The Comparison of Basic Science Research Capacity of OECD Countries

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〈 목 차 〉

Summary: This paper presents a new measurement technique to derive the level of BSRC (Basic Science and Research Capacity) index by use of the factor analysis which is extended with the assumption of the standard normal probability distribution of the selected explanatory variables. The new measurement method is used to forecast the gap of Korea's BSRC level compared with those of major OECD countries in terms of time lag and to make their international comparison during the time period of 1981~1999, based on the assumption that the BSRC progress function of each country takes the form of the logistic curve.

The US BSRC index is estimated to be 0.9878 in 1981, 0.9996 in 1990 and 0.99991 in 1999, taking the 1st place. The US BSRC level has been consistently the top among the 16

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selected variables, followed by Japan, Germany, France and the United Kingdom, in order. Korea's BSRC is estimated to be 0.2293 in 1981, taking the lowest place among the 16 OECD countries. However, Korea's BSRC indices are estimated to have been increased to 0.3216 (in 1990) and 0.44652 (in 1999) respectively, taking 10th place.

Meanwhile, Korea's BSRC level in 1999 (0.44652) is estimated to reach those of the US and Japan in 2233 and 2101, respectively. This means that Korea falls 234 years behind USA and 102 years behind Japan, respectively. Korea is also estimated to lag 34 years behind Germany, 16 years behind France and the UK, 15 years behind Sweden, 11 years behind Canada, 7 years behind Finland, and 5 years behind the Netherlands.

For the period of 1981~1999, the BSRC development speed of the US is estimated to be 0.29700. Its rank is the top among the selected OECD countries, followed by Japan (0.12800), Korea (0.04443), and Germany (0.04029). The US BSRC development speed (0.2970) is estimated to be 2.3 times higher than that of Japan (0.1280), and 6.7 times higher than that of Korea. German BSRC development speed (0.04029) is estimated to be fastest in Europe, but it is 7.4 times slower than that of the US. The estimated BSRC development speeds of Belgium, Finland, Italy, Denmark and the UK stand between 0.01 and 0.02, which are very slow. Particularly, the BSRC development speed of Spain is estimated to be minus 0.0065, staying at the almost same level of BSRC over time (1981~1999).

Since Korea shows BSRC development speed much slower than those of the US and Japan but relatively faster than those of other countries, the gaps in BSRC level between Korea and the other countries may get considerably narrower or even Korea will surpass possibly several countries in BSRC level, as time goes by. Korea's BSRC level had taken 10th place till 1999. However, it is estimated to be 6th place in 2010 by catching up the UK, Sweden, Finland and Holland, and 4th place in 2020 by catching up France and Canada.

The empirical results are consistent with OECD (2001a)'s computation that Korea had the highest R&D expenditures growth during 1991~1999 among all OECD countries ; and the value-added of ICT industries in total business sectors value added is 12% in Korea, but only 8% in Japan. And OECD (2001b) observed that Korea, together with the US, Sweden, and Finland, are already the four most knowledge-based countries. Hence, the rank of the knowledge-based country was measured by investment in knowledge which is defined as public and private spending on higher education, expenditures on R&D and investment in software.

키워드 : Science and Technology (S&T), Basic Science and Research Capacity (BSRC), BSRC Progress Function, The Logistic Curve, and Factor Analysis.

1. Introduction

As the effect of S&T on a national economy and even the whole society is significant, we have a fundamental problem of measuring the level of science and technology (S&T) and the choice problem of an appropriate indicator of R&D output. If the level of S&T is not accurately measured and the indicator of R&D output is not appropriately chosen, empirical results of many studies such as the test of Schumpeterian hypothesis, the spill-over effects of R&D, the macroeconomic effects of technological development, etc. might be unreliable and disputable, consequently misleading the corresponding policy recommendations.

There have been many attempts[1] to measure the level of technological development. In the 1950s and 1960s, quantitative measurement of R&D expenditures were prevalent, and ever since 1970s, a more complex concept called S&T indicators has been made for the planning and implementation of technology policy in developed countries, including the United States[2].

In the 1990s, there have been major efforts to seek to develop better innovation indicator. For example, Kleinknecht and Bain (1993) and Kleinknecht (1996) presented a new measurement of innovation output and analyzed the determinants of innovation. OECD (1992) and the European Commission (1997) began the process of defining innovation indicators and coordinating their implementation across countries. These initiatives led, for example, to the OECD's Oslo Manual, first published in 1992 and revised in 1997, which attempted to provide theoretical and methodological foundations and guidelines for new innovation indicators, and to the Community Innovation Survey funded by the European Commission via Eurostat and implemented in 1992~1993, and again 1997~1998. IMD announces measured international competitiveness in the field of S&T.

Based on the field-focused division, OECD (1992) classifies the types of

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1) For example, Feinman and Fuentevilla (1976).

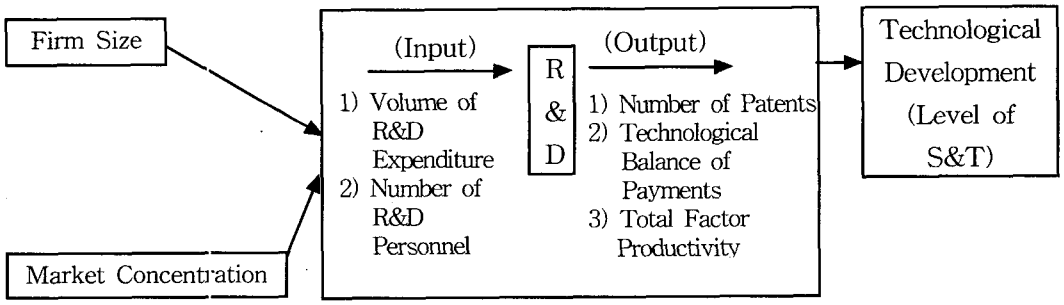
2) See M. N. Sharif (1986).

statistics and indices of S&T into four categories: 1) internal indicators for identifying internal resources and status changes, 2) goal indicators showing degree of goal achievement, 3) scoreboards indicators measuring the effects of science and technology on economy, society and environment, and 4) predictive indicators for forecasting future.

Viewing S&T activities from the standpoint of input-output system, Yoon (1994) classifies them into input indicators, output indicators and influence indicators in each stage. Also, Shin · Yoon · Jang · Kwon (1999) put forward new scientific and technological indicators which can be applied to knowledge-based economy.

The types of S&T vary according to how the S&T activity is measured. However, there are mainly two approaches to measure the S&T activity. One is the well-known and conventional input-output approach. This method views the S&T activity as an input-and-output relationship and measures it within this relationship. The other is the utilization-and-impact approach. The impact indicator is constructed by analyzing the quantitative and qualitative effects of S&T activity on the whole society.

Figure 1 summarizes the relationship between R&D and industrial organization (firm size and market concentration), the input-output relationship of R&D, and the relationship between R&D system and the level of S&T.



<Figure 1> The Relationship of R&D System with Industrial Organization and the level of S&T

The Frasctic Manual published by OECD (1981) made a good contribution to the measurement of R&D expenditures and personnel and R&D output. It seems that the measurement of R&D output and the level of S&T are still controversial, whereas the input variables : R&D expenditures and personnel can be accurately and consistently measured by the instruction of the Frasctic Manual, except for the two measurement problems : (1) R&D stock versus R&D expenditures and (2) exchange rate versus purchasing power parity.

