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Measurement of R&D efficiency in NT and BT fields using DEA: a case in Korea

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Abstract

Since the Korean government has increased the R&D budget for both BT and NT areas, it needs to measure R&D efficiency and to manage the budget. The purpose of this study is to measure the efficiency of more than 2,000 BT and NT related projects supported by four basic research programs with the BCC-O model of the DEA method. Two input and five output variables are considered to determine the efficiency. The average efficiencies of both fields are low (0.3532 in the BT and 0.4677 in the NT) and the DEA projection results show that all output measures should be improved as much as 240% to 423% to be at efficiency 1. Also, correlation analysis is used to determine which variables strongly affect the efficiency in the BT and NT areas. This study could facilitate the development of better processes for project selection and many types of evaluation, provided the quantitative method such as the DEA could become widely acceptable for researchers.

Keywords: *BCC-O model, correlation analysis, NT and BT fields, projection, R&D efficiency*

1 Introduction

Both science and technology are believed to be the key factors for improving national competitiveness, while R&D investment is one of the most critical factors in promoting scientific and technological progress. If any country uses the resources inefficiently, it could bear a penalty in the form of achieving a much slower progress [36]. To reflect the importance of science and technology, the South Korean government has been significantly raising R&D investment through the science and technology master plan established in 2008 [23]. The total South Korean R&D budget in 2010 was around $11.9 billion and the budget has increased 11% per annum on average. Especially, the budget invested in basic research areas increased from $424 million in 2008 to $848 million in 2012 [26]. Such investment has meant that more than 30% of all professors from the fields of science and engineering have participated in various R&D research projects, and the number of SCI papers has increased rapidly [24]. Among the total R&D budget, the budget from MEST (Ministry of Education, Science and Technology) was invested in the BT and NT fields. In the case of BT, the budget increased from $224 million in 2006 to $507 million in 2010. The NT budget also increased from $103 million in 2006 to $187 million in 2010 [24].

Despite the exponential growth of the R&D budget, the scientific measurement of R&D efficiency has been inadequate in South Korea. Because the effect of R&D in basic research areas appears very slowly, it has been very difficult to scientifically measure the efficiency. However, as the government funded budget has increased continuously, a reasonable R&D policy needs to be developed on the basis of R&D efficiency in South Korea.

The NRF (National Research Foundation) of South Korea is a government funded research support organization that belongs to MEST and has allocated an R&D budget of as much as $2.5 billion to research agencies including universities in 2012. Various types of R&D programs are included in the NRF such as basic research programs, fundamental technology programs such as nuclear energy and space technology, and programs for the humanities and social sciences on a large scale [24]. Also, the NRF operates an information gathering system that has collected R&D results in the form of variables such as inputs, outputs, and outcomes to evaluate each R&D program on an annual basis. Every fund-awarded researcher is contacted individually to provide accurate data within a given time period. The government evaluates the achievement of each R&D program through these data and determines the level of next year's budget.

Traditionally, efficiency measurement has been the major managerial concern in both the manufacturing and service industries [27]. While many studies in the literature present a wide variety of methods used for measuring efficiency, few attempts have been made to measure the efficiency of R&D programs since, for various reasons, this is difficult to measure. For example, each R&D program has its own goals and objectives by which different parameters of inputs and outputs are defined. Also, academic fields have their own characteristics for measuring outputs. Especially, time lags occur between research outputs and publications or patents in every field. Therefore, a variety of methodologies have been adapted to measure the efficiency of an R&D program for specific fields by using various input and output parameters. Statistical tests such as the correlation analysis and data envelopment analysis (DEA) are typically used. Especially, DEA is a multi-factor, productivity analysis model for measuring the relative efficiency of each DMU (Decision Making Unit) when a number of inputs and outputs exist [21]. DEA allows each DMU to choose optimal weights of inputs and outputs which maximize the efficiency [6]. DEA is capable of mirroring the R&D programs' unique characteristics by assigning high weights to the variables in which each project has strength [22].

