

Estimating Regional Efficiency of Korean Manufacturing Industries Using Data Envelopment Analysis: A Technological Innovation Perspective

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Abstract

In the 1970s and 1980s, Korea achieved rapid economic growth through intensive investment especially in the Seoul metropolitan area and the southeastern part of the nation. The concentration of capital, however, caused some side-effects in regional disparity in social overhead capital and industry development. As a result, the government has had to deal with the policy issue of balancing regional development as its main concern. One of the issues derived from the main concern is anxiety whether the mitigation of intensive investment would be harmful to economic efficiency, which is the principal research interest of this article.

Under the assumption that innovation efficiency of regional firms positively influences economic efficiency of the region, this paper compares the regional technological innovation efficiency among the provinces in Korea based on the innovation activities of regional firms. Data envelopment analysis (DEA) measures the relative efficiencies of the regions and finds where resources are over-invested. The concept of technological regime is used as a control variable to exclude environmental differences of each province. The results show the resource imbalances of the provinces, which means innovation efficiency can be increased by relocating resources in the right place, and, in turn, economic efficiency can be raised. It also implies that the innovation policy needs to be differentiated by regional technological regime.

Keywords: data envelopment analysis (DEA), innovation efficiency, regional disparity, technological regime, research and development (R&D)

1. Introduction

From the 1970s to the 1980s, South Korea built a solid foundation of regional development for economic growth by establishing and implementing the first and second Comprehensive National Physical Development Plans. However, over-focused investment to the metropolitan areas and the southeastern part of the nation (Ulsan, Pohang, Masan, Changwon, Yeosu, etc.), which are considered as having a high capital

investment efficiency, deepened regional disparities and raised several issues, such as a lack of social infrastructure due to the rapid industrialization process and environmental destruction. In addition, the concentrated investment raised another concern in terms of fairness because a gap between the investment beneficiary regions and the non-beneficiary areas tends to become bigger, and at the same time economic growth and loss do not spread out to the provincial areas. To resolve these matters, the government has

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employed various proper means to balanced regional development. In spite of its devoted efforts in policy towards balanced regional development, such as the Seoul Metropolitan Area Readjustment Planning Act (1982), balanced regional development task force (1989), Balanced Regional Development and Fosterage of Local SME Act (1993), the Special Act on Balanced National Development (2003), and the Special Act on the Construction of Multifunctional Administrative City (2005), Korea still has many unresolved issues.

Lee (2006) asserted that the economic disparities between the metropolitan area and other regions have greatly grown, pointing out two main reasons for the imbalance of economic development between the two different areas: centralization of the government functions as historical and political factors, and metropolitan based growth center strategies as economic and administrative issues. The centralization of selective investment and development has been justified for rapid economic growth and effective allocation of resources. In particular, the focused investment to the metropolitan area and the southeastern part of the nation has been distinguished mainly in higher value-added business. Nevertheless, it is necessary to verify the validity of the focused and selective investment towards the metropolitan area and the southeastern area, whether it is still effective and applicable.

In this study, regional efficiency in economic perspective is a subject for analysis. In other words, the purpose of this study focuses on and discovers how efficiently resources are allocated based on the assumption that inefficiency occurs in the process that individual firms create value-added. DEA (Data Envelopment Analysis), as an analysis tool, is utilized in order to analyze regional industry efficiency and over-invested resources.

In addition, particularly, this study adopts regional innovation activities of firms as its analysis of the target agreeing with the claim that long-term competitiveness of firms arises from innovation (Freeman (1994), Guan (2004)). Therefore, the efficiency in this study means the long-term efficiency of industrial production activities in regional firms.

Moreover, the technological regime is treated as a

control variable with the reference to Melerba (1995)'s previous studies that innovation patterns can vary depending on technological regime. In other words, to control the effectiveness of differences in innovation patterns by the different technological characteristics, target industries were classified and analyzed as high-tech industries and low-tech industries in regards to technological opportunity.

Section 2 of this paper introduces the theoretical groundwork and methodologies of DEA and the technological regime. Sections 3 and 4 present data analysis and empirical results respectively, and section 5 includes conclusions and implications for the future studies.

2. Previous Studies

2.1. Data Envelopment Analysis

DEA is originally from Charnnes' (1978) study, who presented a new model which is called CCR and it was combined with a concept of efficiency and linear programming. Based on their study, a various linear programming technique-based DEA model emerged. Banker (1984), in his study, presented the BCC model of the VRS (Variable Return to Scale) assumption, which is a moderate alternative form of the CCR model of the CRS (Constant Return to Scale) assumption.

DEA is a methodology where researchers frame a nonparametric frontier by using DMUs (Decision Making Units), which are considered to have the same Production Possibility Frontier and, in turn, it makes it possible to estimate the relative efficiency of DMUs. For this reason, this nonparametric nature of DEA can be regarded as distinguishable, differing from econometrics, which is a standard methodology for an economic analysis. DEA is a methodology to find relative efficiencies by capturing the nonparametric frontier instead of estimating the parametric function. Nevertheless, Banker (1993) demonstrated that the efficiency estimates obtained by DEA asymptotically converge to actual efficiency. Simar (1999) also substantiated that confidence intervals for efficiency measures can be determined by applying the bootstrap

technique.

