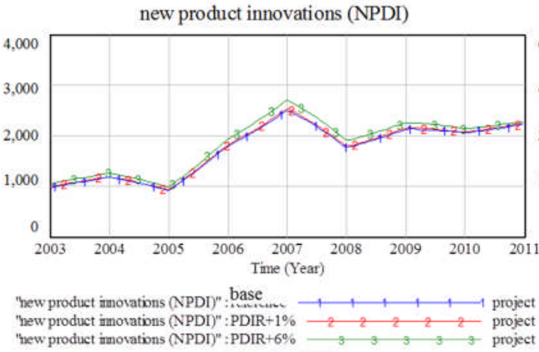
D.8. PDIR (product innovation rate)

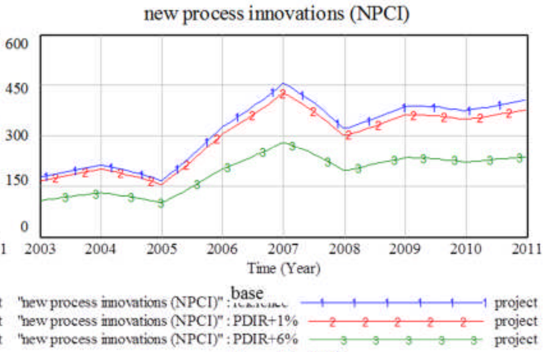


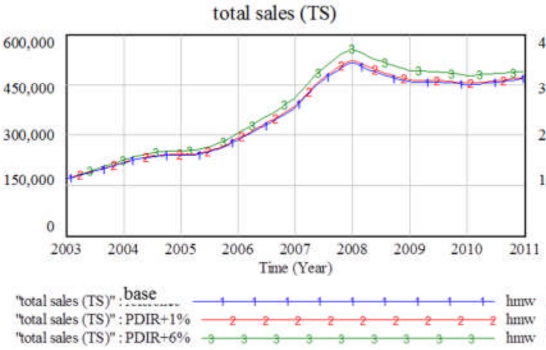


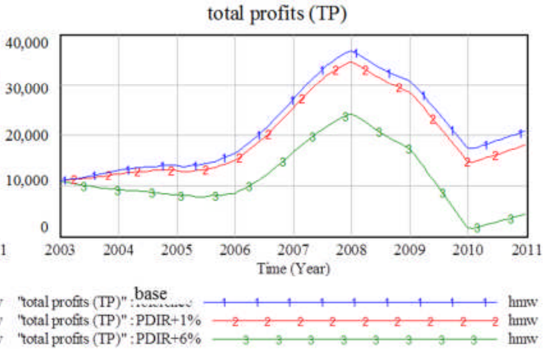