Regarding innovation output measurement, Kleinknecht and Bain (1993) asserted that: in general, there are two measures of innovation output: postal innovation surveys and literature-based counting of innovations. The postal survey measures what firms themselves consider a 'new' or 'improved' product. However, we can find possible drawbacks of this method, because it is probably difficult to give meaningful responses to the questionaires about innovation output. Moreover, low response rates can be expected and consequently aggravated by a possible non-response selection bias, because innovative firms may have a higher probability of responding to an innovation survey than non-innovators.

Meanwhile, the literature-based method may yield some concerns about its completeness and reliability. Firms have no incentive to publicize their internal process innovations. Only process innovations embodied in new investment goods may be captured. In addition, the influence of firm size must be considered. We can expect a priori that large firms would be more active in publishing their innovations, which would increase the probability of their innovations being included in database, As a result, the database should be biased against inclusion of innovations from small firms. There are some other concerns about the availability of journals and consistency of data collection over time. Differences in journal availability occur between sectors within a country, but also between countries. Journals may also disappear or change their editorial policy.

On the other hand, technology balance of payment (TBP) can be used as an output indicator of R&D. However, Fabian (1984) noted that TBP only from royalties paid for technology transfer is not applicable to analysis of technology trade among advanced countries but to that among developing countries. This is not only because, for developing countries, technology trade may include technology

introduction (transfer) caused by introduction of capital goods, in addition to explicit technology transfer, but also because royalties paid for technology transfer must include experts' advices as well as technology itself.

The expression that "a country's R&D expenditures rank in the n-th position internationally" is commonly used. The R&D expenditures used here indicate the expenditure made every year in a certain country. With the volume of the R&D expenditures, the assertion that R&D expenditures of a certain country would stand in world ranking may be controversial. Even if two countries have the same amount of R&D expenditures, they may produce different output by their accumulated scientific knowledge. Therefore, we need R&D stock, which reflects the accumulated scientific knowledge, rather than R&D expenditures.

To measure the value of R&D stock, we need annual data of R&D expenditures, the time lag from the point when R&D expenditure are spent, the rate of obsolescence, and the deflator of R&D expenditures. But it is difficult to standardize these data. The reasons are as follows.

First, R&D expenditures differ according to the country, industry, and the level of technology. They differ according to the level of R&D activity, even in the same industry and application field. For instance, if a certain project emphasizes basic research, the time lag will increase, whereas, if a certain project stresses applied research, the time lag will decrease. Therefore, to calculate the value of R&D stock, the measurement of time lag should be made.

Second, as time passes, new research output will increase, and therefore the value of past R&D output will decrease. Thus, to estimate the present value of R&D stock, the duration of the usefulness of past R&D output should be measured.

Third, to calculate the value of R&D stock, R&D expenditures have to be measured in constant price, which requires the deflator of R&D expenditures. Gross domestic product (GDP) deflator can be used, but it is composed of prices of all commodities. The cost of some equipments can take the most part of the given R&D expenditures. Therefore, an appropriate deflator of R&D expenditures should be used. In consideration of the aforementioned problems, it is almost impossible to calculate the value of R&D stock for each country.

For international comparison of R&D expenditures, it should be done by

comparing each country's currency unit with a standard currency, and thus the exchange rate is commonly used. However, the exchange rate does not reflect the real value of each currency unit. The exchange rate is determined by demand and supply of foreign currency, which are in turn influenced by the corresponding country's trade balance, currency policy, etc. The currency unit converted according to the exchange rate is the nominal value, not the real value. To overcome the aforementioned problem of the exchange rate, purchasing power parity was used in the study of Lim and Song (1996).

Under the previously-described background, the purposes of the current paper can be summarized as follows:

(1) to present a new measurement technique to derive the level of basic science research capacity by use of factor analysis which is extended with the assumption of the standard normal probability distribution of the selected explanatory variables; and

(2) to forecast the level of basic science research capacity and the gap for its international comparison, based on the assumption that the BSRC progress function of each country takes the form of the logistic curve.

For the purposes above, Chapter II shall present a new measurement technique to derive a numerical index of BSRC and forecast the BSRC gap for its international comparison, Chapter III shall review the literature and conduct the current empirical study, and finally Chapter IV shall make conclusion from the preceding analyses.

2. A New Method to measure the BSRC Index and Its Forecasting

2.1 A New measurement Technique

It is not easy to represent the level of S&T in terms of a numerical index. To make an index, we must select appropriate variables and assign appropriate weight to the selected variables for a concerned study. Factor analysis is one of the

statistical methods to derive an index from a given set of variables.[3] A few examples of studies that use factor analysis in evaluating a technology index are Blackman (1972), Blackman, Seligman, and Sogliero (1973), Blackman (1974), Sharif and Haq (1980), Sharif, Dodson (1985), KAIST (1986), and Lim (1986a, 1986b, 1987, 1989a, 1989b, 1991, 1994 and 2000), Klein and Lim (1997), and Kwon and Park (2000).[4]

Lim and Song (1996), and Kwon and Park (2000) have in common in that the two papers derived the weights of selected variables by using factor analysis, and utilized cumulative normal distribution to convert it into comparable index. Differences in the two studies are as follows : Kwon and Park (2000) used cross section data based on 1998 to set index range from 0 to 100, and compared indices of selected countries. In contrast, Lim and Song (1996) used time series data from 1981 to 1992 to set index range from 0 to 1, estimated the development function of basic science research capacity (BSRC), predicted the level of BSRC in 2000 on the basis of the function, and analyzed time lags of Koreas BSRC index compared with those of 19 OECD[5] and Taiwan.

It is notable that Blackman (1974) calculated the composite index of innovation based on sales, value added, capital investment, the ratio of new product to R&D investment, etc. He estimated the propensity to innovate of the electric power and automobile industries, and also the rate of technological diffusion in the US markets of shipping, automobiles, electricity and jet engine.

Similarly, Lim and Song (1996) presented a methodology to calculate a technology index by use of a modified factor analysis method with the assumption of standard normal probability distribution of the selected variables and the driven

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3) Factor analysis is used in redefining the interrelations between several variables into a correlation by finding common variation patterns from the selected variables. This method drives common variation from the correlation of the chosen variables, identifies the measurement overlaps, and extracts a group of fundamental and hypothetical factors, with a view to use the correlation among the factors to redefine the correlation among several variables.

4) They used factor analysis to measure and compare the knowledge-based competitiveness of selected countries.

5) members The 19 OECD members comprise Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Holland, Ireland, Italy, Japan, Norway, Portugal, Spain, Sweden, United Kingdom, and USA.

Index. By the same methodology, Klein and Lim (1997) attempted to solve the fundamental question: which is more effective to improve the technological level of the follower? Is it independent technological development or importation of advanced technologies from the leader? This study leads to the conclusion that more effective is an leader's technologies, i.e., technology transfer from the leader, although it is not something the follower can achieve by its unilateral efforts.