DEA, in particular, has an advantage of indicating a single efficiency index even in the complicated situations where there are multi-inputs and multi-outputs. Along with this benefit, DEA is useful in that it can be applicable for some cases in which the elements of inputs and outputs do not include price information. Due to its advantages, DEA has been utilized for various cases like franchise retail store evaluation, e-Business unit evaluation, and the medical field as well as research for performance evaluation of public institutions Lee, 2010a. A number of studies based on DEA models have been published, which have been utilized in performance measurement of the public sector by the domestic and public authorities (Bak, 2006; Kim, 2009; and Park, 2009).

In this study, the variables are analyzed by using the BCC model whose components are the base of 5 input factors and 3 output factors.

2.2. Technological Regime

Nelson (1982) and Winter (1984) claimed that the technological regime that can appear to be different depending on technological opportunity and appropriability, along with different conditions, can change the contents and patterns of technological innovation, which has become the theoretical foundation in interpreting an innovation process that can be shown in a different form in each individual industry. Cohen (1989) also demonstrated that the technological regime, especially technological opportunity and appropriability are the factors that directly affect the change of innovation patterns of each industry. Technological opportunity means a possibility of being successful in technological innovation when particular funds are invested. On the other hand, appropriability purports a possibility of gaining profits through innovation activities while protecting the results of technological innovation (Lee 2007).

Since then, Malerba (1995), Freel (2003), and their peer researchers conducted empirical studies, postulating that the differences of the innovation patterns of industries result in different technological

regimes. Besides, Lee (2001) introduced a concept of the technological regime to seven industry case studies in Korea. In addition, Lee (2010b) redefined the technological regime not only as technological opportunity and appropriability, but also other additional elements such as accumulation, originality, and uncertainty of technology. He also asserted that the possibility of the technological catch-up and its speed have been influenced by the technological regime citing several precedents of economic development in South Korea and Taiwan.

In addition, Kim (2010) validated that the sizes of firms, R&D efforts, and other factors may considerably affect firm survival depending on the technological regime. The studies that are mentioned above relevant to industrial innovation patterns suggest the necessity of differentiating technological regimes in the studies of innovation relevant policy. They also imply that an analysis based on the classification of technological regimes is a valid and reliable approach in Korea's industrial situations.

In this study, the technological regime is classified depending on technological opportunity, which is a means of sorting the technological regime, with the claim that innovation patterns are influenced by the technological regime. It is appropriate that each group is independently analyzed by DEA if DMUs are divided into the groups that have unique innovation patterns because the basic assumption of this study is that DMUs have the same product possibility frontier.

3. Data Structures

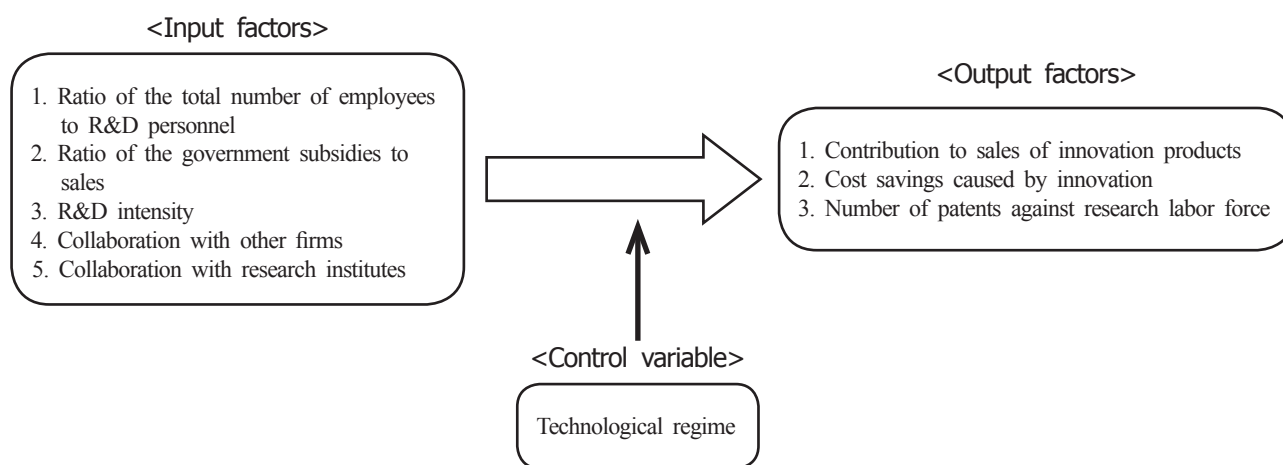
3.1 Selection of Input and Output Elements

In order to decide input and output factors of innovation activities for DEA analysis, the major determinants of technological innovation presented in the previous studies are organized in Table 1 as below (Kim, 2008; Moon, 2005; Shin, 1999; Suh, 2005; Sung, 2005).

