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Innovation Capability Index of Korea's Manufacturing Firms: An Empirical Study Using the Community Innovation Survey (CIS) Dataset

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<Abstract>

과학기술지표는 전통적으로 R&D 투입 데이타와 특허자료가 사용되었지만 본 연구에서는 이들의 단점을 극복할 대안으로 기업의 혁신활동 지표를 제시하고자 한다. 먼저 한국의 CIS 데이터가 소개되고 계량분석을 이용한 방법론이 소개된다. 한편 이를 이용하여 산업별 혁신 능력지수를 제시한다.

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Ⅰ. Introduction

In the knowledge-based economy, innovation is seen to play a central role, but until recently the complex processes of innovation have been insufficiently understood. Better understanding, however, has emerged from many studies in recent years. At the macro-level, there is a substantial body of evidence that innovation is the dominant factor in national economic growth and international patterns of trade. At the micro-level, R&D is seen as enhancing a firm's capacity to absorb and make use of new knowledge, strengthening its competitiveness.

As the economic paradigm shifts to the knowledge-based economy, more concerns have been paid to how to collect and produce indicators which well represents the economic activities in general and S&T activities in particular under the changing regime. The attempt to seek and develop new indicators is inevitable since conventional indicators are not quite appropriate for capturing innovation activities and therefore for policy-making for various socio-economic sectors.

Conventionally, there have been two basic families of S&T indicators, which are directly relevant to the measurement of technological innovation, that is, resources devoted to R&D and patents statistics. R&D data are collected through national surveys according to the guidelines of the Frascati manual. These data have proved valuable in many studies. However, these data have two main limitations. First, R&D is an input. Although it is obviously related to technical change, it does not measure it. Second, R&D does not encompass all the efforts of firms and governments in this area, as there are other sources of technical change, such as learning by doing. On the other hand, patents as an indicator also have a drawback. Many innovations do not correspond to a patented invention. Many patents correspond to invention with a near zero technological and economic values, whereas a few of them have very high value. Many patents never lead to innovation. Thus, it is needed to develop new indicators properly reflecting innovation activities.

In this study, we have attempted to develop a new indicator for firm's innovative activities, using the CIS dataset. In the following chapter, we will discuss the Korean CIS dataset and methodology. The methodology basically employs an econometric model, in which firm's innovative behavior can be accommodated with various determinants of innovation. An advantage using an econometric model is that we can systematically reproduce the results at given conditions. Then, we provide firm's innovation capability index by industries, as an example. In the chapter 4, a discussion about limitations of the study and future work will be provided.

Ⅱ. Korean CIS Dataset

International efforts to develop new S&T indicators have been led and made by CSTP/OECD. "New S&T indicators" activity aims to develop a set of methods and data sources allowing selected indicators to be calculated on an internationally comparable basis. It also aims at using existing data in new ways, or at using new data, or at implementing full-scale methods, which are still at the research stage.

The OECD group of NESTI (National Experts on Science and Technology Indicators) in collaboration of the OECD and Eurostat Secretariats has prepared the Oslo manual in 1992 and revised it in 1996. The manual is designed to serve as a guide for data collection on technological innovation. It is based on the original framework of concepts, definitions and methodology, and updates them to incorporate survey experience and improved understanding of the innovation process. With the guidelines of the manual, many countries undertake the survey and make various analyses based on the CIS dataset. Basically, this survey deals with innovation at the level of the individual firm.

According to the Oslo manual, technological innovation is divided into three categories, i.e., product innovation, process innovation and diffusion. The product innovation is the commercialization of a technologically changed product. Technological change occurs when the design characteristics of a product change in ways that deliver new or improved services to consumers of the product. The process innovation occurs when there is a significant change in the technology of the production of an item. This may involve new

Table 1. Measures of innovation and its determinants

Measured variables	
1. Measurement of innovation	-Innovative inputs -Innovative outputs -Innovation count -Qualitative data for innovation
2. Firm-specific determinants	-Firm size -Cash flow -Product diversification -Firm-specific R&D related capability: organizational, managerial, sociological and psychological attributes of firms -Division of innovative labor
3. Industry-specific determinants	-Market concentration -Demand -Technological opportunities -Appropriability conditions

Source: Kamien & Schwartz (1982), Baldwin & Scott (1987), Cohen (1995), Symeonidis (1996) equipment, new management and organization methods, or both. The diffusion is the way in which innovations spread, through market or non-market channels. Without diffusion, an innovation will have no economic impact. The manual recommends six areas for investigation, such as (1) corporate strategies, (2) role of diffusion, (3) sources of information for innovation and obstacles to innovation, (4) inputs to innovation, (5) role of public policy in industrial innovation, and (6) innovation outputs.