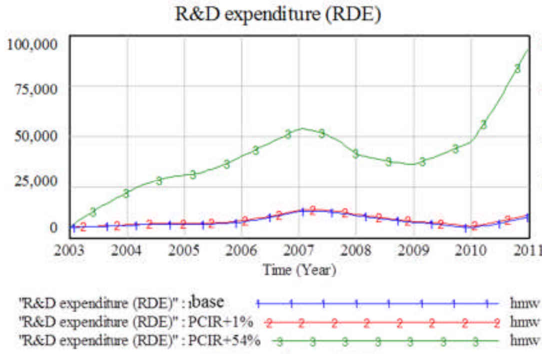


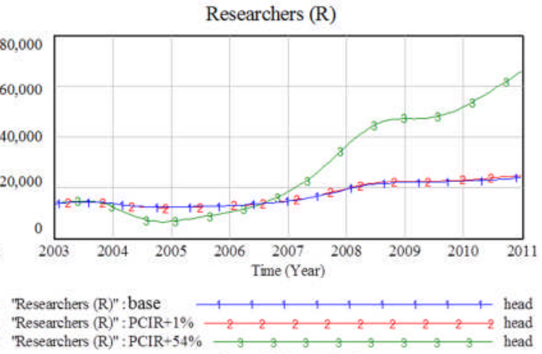


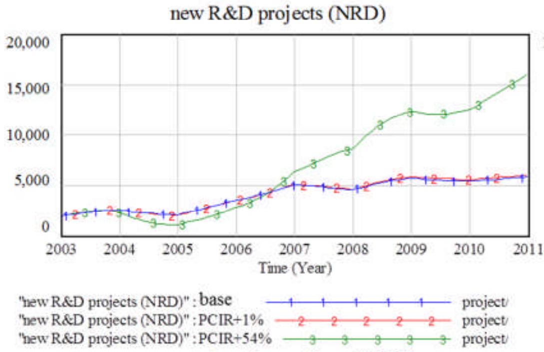


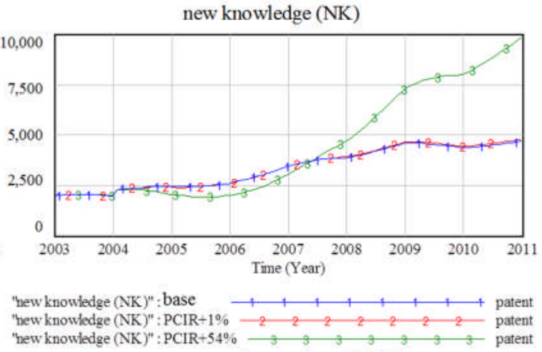


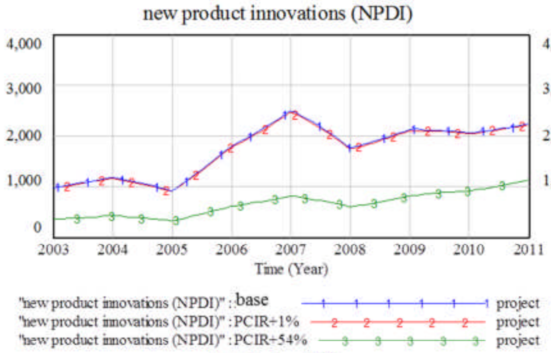
D.9. PCIR (process innovation rate)