As seen in Figure 1, the input factors of technological innovation are selected as five: ① the ratio of the total number of employees to R&D personnel, ② the ratio of the government subsidies to

Table 1 Technological innovation measurement and the main determinants

Classification	Main variables
Internal characteristics of a firm	<ul style="list-style-type: none"> • Size of a firm • Age of a firm • Cash flow (profit rate) • Product diversification • Specific R&D capacity of a firm (organizational, administrative, social, and physical characteristics of a firm, etc.) • Foreign ownership, export ratio, etc. • Degree of separation of innovative work
External characteristics of a firm	<ul style="list-style-type: none"> • Market concentration • Market structure • Technological regime (technological opportunity & technological appropriation) • Collaboration
Innovation performance measurement	<ul style="list-style-type: none"> • Sales contribution of innovation product • Number of innovation • Effect of cost reduction due to innovation • R&D statistics and patents

**Figure 1** Innovation System

sales, ③ R&D intensity, ④ collaboration with other firms, and ⑤ collaboration with research institutes, and likewise the output factors of technological innovation are chosen as three: ① contribution to sales of innovation products, ② cost savings caused by innovation, and ③ the number of patents against research labor force. In addition, this study assumes that technological innovation has systems as seen above in Figure 1.

The technological regime is classified as high-tech and low-tech industries. This is executed by comparing the average of technological opportunity in industries

to the average of technological opportunity in the whole sample number. The average R&D intensity is a proxy variable for technological opportunity based on the previous studies that technological opportunity is proportional to the average of R&D intensity in industries (Kim, 2010). Meanwhile, R&D intensity as an input factor means unique R&D intensity of each individual firm.

3.2 Analysis data

The Korean Innovation Survey (KIS) 2008 from

Science and Technology Policy Institute (STEPI) is used as data for the analysis in this study, and product innovation and process innovation are selected as the analyzed subject among the four innovation activities of the survey data. Along with financially quantitative estimates, KIS places a five-point scale, on each item by using a Likert scale, measuring the importance of each item as follows: “not applicable,” on the lowest point, “very low,” and “very high.” For example, the importance of collaboration between firms and research institutes, which is one of the input factors analyzed in this study, can be measured based on a Likert scale.

Out of the total 3,081 samples of the registered firm data of KIS 2008, 2,794 samples of data are utilized to classify the technological regime. This number does not include the missing values from

R&D expenditures, sales, regular employment staff, R&D personnel, the government-funded items, etc. Besides, 1,013 samples of data are utilized to analyze innovation efficiency, which is the number of firms which carried out product or process innovation. This figure also excludes the outlier (the data whose z-value is beyond 5 or more, which means that the data is not included in the confidence interval of 99.99%; total 19). Table 2 defines input and output variables by taking advantage of the questionnaire items.

To categorize the technological regime, which is a control variable, R&D intensity is calculated. The calculated R&D intensity of an individual firm, in turn, is used to get the average of each industry. If the average value of each industry is higher than the average value of R&D intensity of the entire samples,

Table 2 Definition of input and output variables

Classification	Name of variable	Definition of variable	Note
Input variables	Ratio of the total number of employees to R&D personnel	$(R \& D \text{ personnel} + \text{researchers working in parallel}) \div \text{permanent employees}$	Each term is the sum of the data from 2005 to 2007
	Ratio of the government subsidies to sales	$(\text{Amount of tax reduction and technology development} + \text{technology development funds} + \text{funds for commercialization}) \div \text{sales}$	
	R&D intensity	$(\text{Expenditure for internal R\&D activities} + \text{expenditure for external R\&D activities}) \div \text{sales}$	
	Collaboration with other firms	The maximum value of the contribution of each of the following organizations : affiliates / suppliers / businesses in demand and customers / competitors in the same industry and other companies	In the case of collaboration with firms and institutes
	Collaboration with research institute	The maximum value of the contribution of each of the following organizations : Private service providers / universities and R&D institutes / national research institutes	
Output variables	Contribution to sales of innovation products	Sales contribution of the market-first innovation product + sales contribution of the innovation product except market-first innovation product	Each term is sum of data from 2005 to 2007
	Cost savings caused by innovation	Cost saving efficiency due to process innovation	
	Number of patents against research labor force	$\text{Number of patents} \div ((R \& D \text{ personnel} + \text{researchers working in parallel}) \div 2)$	
Control variable	Technological regime	$(\text{Internal R\&D costs} + \text{external R\&D costs}) \div \text{the sum of sales}$	

the industry itself is classified as a high-tech industry and if lower than the average, it is classified as a low-tech industry. The KSIC (Korean Standard Industrial Classification) 2000 is used as the standard of industrial classification and the industry classification code of 3-digit is adopted for analysis.

3.3 Basic Statistics

The calculated statistical values of products/process innovation and input/output factors of performing firms classified by industry, is used as analyzed data by setting up the variables mentioned above and are presented in the appendix. Out of the total 22 industry areas, in 12 industries, the sales contribution of innovation products show a higher value than the average and these industries are as follows: Food Products and Beverages / Sewn Wearing Apparel and Fur Articles / Tanning and Dressing of Leather, Manufacture of Luggage and Footwear / Fabricated Metal Products / Other Machinery and Equipment / Computers and Office Machinery / Electrical Machinery and Apparatuses n.e.c. / Electronic Components, Radio, Television and Communication / Medical, Precision and Optical Instruments, Watches and Clocks / Other Transport Equipment / Furniture, Manufacturing of Articles n.e.c. / Recycling.