However, the measurement of innovation is no easy matter and there are a number of factors to influence innovative behavior of the firm. Several alternatives have been suggested from innovation-related studies ever since Schumpeter in early 1940. They are summarized in the following table.

The Korean CIS (Community Innovation Survey) dataset is to collect data about innovation activity at the firm level. The dataset covers more than 3,000 firms and includes information on both inputs to the innovation process, cooperation about innovation, outputs from the innovation process, and institutional and environmental factors influencing firm's innovative behavior.

The Korean survey has been undertaken regularly since 1995 by the STEPI. The survey deals mainly with product and process innovations; the product innovation is divided into two such as new product innovation and product improvement. In this survey, new product innovation implies a technologically new product whose technological characteristics or intended uses differ significantly from those of previously produced products. The product improvement implies a technologically improved (existing) product whose performance has been significantly enhanced or upgraded. The process innovation implies the adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment, or production organization, or a combination of these changes, and may be derived from the use of new knowledge.

In the Korea survey, the questionnaire includes ten categories of survey parameters, such as (1) general information about the business operation, (2) innovative performance of the firm, (3) information sources of innovation, (4) purposes of innovation, (5) innovation cost, (6) impacts of innovation, (7) technology acquisition and transfer, (8) protection of intellectual property rights, (9) assessment of institutional/governmental support for innovative activities, and finally (10) obstacles to innovation. The measures of survey parameters include quantitative and qualitative ones.[1]

1) For detail, see 장진규 & 윤문섭, (forthcoming), "우리나라 제조업의 기술혁신조사," STEPI.

Ⅲ. Innovation Capability Index

1. Methodology

There could be various ways to produce new indicators based on the dataset. Using the CIS dataset, we could employ the probit model. In specification of the probit, the observed data for dependent variable is represented by the binary variable, that is, it has the discrete values of either 0 or 1. In the survey, in fact, innovation is measured as a binary variable, i.e., yes or no for making innovation. However, the fitted values of the probit model can have continuous values for the dependent variable.

It can be explained from Fig. 1. The observed values, which denote the innovation performance of the firm, take either 0 or 1. If the firm have made no innovation, the observed value will be 0; on the other hand, if the firm have made an innovation, it will be 1. Those observed values are shown by circles in the figure along the lines of y-axis and y=1. If the probit is employed, whose values have the range between 0 and 1[2], then the fitted values from estimated probit model will be continuous ranging between 0 and 1. These fitted values can be taken account of as an innovation capability index.