By applying the previously-mentioned method of Lim (1986a, 1986b, 1987, 1989a, 1989b, 1991, 1994 and 2000), we can derive a numerical index of S&T involves the following six steps : (1) calculation of the correlation coefficient matrix ; (2) extraction of the unrotated factor loading matrix ; (3) calculating the weights of the selected variables by using the Z-scores of the selected variables in the standard normal probability distribution ; (4) transforming the value of each variable with different measurement units into the corresponding Z-scores ; (5) computing the technology indices with the range of $-\infty$ to $+\infty$ for each year over time ; and (6) transforming the above technology indices with the range of $-\infty$ to $+\infty$ into those with that of 0 to 1 in the standard normal probability distribution.

The variables should be unified into identical measurement units. A statistical method used in converting variables with different measurement units to the same measurement unit transforms the value of each variable to the corresponding probability variable, under the assumption that each factor forms the standard normal probability distribution. For example, the value of each variable can be transformed to the Z-Score with the average value of 0 and the variance of 1 under the assumption that each variable is normally distributed. Table 1 illustrates the factor loading matrices of the five variables : X_1, X_2, X_3, X_4 and X_5.

<Table 1> Factor Loading Matrices

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
X_1	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	$C_1=\Sigma(F_{1j})^2$
X_2	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}	$C_2=\Sigma(F_{2j})^2$
X_3	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	$C_3=\Sigma(F_{3j})^2$
X_4	F_{41}	F_{42}	F_{43}	F_{44}	F_{45}	$C_4=\Sigma(F_{4j})^2$
X_5	F_{51}	F_{52}	F_{53}	F_{54}	F_{55}	$C_5=\Sigma(F_{5j})^2$
Eigen Value	$E_1=\Sigma(F_{i1})^2$	$E_2=\Sigma(F_{i2})^2$	$E_3=\Sigma(F_{i3})^2$	$E_4=\Sigma(F_{i4})^2$	$E_5=\Sigma(F_{i5})^2$	5

In principle, the five variables are respectively matched by the corresponding five factors, because the meaning of each factor differs so long as the five variables are not identical. In the factor loading matrix, the factor loading value (Fij, i=1, 2, ⋯, 5); j=1, 2, ⋯, 5), the communality, the factor loading matrix, and the eigen value have the following relations:

$\Sigma(Fij^2)=Ci=1$ (j=1, 2, ⋯, 5) ..... (1)

$\Sigma(Fij^2)=Ej=1$ (i=1, 2, ⋯, 5) ..... (2)

$\Sigma Ej=5$ (j=1, 2, ⋯, 5) ..... (3)

where

F = the factor loading value

C = the communality

E = the eigen value

Suppose that F^2_{11} and F^2_{12} stand for the variation of X_1 explained by factor 1 and the variation of X_1 explained by factor 2, respectively. The total variation of X_1 explained by factor 1 through factor 5 ($F^2_{11} + F^2_{12} + F^2_{13} + F^2_{14} + F^2_{15}$) amounts to 1. The total variation of the five variables ($X_1 \sim X_5$) that is explained by factor 1 ($F^2_{11} + F2_{21} + F^3_{21} + F^4_{21} + F^5_{21}$) is called the eigen value. This value represents the portion that factor 1 explains out of the total variation. For instance, if the eigen value is 3.50%, the total variation of the five variables ($X_1 \sim X_5$) is 5, and therefore factor 1 explains 70% (3.5 out of 5) of the total variation.

The selected variables are needed to be grouped and the weight of each factor is needed to be determined. Assume that F_{11}, F_{21}, F_{31}, F_{42} and F_{52} have, respectively, the highest value in the corresponding factor loading matrix of X_1, X_2, X_3, X_4 and X_5. In this case, X_1, X_2 and X_3 can be categorized as a group that shares an identical characteristic of factor 1, and so can X_4 and X_5 as a group that has the characteristic of factor 2. As a result, X_1, X_2, ⋯⋯, X_5 can be divided into two groups represented by factor 1 and factor 2. Such a process leads to the selection of variables required for the derivation of the index.

When X_1, X_2 and X_3 are grouped together, their weights are calculated from the factor loading matrix. The weight of each factor amounts to the variation of each variable (F_{ij}^2, i =1, 2, 3) divided by the total variation of X_1, X_2 and X_3. Therefore, the weight of X_1 is $F^2_{11}/(F^2_{11} + F^2_{21} + F^2_{31})$, that of X_2 is $F^2_{21}/(F^2_{11} + F^2_{21} + F^2_{31})$, and that of X_3 becoming $F^2_{31}/(F^2_{11} + F^2_{21} + F^2_{31})$. Using the weight and Z-score of each variable, the technology index I can be calculated as follows:

$$I = W_1Z_1 + W_2Z_2 + W_3Z_3 \quad (4)$$

where

Z_1, Z_2 and Z_3 = the Z-scores of X_1, X_2 and X_3, respectively, in the standard normal probability distribution

W_1, W_2 and W_3 = the weights of X_1, X_2 and X_3, respectively,

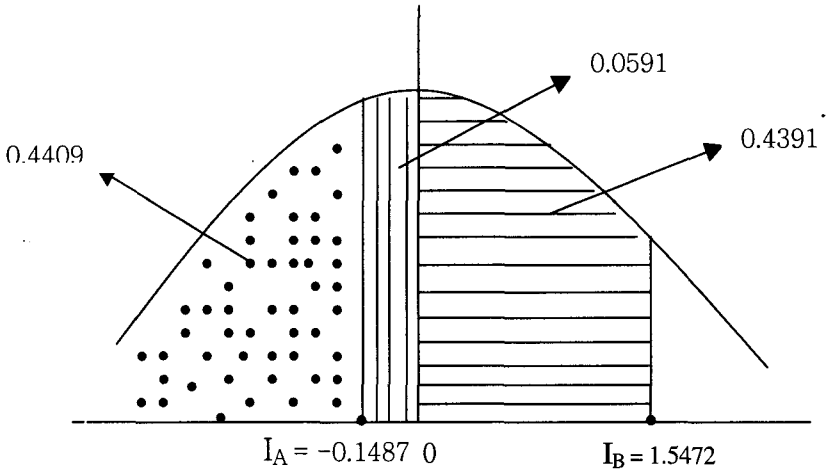
$$W_1 = \frac{F_{11}^2}{F_{11}^2 + F_{21}^2 + F_{31}^2}$$

$$W_2 = \frac{F_{11}^2}{F_{11}^2 + F_{21}^2 + F_{31}^2}$$

$$W_3 = \frac{F_{11}^2}{F_{11}^2 + F_{21}^2 + F_{31}^2}$$

Since the technology index I is a Z-score, it takes on positive and negative values. It is necessary to transform the index so as to enable the index to have positive values in a certain range. Lim (1986a) has originally developed the methodology of transforming an index with positive and negative values into an index with nonnegative value between o and 1 by the Z-score method.

Figure 2 shows how to transform the weight of each variable and index I with positive and negative values into an index with its value between 0 and 1. The Z-score has the average value of 0 and a variance of 1. The probability that a value of less than 0 can occur is 0.5, which is also the probability area under the standard normal curve that a value of more than 0 can occur.



<Figure 2> Transformation of an Index with negative value into an Index with nonnegative value (0~1).