Out of the total 22 industry areas, 10 industries show higher efficiency than the average on cost saving efficiency resulting from process innovation. Among these industries, the industries that display a higher value on “number of patent against research labor force” than the average are respectively 6 out of 12 industries (product innovation) and 6 out of 10 industries (process innovation). Based on the presented results, it is obvious that the high “number of patents against research labor force” does not necessarily entail contribution of innovative product to sales or cost savings. In addition, it is clear that the ratio of the government subsidies to sales is relatively high on the specific industries, especially on Coke, Refined Petroleum Products and Nuclear Fuel / Medical, Precision and Optical Instruments, Watches and Clocks / Recycling (nearly twice the average).

The next information presented in the appendix

is the calculated value of the basic statistics of input and output variables in different regions. Among the analyzed areas, the areas that indicate higher contribution of innovative product to sales than the average are the Seoul metropolitan area, Daejeon, Gwangju and Jeolla, Busan, and Gangwon (total five areas of the nine regions).

Among these areas mentioned above, the areas, which display the higher “number of patent against research labor force,” are Daejeon and Gwangju and Jeolla. The Seoul metropolitan area, Daejeon, and Jeju show a higher ratio of R&D employees to input elements than other areas. On the other hand, Daejeon, Gwangju and Jeolla, Busan, and Jeju display a higher proportion of the government subsidies to sales than the average.

In the basic statistics, in particular, Gangwon and Jeju are judged as not being representative for the reason that the number of firms within samples is 10 and 3 respectively, which is less than expected.

4. Results

4.1 Analysis of Regional Distinctiveness

After performing DEA analysis with a BCC model, a regression analysis was conducted with dummy variables in the different regions as seen in Table 3, whose purpose is to examine whether the average efficiency of each business would be able to represent local firms.

Analytical results show that, Gangwon and Jeju province in both high-tech and low-tech industries have fewer sample numbers of businesses and greater variance compared to the other regions. So the coefficients of both areas are not significant. In addition, in the case of Daejeon, a significance level in high-tech industries is relatively low (10% significance level). All the other cases, however, are approximately at the 1% significance level, which means that the average efficiency of each region can represent regional distinctiveness.

Comparing coefficients of high-tech industries, it is noticeable that the non-beneficiary regions (Chungcheong, Gwangju/Jeolla, Daegu/Gyeongbuk) in terms of

Table 3 Efficiencies from regression analysis using a regional dummy

	Seoul metropolitan area	Daejeon	Chungcheong	Gwangju/Jeolla	Daegu/Gyeongbuk	Ulsan/Gyeongnam	Busan	Gangwon	Jeju
High-tech industry	.256*** (.019)	.138* (.080)	.389*** (.047)	.392*** (.065)	.296*** (.056)	.224*** (.053)	.199*** (.071)	.103 (.155)	.014 (.311)
Low-tech industry	.250*** (.017)	.283*** (.109)	.283*** (.041)	.241*** (.048)	.175*** (.034)	.236*** (.033)	.241*** (.041)	.121 (.117)	.083 (.203)

Notes: 1) ***: 1%($p < 0.01$), **: 5%($p < 0.05$), *: 10%($p < 0.1$) significance level respectively.

2) The values in parentheses denote the standard deviation

intensive investment ironically show higher efficiency than the other beneficiary areas. It implies that investment efficiency, which is the basis for intensive investment, is not guaranteed exclusively in high-tech industries. By analyzing the slack of DEA, it is possible to specifically figure out which input element causes inefficiency.

4.2 Regional Analysis in High-tech Industries

The analysis in high-tech industry is presented in

Table 4. Gangwon and the Jeju province are excluded from Table 4 because their significance level is low as seen in the previous regression analysis. According to the analysis results, Chungcheong, Gwangju and Jeolla, Daegu and Gyeongbuk show higher efficiency than the average of the other areas. On the other hand, the Daejeon area displays the lowest efficiency average recorded as 0.14 followed by the Seoul metropolitan area, Busan, and Ulsan/Gyeongnam. In other words, it is considered that in those areas excessive inputs have been invested, compared to the other areas.

Table 4 Analysis of regional efficiency and slacks in high-tech industries

Area	Number of firms	Efficiency	Input slack				
			Ratio of the total number of employees to R&D personnel	Ratio of the government subsidies to sales	R&D intensity	Collaboration with other firms	Collaboration with research institute
Seoul Metro. area	269	0.256	0.18	0.07	0.15	0.15	0.04
Daejeon	15	0.138	0	0.06	0.07	0.09	0
Chungcheong	43	0.389	0	0.05	0.18	0.1	0.01
Gwangju/Jeolla	23	0.392	0	0.07	0.06	0.02	0.01
Daegu/Gyeongbuk	31	0.296	0.08	0.13	0.07	0.12	0.02
Ulsan/Gyeongnam	34	0.224	0.19	0.03	0.19	0.25	0.04
Busan	19	0.199	0	0.2	0.24	0.03	0.05
Gangwon	4	0.103	0	0.02	0.02	0	0
Jeju	1	0.014	0	0.37	0.14	0	0
Total and average	439	0.268	0.13	0.07	0.15	0.14	0.03