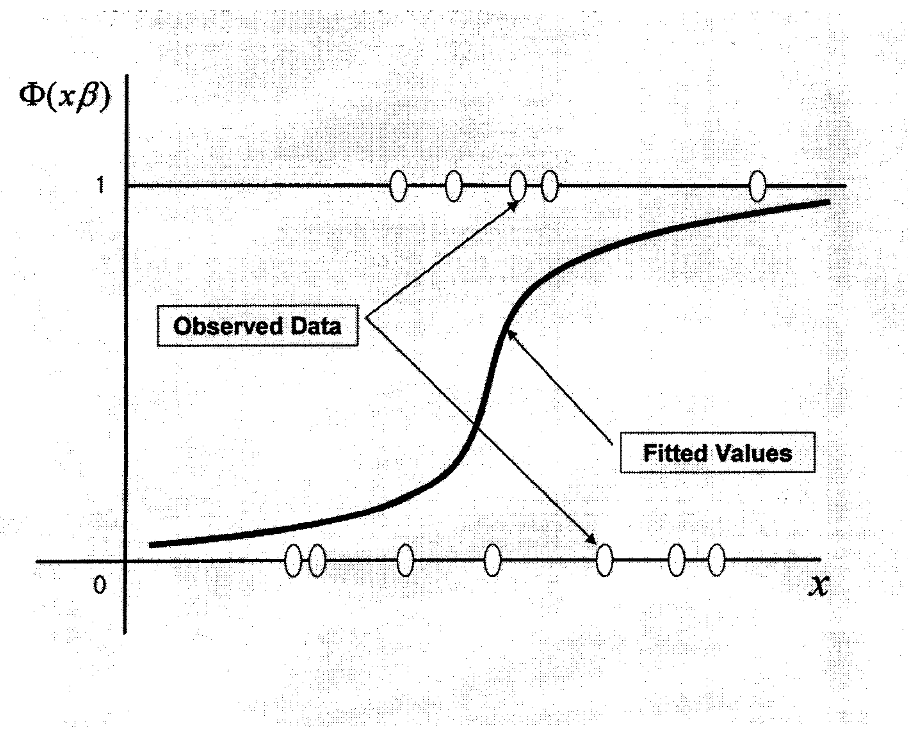

Fig. 1. Observed and Fitted Values of the Probit

2) If we assume a linear function instead, the functional values moves outside of the range 0<x<1. This is why we employ a probit or logit.

The probit can be written as

$$(1)\quad P(y=1)=F(x\beta)\ \text{or}$$
$$P(y=0)=1-F(x\beta)$$

where P denotes a probability that the firm made innovation during the observed period if $y=1$, F a probability distribution function, y the dependent variable, x the vector of the independent variables, and β parameters to be estimated. Thus, Eq.(1) represents the probability that a firm makes at least a one innovation during the period of consideration, given a set of independent variables. This model is called sometimes as a probit or logit according to the characteristics of *F*.

Suppose Eq.(1) is specified by a probit and let us assume that firm's innovative behavior is influenced by both firm-specific and industry-specific variables; such as firm's age, firm size and industrial (market) concentration (CR3), among others, as shown in Table 1. Then, we may rewrite the model as follows;

$$(3)\quad P(y=1)=\Phi(AG,EM,EMSQ,CR3)$$

where *AG* represents age of the firm, *EM* the number of the employed, $EMSQ=EM\times EM$, *CR3*, the ratio of sales of top three firms to total sales of the industry, and Φ(g) a standard normal cdf.

Therefore, Eq.(3) explains that firm's innovative behavior[3] is determined by both firm-specific variables, *AG*, *EM*, and *EMSQ*, and industry-specific variable, *CR3*. For the firm-specific variables, *EMSQ* is included, to investigate a quadratic relationship between innovative behavior and firm size.[4]

2. Firm's Innovation Capability Index

To estimate the model, we used the raw data from "Innovation Survey 1999," carried out by the STEPI.[5] It includes more than 3,000 firms in the manufacturing sector. However, 2299 firms were selected for the empirical analysis after removing missing data. In this dataset, the innovation is divided into the categories, i.e., *product innovation, product improvement, and process innovation.*

The estimation results of the model are reported in the following table. We first estimated the model without the quadratic term for the number of the employed, but we could not obtain significant results. By including the quadratic term, however, we were able to obtain

3) More specifically, it denotes the probability that the firm will make at least a one innovation.

4) This variable has an important implication regarding to the Schumpeterian Hypothesis. That is, if the quadratic term has a negative sign, it could be said that the larger firm might not be more innovative in proportion to the size.

5) This is the second survey ever since.