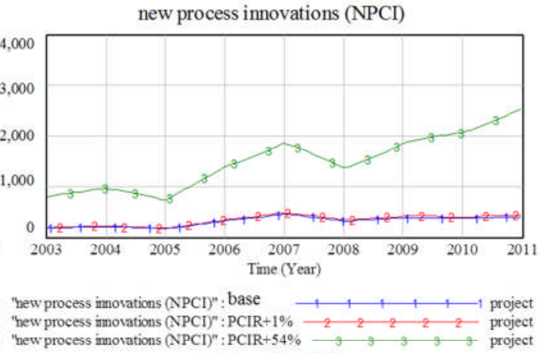


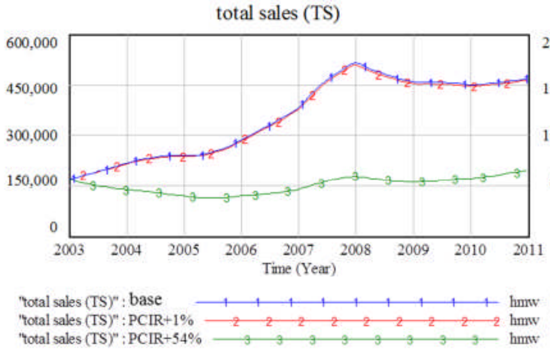


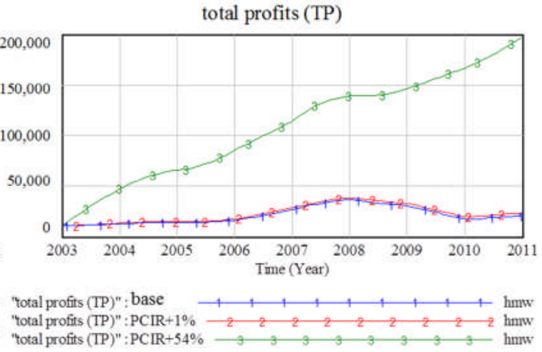




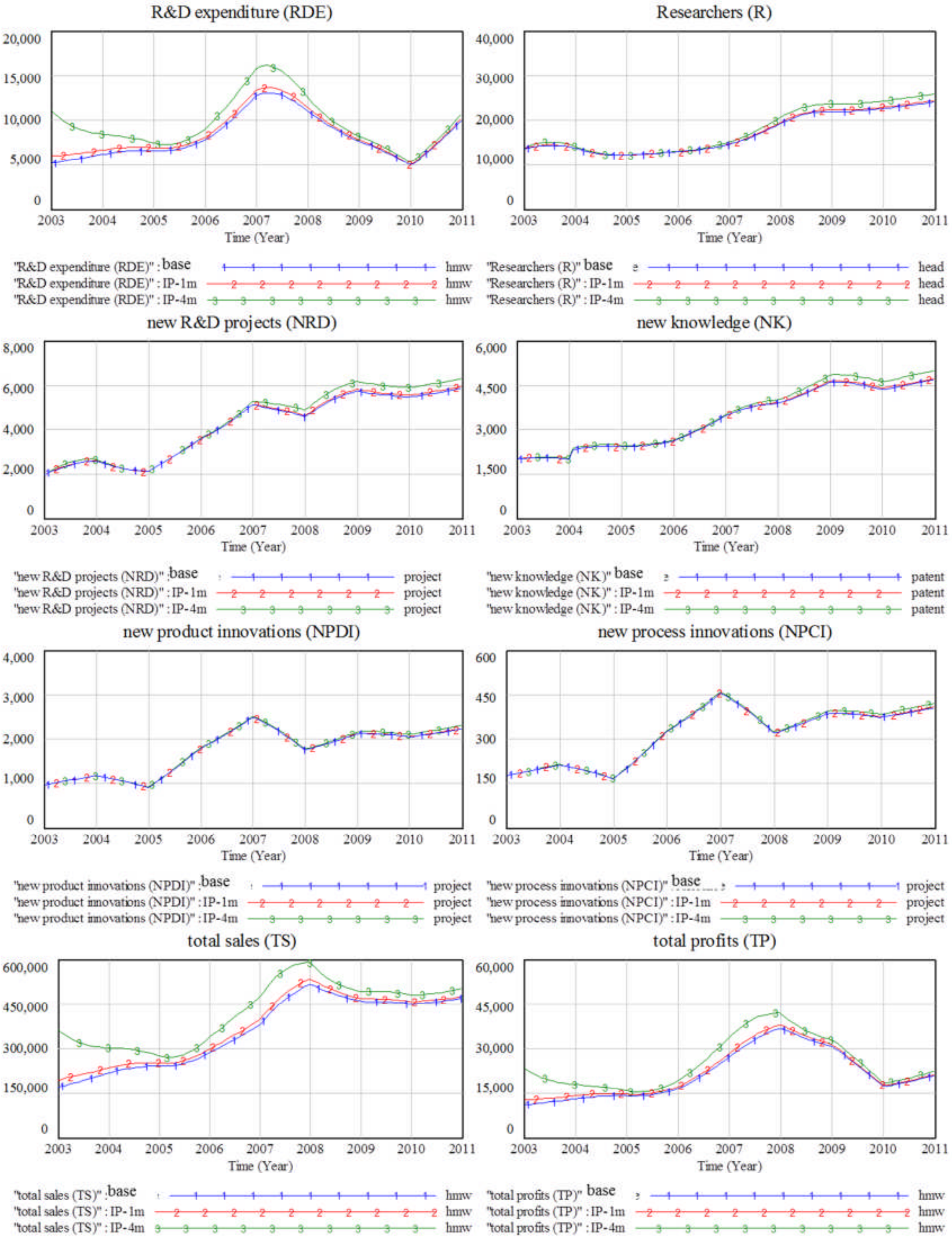








D.10. IP (innovation period)



D.11. ISR (innovation success rate)