Next, to examine the relative excessive input factors, the left side of Table 6 shows the ratio of firms that retain slack in every input factor. According to the table, three input factors, which are the “ratio of government subsidies to sales”, “R&D intensity”, and “collaboration with other firms”, signify that they are relatively over-invested compared to the “ratio of the total number of employees to R&D personnel” and “collaboration with research institutes.” In the case of the government subsidies, across all the areas, the percentage of firms with excessive inputs is high, especially in the southeastern region. In terms of R&D intensity, the percentage of firms with excessive input is shown as high as approximately 20% in all areas except Busan (36.8%). In collaboration with other firms, Daejeon and the Ulsan and Gyeongnam area show the high figure.

Therefore, either to decrease the percentage of the three input factors mentioned above or to increase the “ratio of the total number of employees to R&D personnel”

and the “collaboration with research institutes” can be an effective way to increase innovation efficiency in high-tech industries.

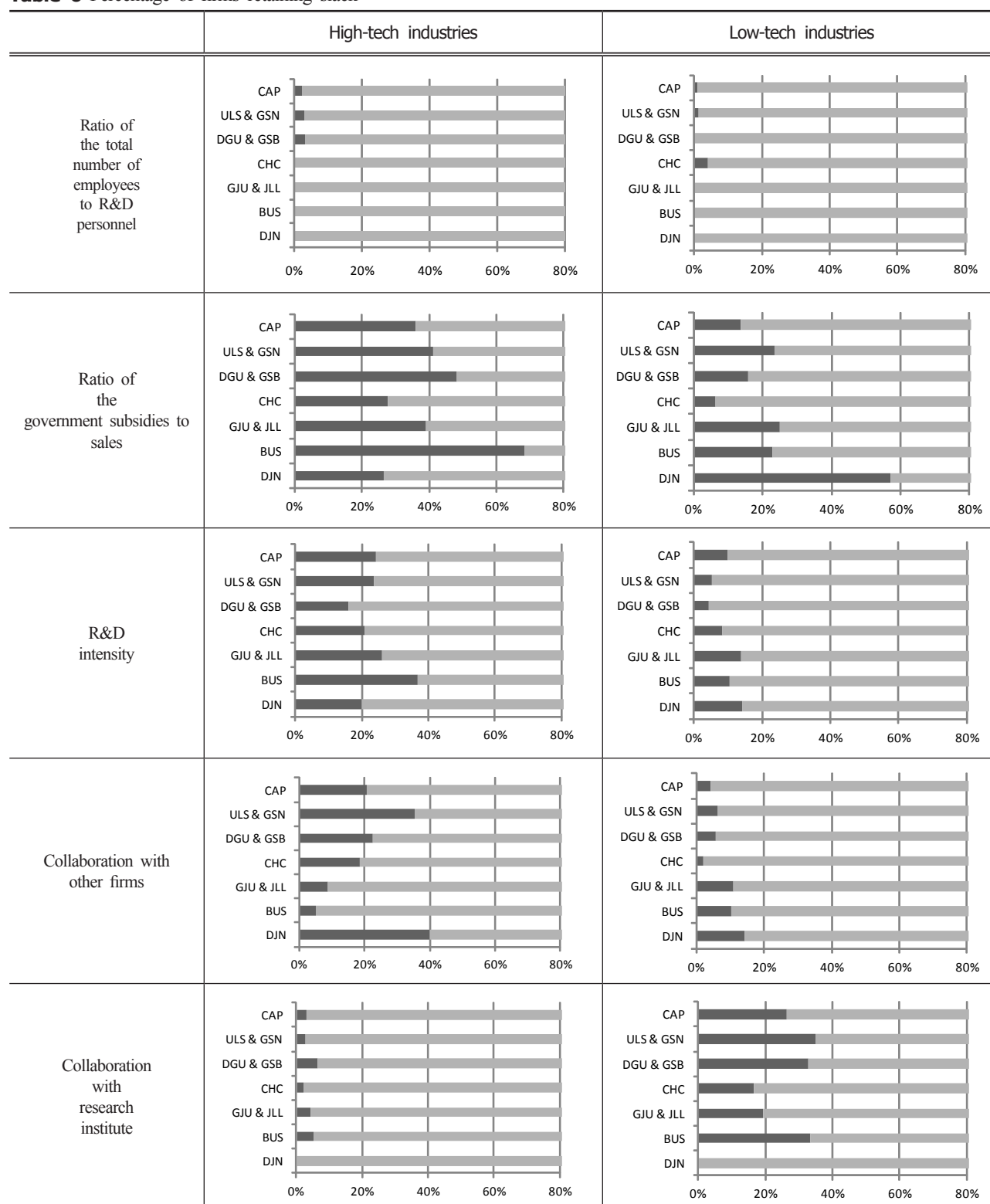
4.3 Regional Analysis in Low-tech Industries

The results of the analysis of low-tech industries are seen as Table 5. For the same reason explained above, Gangwon and Jeju are excluded in the subsequent analysis. Among the regions within low-tech industries, efficiency differences are not distinguished from one another.