Table 2. Estimation of the Model: Eq.(3)

Independent Variables	Dependent Variables		
	New product innovation	Product improvement	Process innovation
Constant	-0.1652 (-1.790)	-0.4975 (-5.322)	-0.8827 (-8.554)
AG	0.0127 (5.504)	0.0054 (2.252)	0.0097 (3.835)
EM	8.32E-05 (2.673)	0.0001 (3.033)	0.0002 (3.892)
EMSQ	-1.88E-09 (-2.686)	-5.39E-05 (-2.248)	-6.21E-09 (-2.336)
CR3	-0.7730 (-4.704)	-0.3271 (-1.9764)	-0.3731 (-2.036)
Log likelihood	-1531.821	-1412.268	-1174.865
LR statistic (4 df) (Prob. of LR statistic)	62.663 (7.99E-13)	28.949 (8.01E-06)	58.277 (6.67E-12)
Fraction of Correct prediction			
% of E(# of Dep=0)	60.16	69.22	78.87
% of E(# of Dep=1)	42.79	32.05	23.88
Total (% of correct)	52.88	57.63	66.91
OBS with Dep=0	1336	1582	1799
OBS with Dep=1	963	717	500

Note : 1. The number in the parentheses are t-values
2. LR statistic is an analogue to F-statistic.
3. Fraction of correct prediction is shown as an analogue to goodness-of-fit.

significant results as shown below. Coefficients are all but *CR*3 for the product improvement significant at 5 % level.

The estimation results have important implication for the firm's innovative behavior and hence industrial policies. The interpretation of the results will not be made here in detail, because our purpose in this exercise is to produce an innovation capability index. In brief, though, the results show that the age of the firm has the positive relationship with the possibility of making innovations. The relationship between firm

Table 3. Innovation capability indices by industries

	# of samples	Innovation capability index			
		New product	Improvement	Process	Combined
Chemicals and chemical products	395	0.460	0.325	0.260	0.723
Rubber and plastic products	50	0.438	0.314	0.248	0.707
Non-metallic mineral products	76	0.451	0.321	0.256	0.717
Basic metals	89	0.392	0.305	0.249	0.675
Fabricated metal products	76	0.451	0.316	0.247	0.715
Machinery and equipment	235	0.382	0.294	0.232	0.661
Office and computing machinery	60	0.353	0.281	0.218	0.634
Electrical machinery, nes.	168	0.308	0.269	0.216	0.599
Radio, TV and communication equipment	189	0.385	0.299	0.240	0.665
Medical, optical & precision instruments	90	0.411	0.301	0.233	0.683
Motor vehicles and trailers	153	0.402	0.306	0.247	0.683
Other transport equipment	38	0.329	0.290	0.244	0.624
Manufacturing industry	2253	0.412	0.307	0.245	0.686
All industries	2299	0.411	0.307	0.245	0.685

Note : The combined index represents the probability that a firm makes at least one of three types of innovation.

size and innovation shows the inverse U-shape, which is not consent with the Schumpeterian hypothesis. In addition, the greater the market power of the firm, the smaller chances of making innovation are. In a word, it could be said that the medium-sized firms with relatively high competition would make greater innovation activities in Korea's manufacturing sector.

In fact, the observed data for the dependent variable are discrete. It has only either 0 or 1. However, if we compute fitted values of the dependent variable using the estimated model, they are continuous from 0 to 1. Those fitted values can be taken as an innovation capability index, which denotes the possibility of firm's making innovation. If the value of index is closer to one, the greater possibility of making innovation shows the firm. Vice versa.

In so doing, we obtain the innovation capability indices of the firm. Those indices are summarized in Table 3. All industries include 2299 firms and the manufacturing industry 2253 firms. The manufacturing industry is broken down into sub-industries. By such classification, we compute the average of firm's innovation capability indices.