Assuming that the indices of (I_A and I_B) are -0.1487 and 1.5472, respectively, the probability area where -0.14 can occur is 0.0557 and the probability area for -0.15 is 0.0600. The probability area where -0.1487 can occur is 0.0591. The probability area under the standard normal curve from minus infinity (-∞) to -0.1487 is 0.4409. When I_A with the value of 0.1487 is transformed into an index with a value between 0 and 1, the result is I_A with the value of 0.4409. By the same way, the index I_B may also be obtained. The probability area from 0 to 1.5472 is 0.4391. When I_B with the value of 1.5472 is transformed into an index with a value between 0 and 1, the index of IB is consistent with the value of 0.9391 in the probability area with the range of -∞ to -1.5472.

2.2 BSRC Progress Function of the Logistic Form and Forecasting of BSRC

This author assumes that a BSRC progress function can be represented by equation (5) which is a logistic curve :

$$I(t) = \frac{1}{1+ae^{-b \cdot t}} \quad \cdots\cdots (5)$$

I(t) is the BSRC progress function with $0 \leq I(t) \leq 1$, the two constants (a and b) have positive values, b represents the development speed of BSRC, and t is time index. This function shows the level of technological development over time, *i.e.*, the BSRC development curve. We can identify the function (curve), I(t) by setting dI(t)/dt (velocity) and $d^2I(t)/dt^2$ (acceleration) below.

$$\frac{dI(t)}{dt} = \frac{abe^{-b \cdot t}}{(1+ae^{-b \cdot t})} \quad \cdots\cdots (6)$$

$$\frac{dI^2(t)}{dt^2} = \frac{(1+ae^{-b \cdot t})ab^2e^{-b \cdot t}}{(1+ae^{-b \cdot t})^3} \quad \cdots\cdots (7)$$

Thus, the value of t at the inflection point of ($d^2I(t)/dt^2 = 0$) can be calculated by equation (8).

$$t = \frac{\ln a}{b} \quad \cdots\cdots (8)$$

The BSRC index, particularly at the inflection point, i.e., the value of I(t) is 1/2 by the nature of a logistic curve.

$$I(t) = \frac{1}{2} \quad \cdots\cdots (9)$$

Thus, the BSRC progress function I(t) may be classified into the three parts of the logistic curve as follows :

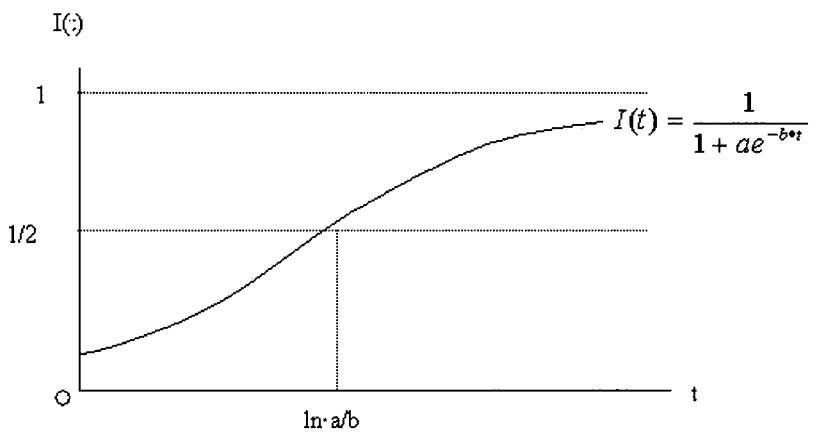
$d^2I(t)/dt^2 > 0$ for the case of $I(t) > 1/2$
$d^2I(t)/dt^2 = 0$ for the case of $I(t) = 1/2$
$d^2I(t)/dt^2 < 0$ for the case of $I(t) < 1/2$

The values of I(t) for the cases of t = 0 and t = are, respectively, calculated as 1/(1+a) and 1.

$$I(0) = \frac{1}{(1+a)} \quad \text{.....} (10)$$

$$I(\infty) = 1 \quad \text{.....} (11)$$

For the general case where a >1, the BSRC progress function takes the S-shaped logistic form, as shown in Figure 3.



<Figure 3> BSRC Progress Function of the Logistic form

To estimate the BSRC progress function represented by equation (5), we can take the natural logarithm on both sides and converting it into linear regression equation (12).

$$Y = \alpha + \beta \cdot t \quad \text{.....} (12)$$

where

$Y = \ln(1/I(t)-1)$

$\alpha = \ln a, \ -\infty < \alpha < \infty$

$\beta = -b, \quad \beta<0$

3. Empirical Analysis

3.1 Review of the Literature

Basic science research capacity (BSRC) can be defined as social capacity for basic science research. Basic Research is defined by the National Foundation (NSF) "as original investigations for the advancement of scientific knowledge … which does not have immediate commercial objectives" (NSF (1959), p 124).

Mansfield (1980) empirically tested whether basic research, as contrasted with a significant contribution to an industry's a firm's rate of technological innovation and productivity change. His test results indicate that there is a statistically significant and direct relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, when its expenditures on applied R&D are held constant. His findings also indicate that the composition of many industries' R&D expenditures has changed in the last decade.

The authors shall measure and predict the BSRC levels of selected OECD countries by use of the aforementioned Lims method and estimate time lags of Koreas BSRC level compared with those of advanced countries. There are many other methods such as analogy, extrapolations, correlation analysis, causal model, technometrics, morphology, and Delphi, which are proposed by Jantach (1967), Certron and Ralph (1971), Bright (1978), Jones and Twiss (1978), Lenz (1985) and Martino (1993), in order. However, the authors shall use the method of the logistic curve approach, due to its mathematical usefulness, e.g., the introduction of its slope which is interpreted as the BSRC development speed in our study.

Lim and Song (1996) was the first study to calculate BSRC index to predict and compare international differences in BSRC level on the basis of Koreas BSRC level. The current paper intends to extend the time coverage (1982~1992) of Lim and Song (1996) to the period 1981~1999 and update it. This study was

initially attempted to analyze all the countries that could provide source data needed for BSRC index among statistical data of OECD, but only 16 countries were selected for this analysis.[6] The 16 countries are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Korea, Norway, The Netherlands, The United Kingdom, USA, Spain, Sweden and Japan.

Comparing the predictions of Lim and Song (1996) from the standpoint of the present, the forecasted BSRC level of Korea in 2000 took 15th place, whereas SCI publications of Korea in 1999 took 16th place, showing that the prediction was very close to the performance. However, the previous study overestimated the BSRC of relatively small countries showing enthusiasm about R&D, and underestimated relatively the BSRC of large countries taking passive stance toward R&D. It seems that this distorted estimation was due to the fact that among the variables used, BSRC index comprising variables reflecting absolute values and relative values (numeric value per head, ratio per head, etc.) was calculated in relative favor of small countries.

3.2 Statistical Data

Statistical data for empirical analysis of this study comprises primary R&D input indicators from OECD (1994) and other indicators recommended by scientific and technological service (STE) of UNESCO (1978). As shown in Table 2, eight variables are selected through factor analysis. The variables : X_1, X_2, X_3 and X_4 are related to national R&D activity, whereas the remaining variables : X_5, X_6, X_7 and X_8 are related to basic science research activity. The values of these 8 indicators of 16 countries between 1981 and 1999 are drawn from the statistical data of OECD (2000).