The regional analysis shows a somewhat different pattern from the analysis of high-tech industries. Daejeon, which displays the lowest efficiency in high-tech industries, shows over the average efficiency. On the other hand, Daegu, which shows the high efficiency rate over the average in high-tech industries, shows the lowest efficiency. The efficiency of Chungcheong and the Gwangju/Jeolla area shows

Table 5 Analysis of regional efficiency and slack in low-tech industries

Area	Number of firms	Efficiency	Input slack				
			Ratio of the total number of employees to R&D personnel	Ratio of the government subsidies to sales	R&D intensity	Collaboration with other firms	Collaboration with research institute
Seoul Metro. area	280	0.250	0.02	0.03	0.03	0.03	0.14
Daejeon	7	0.283	0	0.08	0.01	0.03	0
Chungcheong	48	0.283	0.03	0.01	0.03	0.01	0.07
Gwangju/Jeolla	36	0.241	0	0.03	0.05	0.04	0.06
Daegu/Gyeongbuk	70	0.175	0	0.01	0.02	0.03	0.13
Ulsan/Gyeongnam	77	0.236	0.01	0.03	0.06	0.06	0.17
Busan	48	0.241	0	0.05	0.02	0.08	0.31
Gangwon	6	0.121	0	0.02	0.03	0	0.17
Jeju	2	0.083	0	0.03	0	0	0.27
Total and average	574	0.239	0.01	0.03	0.03	0.04	0.15

Table 6 Percentage of firms retaining slack

Notes: CAP/Seoul metropolitan area; ULS&GSN-Ulsan/South Gyeongnam; DGU&GSB-Daegu/Gyeongbuk; CHC-Chungcheong; GJU&JLL-Gwanju/Jeolla; BUS-Busan; DJN-Daejeon

lower efficiency than the average in high-tech industries, but higher efficiency than the average in low-tech industries.

The percentage of the firms, which hold slack by input factors, is presented on the right side of Table 6. Based on the observation, over-investment occurs to the two factors, “ratio of government subsidies to sales” and “ratio of collaboration with research institutes” in low-tech industries. In the case of the government subsidies, all areas of the nation except Gyeonggi province and the Daejeon area tend to be excessively invested. Daejeon, especially, records a considerably high percentage with an excessive input of 57.1%. On the one hand, the noticeably excessive input factor throughout all areas except Daejeon is “collaboration with research institutes.” Synthesizing all considerations, to raise innovation efficiency can be fulfilled either by decreasing inputs of “ratio of the government subsidies to sales” and “collaboration with research institutes” or by increasing outputs caused by raising percentage of inputs to research staff.

5. Conclusions

The focus of this study is to compare regional innovation efficiency by using the DEA technique. To control differences caused by the technological regime, all of the industries are categorized into two groups; high-tech and low-tech industries. The results and implications of this study are summarized as follows.

First, the Seoul metropolitan area, Daejeon, and the southeastern area display low efficiency. In other words, in these areas, relatively high excessive input occurs in all the types of input elements. Therefore, to transfer input elements in the areas where efficiency is low to the areas where efficiency is high would be helpful in improving efficiency at the entire national level.

Second, according to the analysis of different input factors in high-tech industries, the “government subsidies”, “R&D intensity”, and “collaboration with other firms” are relatively more invested than other inputs. Those factors tend to be over-invested even in the areas with relatively high efficiency such as Chungcheong province and Jeolla province. Therefore,

providing resources that are transformed in desirable forms can be more effective than merely relocating raw resources in the same forms to the other areas.

Third, in the case of efficiency in low-tech industries, little difference is shown among the analyzed areas except the Daegu/Gyeongbuk area. This can be interpreted that input factors are relatively efficiently allocated to each area.

Fourth, by contrast, input elements are not effectively allocated in low-tech industries. According to the analysis of input elements in low-tech industries, it is obvious that the “government subsidies” and “collaboration with research institutes” are relatively over-invested, and especially Daejeon shows a higher percentage of firms with slack of government subsidies compared to the other areas.

The significance of these results includes the effectiveness of classifying industries with the technological regime in innovation efficiency analysis. In the analysis of the percentage of the firms that retain slacks, a difference is noticeable by the technological regime. For example, “collaboration with research institutes” is an input factor that is seldom excessively invested in high-tech industries, but is excessive in low-tech industries. In contrast, “R&D intensity” and “collaboration with other firms” are on the least excessively invested ones. Based on the examination described above, we can say that establishing an industrial policy requires a differentiated approach in accordance with the technological regime.

The results of this study also suggest that the efficiency of the value-added industries in the Seoul metropolitan area and the southeastern area is not high compared to the other areas. In other words, investment efficiency, which is a basis upon focused investment in those areas, is not verified. It is noticeable that Daejeon, the cradle of South Korea’s industrial growth, displays the lowest efficiency level, and it is necessary to inspect whether the cause of the low efficiency in Daejeon is the accumulated over-investment for the past years. However, a possibility should be taken into consideration that in the case of manufacturing firms, whose ratio of the basic research to application research is relatively high, time lag can be longer than 3 years of the survey period in spite

of being classified as the same high-tech industries category.