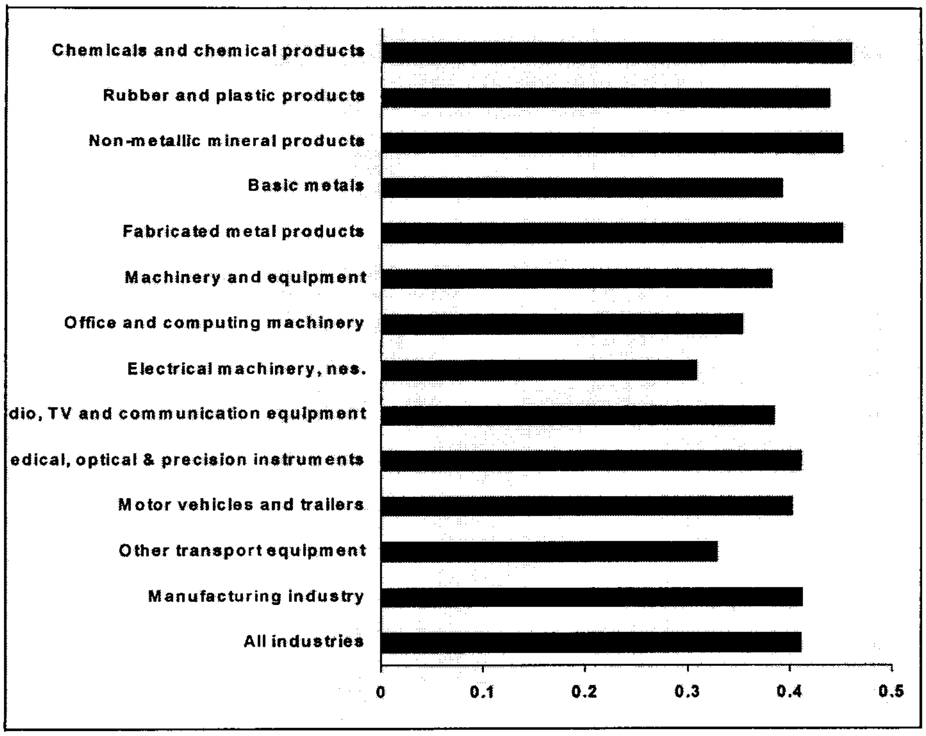

Fig. 1. Innovation Capability Index by Industries: New Production Innovation

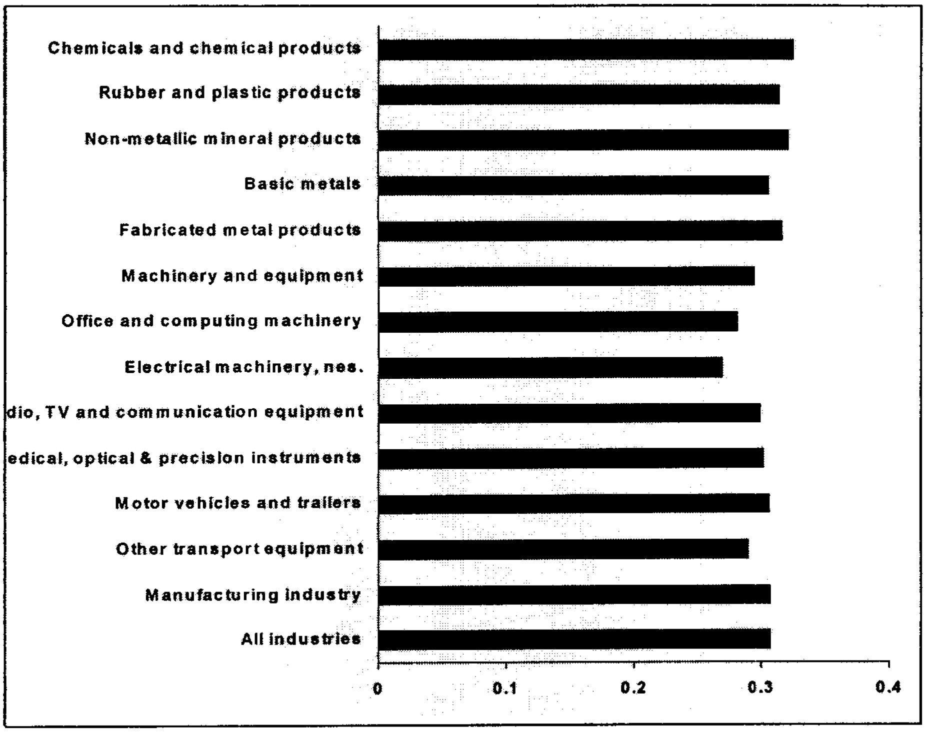

Fig. 2. Innovation Capability Index by industries: Product Improvement

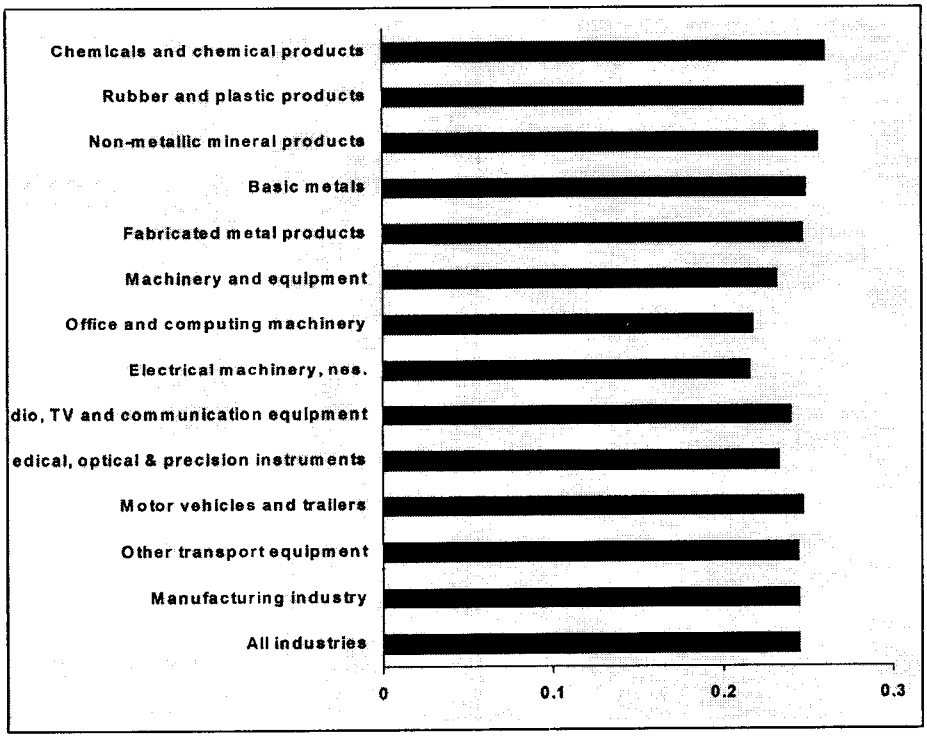

Fig. 3. Innovation Capability Index by Industries: Process Innovation

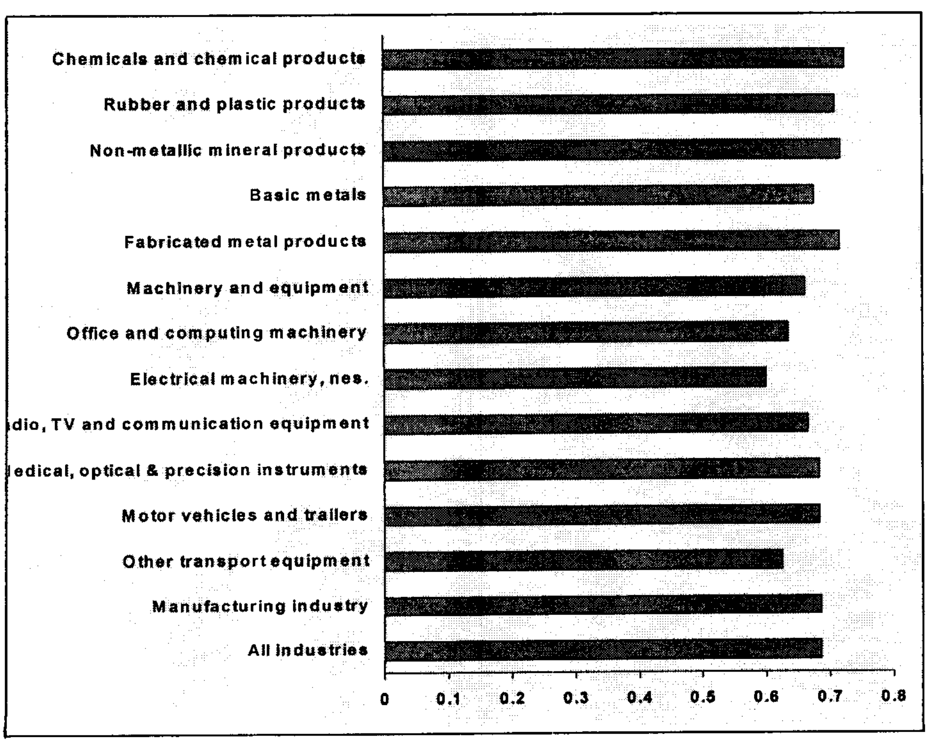

Fig. 4. Combined Innovation Capability Index by Industries

The average innovation capability indices for all industries are 0.411 for new product innovation, 0.307 for product improvement, 0.245 for process innovation, and 0.685 for combined innovation. On the other hand, the manufacturing industry shows 0.412 for new product innovation, 0.307 for product improvement, 0.245 for process innovation, and 0.686 for combined innovation. It can be seen that Korean firms are more product-innovation-oriented. It has been well pointed out that competitiveness of Korean firms is vulnerable due to weak capability of manufacturing process, leaning on labor-intensive or scale-intensive system. Such is reflected by the lower indices for process innovation, relative to those of product innovation.

In the manufacturing sector, the indices for new product innovation are ranging from 0.3 to 0. 5. They are all less than 0.5. On average the highest innovation capability was shown by firms of the chemicals and chemical products; 0.460. Some others like in rubber and plastic products, non-metallic mineral products, fabricated metal products, medical & precision instruments, and motor vehicles and trailer show relative high capability, whose indices are greater than 0.4 on average. It is noted that firms in the areas of machinery and equipment, office and computing machinery, and communication equipment show lower capability with less than 0.4.