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6) Lim and Song (1996) included Australia, Greece, Ireland, Portugal and Taiwan in the analysis. However, they were not covered because of their poor statistics. Especially, Taiwan was excluded from the statistical coverage of OECD.

<Table 2> Selected Variables for BSRC Index

The Variables related to National R&D Activity	X_1 = GERD (Gross Domestic Expenditures on R&D ; 1995 constant million PPP $) X_2 = Total Number of Researchers (FTE) X_3 = GERD (Gross Domestic Expenditures on R&D ; 1995 constant million PPP $) as a percentage of GDP (constant million PPP $) X_4 = Number of Researchers (FTE) per 10,000 population
The variables related to Basic Science Research Activity	X_5 = HERD (higher education expenditures on R&D), i.e., University R&D Expenditures (1995 constant million PPP $) X_6 = Number of University Researchers (FTE) X_7 = R&D Expenditures per Researcher in University (1995 constant million PPP $) X_8 = Number of SCI (Science Citation Index)

Note : PPP $ implies the US dollar reflecting purchasing power parity.

SCI (X_8 in Table 2) among the 8 variables above is generally used as a typical S&T index, because this indicator provides full sight of the trends of development and research in each field of science field, presents desirable research orientation in the future, and shows competing countries level of science and technology, helping each state set strategic goals for national science development. Also, SCI makes it easy to know which research center or researcher has excellent research achievements.

The variables of monetary term (e.g., R&D expenditures) among the variables in Table 2 uses US dollar based on purchasing power parity of each country for international comparison. It is most frequently to use exchange rate to convert currencies of analyzed countries to US dollars. However, OECD (1972) recommends to use US dollar purchasing power parity (ppp $) in comparing R&D expenditures. Because the use of exchange rate has many problems. For example, exchange rate cant reflect real value of each currency. Exchange rate is the ratio for money exchange, which is decided by the demand and supply of money in international financial market, which is in turn influenced by trade

balance and monetary policy (or interest rate policy) of the concerned country. Therefore, comparison of monetary unit based on exchange rate is virtually to compare nominal value instead of real value of money.[7] Also, this study applies 1995 constant price to remove distortion of current price caused by inflation in each country. And, FTE (full-time equivalent) is used as unit of manpower.

3.3 International Comparison of BSRC Indices

Based on Lim's measurement method described above, this study calculates BSRC indices of 16 OECD countries for the sample years : 1981, 1990 and 1999, respectiuely, and compares their BSRC levels in the same years, as shown by Table 3. The US BSRC index is estimated to be 0.9878 in 1981, 0.9996 in 1990 and 0.99991 in 1999, taking the 1st place. The US BSRC level has been consistently the top among the 16 selected variables, followed by Japan, Germany, France and the United Kingdom, in order. In 1990, France and the UK are estimated to be 0.5643 and 0.5329 respectively, showing slight difference. However, the two countries are estimated to be 0.57887 and 0.57414 respectively in 1999, showing narrower gap than in 1990. Meanwhile, Korea's BSRC is estimated to be 0.2293 in 1981, taking the lowest place among the 16 OECD countries. In 1990 and 1999, Korea's BSRC indices are estimated to have been increased to 0.3216 and 0.44652 respectively, taking 10th place.

7) Since IMF bailout in late 1997, Korean currency to dollar in 1998 was about KRW 1,200, but Korean currency to US dollar based on purchasing power parity in the same year was KRW 667.6 per dollar, showing large difference from exchange rate.

<Table 3> International Comparison of BSRC Indices

Country	1981		1990		1999	
	Rank	BSRC Index	Rank	BSRC Index	Rank	BSRC Index
The United States	1	0.9878	1	0.9996	1	0.99991
Japan	2	0.6265	2	0.8315	2	0.97886
Germany	3	0.5679	3	0.6555	3	0.73655
France	4	0.5241	4	0.5643	4	0.57887
The United Kingdom	5	0.4694	5	0.5329	5	0.57414
Sweden	9	0.3404	9	0.3903	6	0.57184
Canada	6	0.4332	7	0.4044	7	0.52920
Finland	8	0.3445	8	0.3958	8	0.48291
The Netherlands	7	0.3707	6	0.4250	9	0.46328
Korea	16	0.2293	10	0.3216	10	0.44652
Australia	10	0.2842	12	0.3054	11	0.39882
Norway	12	0.2819	11	0.3183	12	0.39369
Denmark	14	0.2495	15	0.2894	13	0.38445
Belgium	15	0.2491	16	0.2829	14	0.38444
Italy	11	0.2836	13	0.2960	15	0.36163
Spain	13	0.2814	14	0.2936	16	0.29643

Note : The BSRC development speed is defined as "b" in eqouation (5).

3.4 Estimation of Koreas Time Lag in BSRC with Advanced Countries

The development function of Koreas BSRC index is estimated, as shown by equation (13),[8] which shall be used to calculate Koreas time lag in the index compared to BSRC indices of advanced countries.

$$I(t) = \frac{1}{1 + 2.9772e^{-0.0444t}} \quad \text{.....} \quad (13)$$

This study substitutes time variable in the above equation (13) to estimate

8) Lim and Song (1996) estimated Koreas BSRC development function as follows:

$$I(t) = \frac{1}{1 + 2.9772e^{-0.0444t}} \quad \text{———} \quad (14)$$

how much time it takes for Korea's BSRC level in 1999 to reach the BSRC levels of advanced countries in that year, i.e., how long the relative time lag of Korea's BSRC is. Korea's time lags in the BSRC indices compared with major advanced countries are estimated, as shown by Table 4.

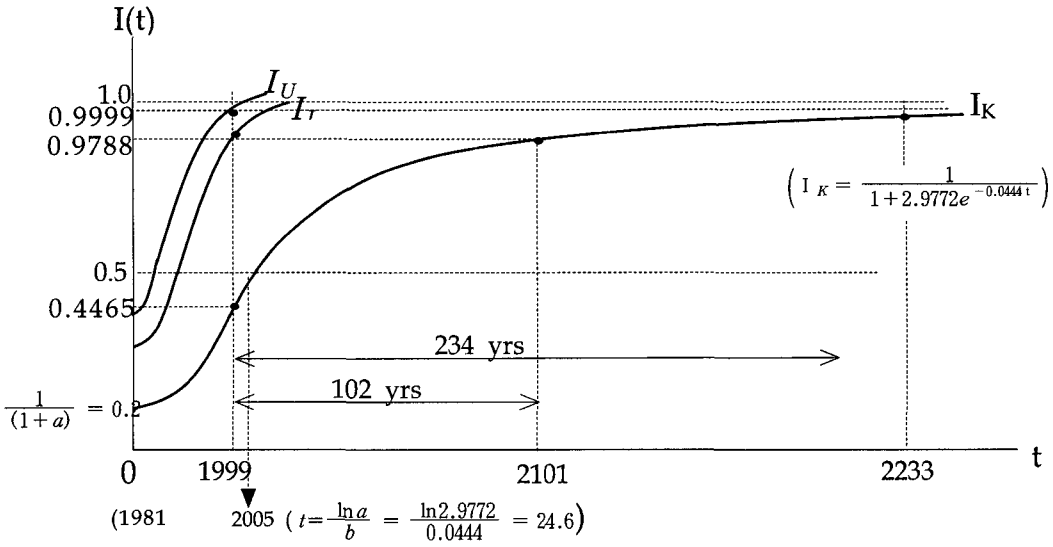
<Table 4> Korea's Time Lags in BSRC compared with major OECD Countries

Country	The 1999 Level of BSRC	The expected year for Korea to reach the 1999 BSRC level of the advanced countries	Time Lag
The United States	0.99991	2233	234
Japan	0.97886	2101	102
Germany	0.73655	2033	34
France	0.57887	2015	16
The United Kingdom	0.57414	2015	16
Sweden	0.57184	2014	15
Canada	0.52920	2010	11
Finland	0.48291	2006	7
The Netherlands	0.46328	2004	5

Note : The 1999 level of Korea's BSRC = 0.446529 as shown in Table 3.