Finally, as another significance of this study, the need of balanced regional development is assessed. Excessively invested resources in the focused invested areas, such as the Seoul metropolitan, Daejeon, and the southeastern area can more efficiently utilized by being shifted to the non-focused invested regions such as Chungcheong, Jeolla, and Gyeongbuk while not causing damage to the output of the existing beneficiary areas. In this process, an advantage of improved efficiency can be obtained in both the beneficiary areas and the non-beneficiary areas by relocating excessively invested input factors to the places in which they are needed. However, it is necessary to provide the resources after transforming them to the desirable forms in the non-focused

invested areas rather than providing raw resources. The needed forms of non-focused invested areas are, especially, research personnel and a network with research institutes, and it is desirable to switch the government subsidies and tax benefits to the other forms of resources such as support for training research staff or support for developing a network with research institutes, etc.

The collected the technological regime data analyzed in this research only aims at the manufacturing industries. It is possible therefore to get a different result in the new field of non-manufacturing industries, which produce added-value based on knowledge. Nevertheless, an efficiency analysis method in this research is applicable for analyzing a geographical location of industries or seeking ways of optimally allocating resources.

Appendix A. Regional average of input and output elements

Area	Number of companies	Output			Input				
		Contribution to sales of innovation products	Cost savings caused by Innovation	Number of patent against research labor force	Ratio of the total number of employees to R&D personnel	Ratio of the government subsidies to sales	R&D intensity	Collaboration with other firms	Collaboration with research institute
Seoul Metropolitan area	549	29.65	7.26	0.17	12.72	0.52	3.04	1.38	1.02
Daejeon	22	37.95	10.57	0.21	16.09	1.30	5.04	1.45	1.23
Chungcheong	91	25.10	6.76	0.23	8.06	0.36	2.48	1.02	0.77
Gwangju/ Jeolla	59	29.42	9.08	0.23	9.33	0.59	2.41	1.20	0.73
Daegu/ Gyeongbuk	101	22.84	6.75	0.16	10.95	0.45	1.97	1.41	1.25
Ulsan & Gyongnam	111	25.17	8.08	0.11	9.98	0.35	2.28	1.50	1.37
Busan	67	30.94	9.91	0.11	10.72	0.92	2.79	1.36	1.30
Gangwon	10	43.90	5.00	0.09	12.00	0.37	2.49	0.80	1.80
Jeju	3	23.33	6.67	0.09	26.27	9.11	12.24	1.33	3.33
Total and average	1013	28.45	7.58	0.17	11.60	0.55	2.81	1.35	1.08

Note: The values in shaded cells are above the overall average

Appendix B. Industrial average of input and output elements

KSIC code	Industry	No. of Firms	Output			Input				
			Contribution to sales of innovation products	Cost savings caused by Innovation	Number of patents against research labor force	Ratio of the total number of employees to R&D personnel	Ratio of the government subsidies to sales	R&D intensity	Collaboration with other firms	Collaboration with research institute
15	Food Products and Beverages	53	31.00	5.20	0.06	5.60	0.61	1.55	1.02	1.23
17	Textiles	36	24.88	7.12	0.22	8.19	0.53	1.95	1.19	1.11
18	Sewn Wearing Apparel and Fur Articles	22	44.87	6.36	0.01	14.64	0.09	1.79	0.82	0.86
19	Tanning and Dressing of Leather, Manufacture of Luggage and Footwear	23	29.70	4.30	0.12	10.23	0.44	2.32	0.87	0.74
20	Wood and Products from Wood/Cork	13	20.77	3.62	0.28	9.43	0.34	2.63	0.38	0.00
21	Pulp, Paper and Paper Products	25	17.92	8.20	0.11	6.41	0.05	1.38	1.44	0.40
22	Publishing, Printing and Reproduction of Recorded Media	16	22.21	10.52	0.08	14.51	0.07	2.29	1.13	0.88
23	Coke, Refined Petroleum Products and Nuclear Fuel	18	19.56	6.28	0.13	14.07	1.23	2.96	1.28	1.33
24	Chemicals and Chemical Products	95	24.38	6.72	0.11	11.86	0.54	2.70	1.56	1.59
25	Rubber and Plastic Products	56	26.98	6.68	0.17	8.79	0.50	1.80	1.54	1.09
26	Other Non-metallic Mineral Products	54	26.07	7.51	0.18	6.60	0.57	1.68	1.17	0.85
27	Basic Metals	58	15.41	7.52	0.13	5.76	0.26	1.11	1.41	1.24
28	Fabricated Metal Products	39	29.90	8.31	0.34	10.14	0.39	2.63	1.00	0.90
29	Other Machinery and Equipment	94	30.19	7.84	0.25	15.05	0.64	3.88	1.19	0.97
30	Computers and Office Machinery	33	35.00	8.02	0.09	21.84	0.78	4.90	1.24	0.61
31	Electrical Machinery and Apparatuses n.e.c.	65	33.09	7.54	0.21	13.66	0.64	3.66	1.82	1.37
32	Electronic Components, Radio, Television and Communication	86	30.19	9.31	0.22	13.76	0.66	3.29	1.72	0.80
33	Medical, Precision and Optical Instruments, Watches and Clocks	62	39.89	7.98	0.19	20.96	0.99	6.91	0.97	1.00
34	Motor Vehicles, Trailers and Semitrailers	94	24.25	8.42	0.10	9.32	0.30	2.03	1.79	1.54
35	Other Transport Equipment	16	30.44	7.38	0.14	8.57	0.19	1.25	1.50	1.31
36	Furniture, Manufacturing of Articles n.e.c.	46	35.30	8.15	0.19	11.39	0.78	2.73	0.98	0.93
37	Recycling	9	31.67	14.44	0.21	9.99	1.60	1.95	1.44	0.00
Total and average		1013	28.45	7.58	0.17	11.60	0.55	2.81	1.35	1.08