In case of product improvement, a similar fashion to the case of new product innovation is shown. But all indices are less than those of new product innovation. The indices for process innovation are all less than 0.3, and not much difference between industries are shown.

The combined index was computed by obtaining the probability that the firm makes at least one of three types of innovations. Therefore, the innovation capability without regard to types of innovation can be represented by this index. It can be seen that firms in areas of chemicals and chemical products, rubber and plastic products, non-metallic mineral products and fabricated metal products exhibit higher innovation capability with the indices of greater than 0.7. Firms in the areas of electronics, machinery and transport equipment exhibit relatively lower innovation capability, though they are the major exporters.

In a concluding remark, it is noted that major industries of Korea, such as automobile, electronics, machinery and computers among others, exhibit relatively lower indices of innovation capability. If innovation capability determines firm's competitiveness in the present and future, such results would have significant implications both for business strategies and for industrial policies. On the other hand, the results could be enriched if an international comparison is possible. However, the access to other CIS dataset is extremely limited. In addition, it is difficult to aggregate the firm-level data to industrial and/ or national levels.

Ⅳ. Concluding Remarks

So far, we have attempted to develop new indicators related to firm's innovation activities. Innovation of the firm is one of most important factors to determine the firm's competitiveness. Conventional data have some limitations to capture firm's innovative behavior. Development of innovation capability index was suggested in the OECD workshop. (OECD, 1999a). In the workshop, six areas for investigation were suggested; i.e., mobility of human resources, patents, innovative capabilities of firms, internationalization of R&D, government support to R&D, and information and communication technology. The aim to develop index of innovation capabilities of firms is to map innovative and absorptive behavior of firms and improve knowledge of the determinants of innovation at the firm level. Innovation surveys, carried out in most OECD countries since 1990, are the basic data to be used.

In our study, we were not able to link our indices to other socio-economic data, due to various restrictions. A further analysis on the relevance of our indices is thus required. It could be done by investigating relationship of innovation capability index to other indicators reflecting industrial performance, such as growth rates of the value added, changes in the number of employment, and export performance, etc. On the other hand, if the survey is regularly undertaken, the panel data analysis will be possible, enriching the empirical results.

In the final note, the innovation capability index in our study does not compare innovation index of other countries. It is very difficult to undertake the innovation survey following the Oslo manual at the international level. But EEC countries in collaboration of OECD have made an attempt for internationally-approved innovation survey. Such possibility within the OECD area should be sought by further developing methodologies and survey manuals, which could be approved internationally. The effort at the multi-national level is very important to develop new indicators.

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