The BSRC levels of the US and Japan in 1999 are estimated to be 0.99991 and 0.97886 respectively. Other things being equal, Korea's BSRC level in 1999 is estimated to reach those of the two countries in 2233 and 2101 respectively, as depicted by Figure 4. This means that Korea falls 234 years behind USA and 102 years behind Japan, respectively. On the other hand, Korea is estimated to lag 34 years behind Germany, 16 years behind France and the UK, 15 years behind Sweden, 11 years behind Canada, 7 years behind Finland, and 5 years behind the Netherlands.[9)]

9) It is worthwhile to note that Lim and Song (1996) estimated the 1992 BSRC index of Korea lagged 68 years behind the United States, 41 years behind Japan, 16 years behind Germany, 10 or more years behind the Netherlands, England, Sweden, and Canada.



<Figure 4> The BSRC Progress Function of the US, Japan and Korea

The estimated time lags may be exaggerated due to the inherent characteristics of the logistic curve. However, the comparative data in Table 5 demonstrates how much Korea's technological competitiveness should be further promoted.

<Table 5> Comparison of Technological Comparativeness between the US, Japan and Korea

	R&D Inputs				Performances		
	R&D Expenditures (billion US $)	R&D/GDP (%)	R&D/Sales (%)	Researchers (thousand)	Patents (thousand)	Research Papers (thousand)	Technology Exports (billion US $)
The US	205.6	2.5	4.0	936	110	307	33.70
Japan	130.2	3.1	3.7	614	148	75	7.30
Korea	12.8	2.9	2.6	138	25	10	0.14

Source : Korea Industry Technology Promotion Association (2000).

3.5 Forecasting of the BSRC Indices

By regressing the BSRC development functions of the selected OECD countries based on the BSRC indices for the years of 1981~1999, the author estimates the development speeds and then forecasts the levels of BSRC indices for 2010 and 2020, as shown in Table 4. The BSRC development speed of the US is estimated to be 0.29700. Its rank is the top among the selected OECD countries, followed by Japan (0.12800), Korea (0.04443), and Germany (0.04029).

<Table 6> Forecasts of BSRC Indices of the selected OECD Countries

Country	Development Speed of BSRC index	2010		2020	
		Rank	BSRC index	Rank	BSRC index
The United States	0.29700	1	0.99999	1	1.00000
Japan	0.12800	2	0.99593	2	0.99932
Germany	0.04029	3	0.81635	3	0.87189
France	0.02924	4	0.68665	5	0.75924
Canada	0.02495	5	0.64486	6	0.74904
Korea	0.04443	6	0.64284	4	0.77638
Sewden	-0.00645	7	0.59479	8	0.64240
Finland	0.01651	8	0.56523	7	0.67927
The United Kingdom	0.01015	9	0.56186	11	0.57192
The Netherlands	0.02039	10	0.53547	10	0.60828
Australia	0.02278	11	0.52550	9	0.62577
Norwway	0.00825	12	0.48246	13	0.55919
Denmark	0.01082	13	0.47502	12	0.56292
Belgium	0.01760	14	0.45557	14	0.53365
Italy	0.01227	15	0.39937	16	0.42382
Spain	0.02783	16	0.39217	15	0.48121

The US BSRC development speed (0.2970) is estimated to be 2.3 times higher than that of Japan (0.1280), and 6.7 times higher than that of Korea. German BSRC development speed (0.04029) is estimated to be fastest in Europe, but it is 7.4 times slower than that of the US. The BSRC development speeds of the

other countries are estimated to be less than 0.03. The estimated BSRC development speeds of Belgium, Finland, Italy, Denmark and the UK stand between 0.01 and 0.02, which are very slow. Particularly, the BSRC development speed of Spain is estimated to be minus 0.0065, staying at the almost same level of BSRC over time (1981~1999).

In 1999, the US maintains first with 0.99991, followed by Japan with 0.97886, Germany with 0.73655, France with 0.57887, and the UK with 0.57414. Korea takes 10th with 0.44652. However, as time passed, there is a big change. In the year 2010, there is no change in the top four spots, but Canada takes 5th with 0.82701, and Korea 6th with 0.64284. Also, in 2020, there is no change in the first to third places. However, Korea takes 4th, France 5th, and Canada 6th.

It should be noted that BSRC levels of the UK, Sweden, Finland, Holland and Denmark are estimated to be low in the current analysis, whereas they were forecasted to be high in the study of Lim and Song (1996), and Koreas BSRC development speed has been accelerated, which is estimated to rise to 6th place in 2010 and 4th in 2020.

Since Korea shows BSRC development speed much slower than those of the US and Japan but relatively faster than those of other countries, the gaps in BSRC level between Korea and the other countries may get considerably narrower or even Korea will surpass possibly several countries in BSRC level, as time goes by. As shown in Table 3, Korea's BSRC level had taken 10th place till 1999. However, as shown in Table 4, it is estimated to be 6th place in 2010 by catching up the UK, Sweden, Finland and Holland, and 4th place in 2020 by catching up France and Canada. The empirical results are consistent with OECD (2001a)'s computation that Korea had the highest R&D expenditures growth during 1991~1999 among all OECD countries ; and the value-added of ICT industries in total business sectors value added is 12% in Korea, but only 8% in Japan. And OECD (2001b) observed that Korea, together with the US, Sweden, and Finland, are already the four most knowledge-based countries. Hence, the rank of the knowledge-based country was measured by investment in knowledge which is defined as public and private spending on higher education, expenditures on R&D and investment in software. These variables for

the knowledge-based country are contrast with the selected variables for BSRC index which are listed in Table 2.

4. Conclusion

Although it is only a numerical analysis, Koreas time lags in the BSRC index compared with the advanced countries clearly suggested how Korea should further promote basic science research capacity (BSRC). The reason why Koreas time lags considerably behind the advanced countries in BSRC is because basic science and technology take a very small share in whole R&D expenditures, in addition to small scale of whole R&D expenditures.[10] Universities play the most important role in development of basic science. However, Korean universities of science and engineering show sluggish R&D activities because of very small investment in R&D, although they have relatively high quality manpower.[11] Therefore, Korean government should increase R&D expenditures to rise the share.[12] As UR agreements allows governments to provide financial support for basic science, Korean government should improve support systems in financial support in order to induce firms to invest in basic science.[13]

Therefore, Korean government must seek to maximize BSRC by supporting more positively research activities of universities in basic science. Creative personnel should be emphasized as one of the most important driving forces

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10) In 1996, KRW 1,439 billion won was invested in basic science research, accounting for only 13.2% of total R&D expenditures (USD 13.5 billion). This is low compared with 16.2% in USA, 14.1% in Japan, 21.0% in Germany (1991) and 21.0% in France (1992).