Note: The values in shaded cells are above the overall average

Appendix C. Analysis by Industries

C.1. Efficiency and input slack by industry in high-tech industries

KSIC code	Name of industry	Number of firms	Efficiency	Input slack				
				Ratio of the total number of employees to R&D personnel	Ratio of the government subsidies to sales	R&D intensity	Collaboration with other firms	Collaboration with research institute
15	Food Products and Beverages	14	0.42	0.00	0.11	0.02	0.22	0.00
21	Pulp, Paper and Paper Products	13	0.38	0.00	0.02	0.10	0.09	0.00
23	Coke, Refined Petroleum Products and Nuclear Fuel	2	0.06	0.00	0.23	0.30	0.02	0.00
24	Chemicals and Chemical Products	68	0.23	0.00	0.05	0.23	0.16	0.05
25	Rubber and Plastic Products	12	0.19	0.00	0.09	0.05	0.22	0.00
28	Fabricated Metal Products	9	0.38	0.00	0.13	0.13	0.16	0.00
29	Other Machinery and Equipment	93	0.28	0.03	0.06	0.10	0.10	0.01
30	Computers and Office Machinery	33	0.18	0.00	0.08	0.13	0.09	0.01
31	Electrical Machinery and Apparatuses n.e.c.	38	0.29	0.00	0.11	0.25	0.09	0.13
32	Electronic Components, Radio, Television and Communication	86	0.31	0.57	0.05	0.12	0.18	0.04
33	Medical, Precision and Optical Instruments, Watches and Clocks	62	0.24	0.12	0.12	0.18	0.14	0.01
34	Motor Vehicles, Trailers and Semitrailers	7	0.25	0.00	0.00	0.20	0.17	0.00
35	Other Transport Equipment	2	0.04	0.00	0.03	0.00	0.07	0.00
Total and average		439	0.27	0.13	0.07	0.15	0.14	0.03

C.2. Efficiency and input slack by industry in low-tech industries

KSIC code	Name of industry	Number of firms	Efficiency	Slacks of input factors				
				Ratio of the total number of employees to R&D personnel	Ratio of the government subsidies to sales	R&D intensity	Collaboration with other firms	Collaboration with research institute
15	Food Products and Beverages	39	0.34	0.00	0.00	0.01	0.02	0.20
17	Textiles	36	0.21	0.00	0.01	0.06	0.02	0.17
18	Sewn Wearing Apparel and Fur Articles	22	0.21	0.20	0.01	0.00	0.01	0.08
19	Tanning and Dressing of Leather, Manufacture of Luggage and Footwear	23	0.13	0.00	0.02	0.02	0.01	0.03
20	Wood and Products of Wood/Cork	13	0.23	0.00	0.00	0.06	0.22	0.00
21	Pulp, Paper and Paper Products	12	0.42	0.00	0.00	0.00	0.00	0.16
22	Publishing, Printing and Reproduction of Recorded Media	16	0.28	0.00	0.00	0.01	0.08	0.18
23	Coke, Refined Petroleum Products and Nuclear Fuel	16	0.20	0.09	0.03	0.01	0.00	0.04
24	Chemicals and Chemical Products	27	0.25	0.02	0.01	0.00	0.02	0.24
25	Rubber and Plastic Products	44	0.26	0.00	0.12	0.02	0.02	0.12
26	Other Non-metallic Mineral Products	54	0.26	0.02	0.03	0.12	0.04	0.17
27	Basic Metals	58	0.37	0.00	0.01	0.01	0.10	0.28
28	Fabricated Metal Products	30	0.20	0.00	0.02	0.03	0.04	0.04
29	Other Machinery and Equipment	1	0.03	0.00	0.00	0.00	0.00	0.09
31	Electrical Machinery and Apparatuses n.e.c.	27	0.15	0.00	0.02	0.00	0.05	0.19
34	Motor Vehicles, Trailers and Semitrailers	87	0.16	0.00	0.02	0.04	0.01	0.15
35	Other Transport Equipment	14	0.34	0.04	0.01	0.03	0.14	0.29
36	Furniture, Manufacturing of Articles n.e.c.	46	0.18	0.00	0.04	0.03	0.01	0.04
37	Recycling	9	0.29	0.05	0.13	0.05	0.03	0.00
Total and average		574	0.24	0.01	0.03	0.03	0.04	0.15

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