11) For instance, in 1999, the number of SCI publication which is one of S&T indices showing the level of basic science, is 9,124 taking 17th place in the world. SCI share is only 1.02%. International comparison of R&D expenditures per researcher in 1998 shows that Korea recorded USD 88,000, compared with 2.0 times higher USD 172,000 in USA, 2.2 times higher USD 196,000 in Japan, 2.7 times higher USD 240,000 in Germany, 2.6 times higher USD 154,000 in France, and 1.8 times higher USD 154,000 in UK. See Yang-Taek Lim (1998), KMOST (1998), and OECD (1999).

12) Government's share of R&D expenditures of Korea in 1998 recorded 26.9%, compared with 24.9% in Japan, 34.3% in the US, 35.2% in Germany, 35.6% in the UK, 42.1% in Taiwan and 43.1% in France. See OECD, *Main Science and Technology Indicators*, various issues.

13) For details, see Yang-Taek Lim (1996).

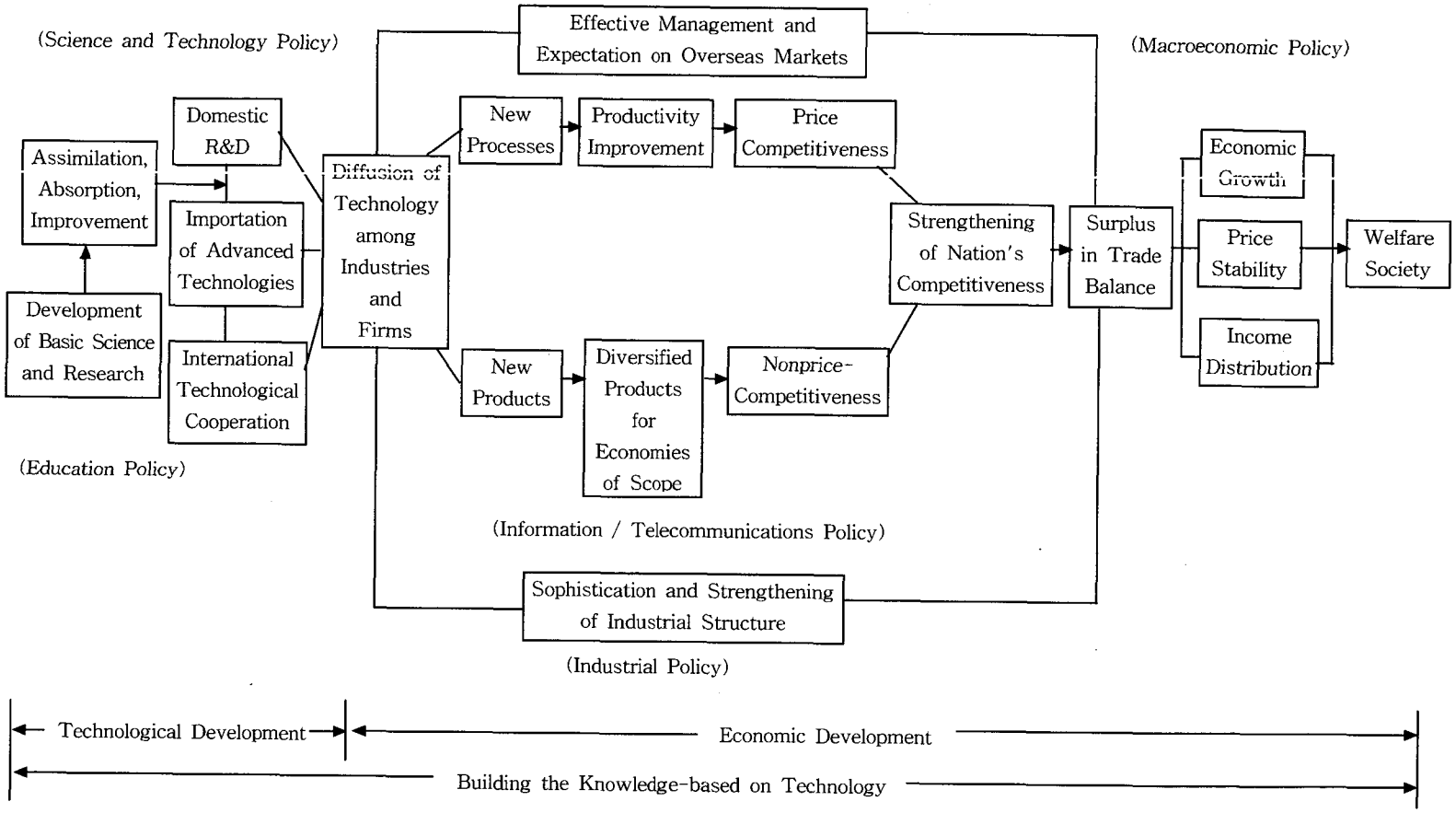
towards knowledge-based economy. Otherwise, Koreas industrial development will reach its limit. Basic science is a root for developing creative high technology and a critical factor of national competitiveness. New technologies and products influencing national competitiveness are from new ideas, and basic science bearing them.

Korean government should also provide increased support for interdisciplinary studies. Usually, universities focus on growing manpower and researching basic science. Firms desire to link R&D with economic performance or commercialization, and national and public research institutes are responsible for application research. The more S&T develop, in-depth researches on nature and researches for solving economic and social problems require more interdisciplinary studies by experts from various fields, instead of researches from specialists in a field.

Firms also should recognize that basic science is needed for improving competitiveness of their products because price competitiveness can be improved through reduction in production cost paid for input materials. Therefore, new idea or knowledge about the process of manufacturing raw materials or materials is a basic scientific technology.

We should be able to access to knowledge on S&T in the world and benefit from cooperation through international collaboration in S&T. International collaboration in basic science is one of effective challenges to technology protection barrier of developed countries, and a window for predicting future trends in high technology.

Finally, as shown by Figure 5, Lim (1995), suggests a new technology development strategy for the knowledge- based economy, with an emphasis on the role of basic science in the dynamic process of technological development and on the importance of the functional relationship of S&T policy with the other policies such as education, technology diffusion, information and telecommunication, industrial and macroeconomic policies in the pursuit of synergy effect resulting from the Schumpeterian "creative destruction".



< Figure 5 > A New Technology Development Strategy for the Knowledge-based Economy

〈References〉

Blackman, A. W. (1972), "A Mathematical Model for Trend Forecasts", *Technical Forecasting and Social Change*, Vol. 3, pp. 54~72.

Blackman, A. W. (1974), "The Market Dynamics of Technological Substitutions", *Technological Forecasting and Social Change*, Vol. 3, pp. 114~129.

Blackman, A. W., Seligman, E. J., and Sogliero, G. C. (1973), An Innovation Index Based on Factor Analysis, *Technological Forecasting and Social Change,* Vol. 4, pp. 65~86.

Bright, J. (1978), *Practical Technology Forecasting; Concepts and Exercise*, Austin: Industrial Management Center, Inc.

Cetron, M. J and C. A. Ralph (1971), *Industrial Applications of Technological Forecasting; Its Utilization in R&D Management*, New York: Wiley-Interscience.

Dodson, E. N. (1985), "Measurement of the State of the Art and Technological Advance", *Technological Forecasting and Social Change*, Vol. 27, pp. 129-146.

European Commission (1997), *Second European Report on S&T Indicators,* Brüssels.

Fabian, Y. (1984), "The OECD International S&T Indicators System", *Science and Public Policy*, Vol. 11, pp. 25~47.

Feinman, S. and W. Fuentevilla (1976), *Report for the National Science Foundation* (PB-263 738), Gellman Research Associates Indicators of International Trends in Technological Innovation, Washington, D. C.: National Science Foundation.

Jantsch, E. (1967), T*echnological Forecasting in Perspective*, Paris: OECD.

Jones, H and Twiss, B. C. (1978), *Forecasting Technology for Planning Decision*, New York: PBI.

Klein, John J. and Lim, Yang-Taek (1997), "An Econometric Study on the Technology Gap between Korea and Japan: the Case of the General

Machinery and Electric & Electronic Industries", *Technological Forecasting and Social Change,* Vol. 55, No. 3, pp. 125~142.

Kleinknecht, A. (1996), ed., *Determinants of Innovation: The Message From New Indicators,* London : Macmillan.

Kleinknecht, Alfred and Bain, Donald, ed. (1993), *New Concepts in Innovation Output Measurement,* New York: St. Martin's Press.

Korea Advanced Institute of Science and Technology (1986), *A Study on the Evaluation of Technology Levels and Technological Development (1)-Development of Science and Technology Indices,* Seoul: KAIST (*in Korean*).

Korea Industry Technology Promotion Association, *Statistics on Industry and Technology,* 2000 (*in Korean*).

Korea Ministry of Science and Technology (1998), *An International Comparison of SCI Publications,* Seoul: KMOST (*in Korean*).

Kwon, Yong-Su and Byung-Mu Park (2000), *A Study on Knowledge-based S&T Capacity Indicator Development,* Seoul: Korea Science Technology Policy Research Institute (*in Korean*).

Lenz, R. C. (1985), "A Heuristic Approach to Technology Measurement." *Technological Forecasting and Social Change,* Vol. 27, pp. 249~264.

Lim, Yang-Tack and Song, Choong-Hwan (1996, May), "An International Comparative Study of Basic Scientific Research Capacity: with reference to the OECD Countries, Taiwan and Korea", *Technological Forecasting and Social Change,* Vol. 52, No. 1, pp. 75~94.

Lim, Yang-Taek (1986a), "*A Study on Korea's Technological Dependence : with respect to Technology Transfer from Japan and Technology Diffusion in the Korean Machinery Industry",* Seoul: Korea Ministry of Technology and Science (*in Korean*).

Lim, Yang-Taek (1986b), "A Model of Technology Transfer from Japan to Korea", paper presented at the Korean International Economic Association, Seoul, Korea (*in Korean*).

Lim, Yang-Taek (1987), "An Analysis of the Effects of Strategic Variables on the Speeds of Technological Progress and Imitation in the Korean

Manufacturing Sector", paper presented at the Korean Economic Association, Seoul, Korea (*in Korean*).

Lim, Yang-Taek (1991), "Economic Effects of Measurement related Investment and Evaluation of Measurement Technology Level", *Economic Studies*, Seoul: The Institute of Economic Research, Hanyang University (*in Korean*).

Lim, Yang-Taek (1996), *A Study on the Effective Tax Incentives for Stimulating Research and Development in Korea* (with the coauthor Young-Hoon Kwon), Seoul: Asian Social Welfare Foundation (*in Korean*).

Lim, Yang-Taek (1998), *The Status of Korean Governmental Support for Technology Progress and Its Further Development,* Seoul: Korea Development Institute.

Lim, Yang-Taek (2000), "A New Measurement of the Level of S&T, Its International Comparison and Some Econometric Application in the Knowledge-based Economies", paper presented at the International Symposium on Industrial/Technological Competitiveness of the knowledge-based Economics, Taipei: Taiwan Economic Development Institute.

Lim, Yang-Taek, *The People Perish Where There is No Vision,* Seoul: Mail Economic Daily Press, September 1995 (*in Korean*).

Lim, Yang-Teak (1989a), "An Empirical Study on the Technological Transfer from the United States to Korea", *Hanyang Journal of Economic Studies* 10 (2), Seoul: The Institute of Economic Research, Hanyang University (*in Korean*).

Lim, Yang-Teak (1989b), "The Economic Effects of Measurement-Related Investments and Evaluation of Measurement Technology Levels", *Hanyang Journal of Economic Studies* 12 (2), Seoul: The Institute of Economic Research, Hanyang University (*in Korean*).

Lim, Yang-Teak (1994), "An Econometric Study on the Technology Gap between Korea and Japan: the General Machinery and Electric & Electronic Industry", in *Economic Development and Technological Progress of Japan and Korea : Their Role in East Asia,* Kobe: Proceedings of the Workshop and Seminar.

Mansfield, Edwin (1980), "Basic Research and Productivity Increase in Manufac-

turing, *The American Economic Review*, Vol. 70, No. 5, pp. 863~873.

Martino, J. (1993), *Technological Forecasting for Decision Making*, New York: McGraw-Hill.

National Science Foundation (1959), *Methodology of Statistics on Research and Development*, Washington D. C.

OECD (1981), *The Measurement of Scientific and Technical activities : Proposed Standard Practice for Surveys of Research and Experimental Development*, "Frascti Manual", Paris: OECD.

OECD (1992), *Innovation Manual: Proposed Guidelines for Collecting and Interpreting Innovation Data (Oslo Manual)*, Directorate for Science, Technology and Industry, Paris: OECD.

OECD (1992), *Technology and The Economy*, Paris: OECD.

OECD (1994), *Main Science and Technology Indicators* (diskette), Paris: OECD.

OECD (1999), *Science, Technology and Industry Scoreboard : Benchmarking Knowledge-based Economies*, Paris: OECD.

OECD (2001a), *Science, Technology and Industry Outlook*, Paris: OECD.

OECD (2001b), *Science, Technology and Industry Scoreboard*, Paris: OECD.

OECD (2000), *Main Science and Technology Indicators*, No. 2 (CD-ROM), Paris: OECD.

Sharif, M. Nawaz (1986), "Measurement of Technology for National Development", *Technological Forecasting and Social Change*, Vol. 29, pp. 17~32.

Sharif, M. Nawaz, and Haq, A. K. M. A. (1980), "Evaluating the Potentials of Technical Cooperation among Developing Countries", *Technological Forecasting and Social Change*, Vol. 16, pp. 125~143.

Shin, Tae-Young, Mun-Seop Yoon, Jin-Kyu Zhang, and Yong-Su Kwon (1999), *A New S&T Indicator Development for the knowledge-based Economy*, Korea Science Technology Policy Research Institute (*in Korean*).

UNESCO (1978), *Guidelines for the Evaluation of Information Systems and Services*, Paris: UNESCO (PG1/78/WS/18).

Yoon, Mun-Seop (1994), *A Study on S&T Indicator Development of OECD Countries*, Seoul: Korea Science Technology Policy Research Institute (*in*