This st udy measures and compares the performances of four national R&D programs of MEST in using the DEA method. Both the BT and NT fields are selected for micro-analysis of each program because the highest budget among the 6Ts was allocated to them in 2010. Also, many researchers from universities, institutions, and industries are involved in various projects and programs of either BT or NT. Their performances are evaluated regularly in terms of excellence of publication, patents, technology transfer, etc. The Korean government needs to scientifically measure the R&D efficiency of both areas to observe their excellence and competitiveness compared to developed countries because it believes that both areas represent all of the science and technology fields in terms of R&D performance excellence. Also, the government will attempt to make decisions on continuous budget allocation to both fields in the future years based on their performance.

The Kruskal-Wallis test with a Mann-Whitney U test is then performed to verify the results from the DEA method. Also, projections are performed to bring the inefficient projects to an efficiency of 1. Linear regression analysis is then run to specify the correlation between variables of input and output of the R&D program. In this study, the efficiencies are measured for more than 2,000 projects in both NT and BT areas supported by four national R&D programs for better investment of the R&D budget. Through this study, several suggestions would be derived for the Korean government to allocate rapid growing R&D budgets to researchers in BT and NT areas.

This paper is organized as follows: Section 2 presents a review of the relevant literature on DEA related subjects. Section 3 discusses the DEA model for measuring the efficiency. Section 4 describes the raw data collected from NT and BT projects in R&D programs and both input and output variables to be analyzed. Section 5 gives the analysis results of DEA and the final section provides a conclusion and final discussion.

2 Relevant literature review

As stated earlier, a few attempts have been made to measure the efficiency of R&D programs. Jung and Seo [19] used the analytic network process (ANP) approach for the evaluation of R&D projects that are elements of six national R&D programs having heterogeneous objectives. Erdogmus et al. [10] used the ANP method to solve a real-world, multicriteria, high-tech selection problem. The proposed ANP model consists of a control hierarchy, a network of connections among the clusters of alternatives, actors and criteria. Sohn et al. [34] proposes a structural equation model (SEM) to evaluate the performance of the national R&D program supporting small and medium-size enterprises in terms of three aspects, including output, outcome, and impact under given funding inputs, the R&D environment of the recipient company, and external evaluation programs of funding organization. Corley [9] presents a use-and-transformation model for evaluating public R&D, which explicitly focuses on measuring capacity-based metrics instead of outcome-based metrics for evaluation.

Several key input and output parameters can be used for evaluating national R&D projects. As an output parameter, the total number of publications including journal papers and proceedings papers can be an index measuring productivity and scientific excellence because scientists working in research institutes and universities show their current state of research and disseminate the result [17]. However their quality and impact of the publications are to be measured carefully by considering different characteristics of academic fields. Glanzel and Zhou [14] mentioned a publication trend in the BT field in a group of emerging economies (Korea, Brazil, India, and Turkey) that challenges the traditional global landscape.

Impact factor (IF) is another output parameter used to estimate the quality of publications. It is a measure of the frequency with which the "average article" in a journal has been cited in a given period of time. The impact factor of a journal in a particular year is the average number of times it is cited during the year in question for papers published in the previous two years. Because of the characteristic of IF, however, it can be badly skewed by a 'blockbuster' paper [31]. IF is also varied by academic disciplines, thus some studies suggested other indicators that normalize IF [29, 30, 35]. As a citation measure, IF remains useful for measuring the quality of journals within a given discipline.

A patent is a form of intellectual property that consists of a set of exclusive rights granted by a sovereign state to an inventor or their assignee for a limited period of time, in exchange for the public disclosure of the invention. As the direct output of R&D activities, the number of patents is a common measure of innovative outputs that can be transferred into technological applications [16]. However, patents alone may not be extremely reliable as the measure of R&D efficiency in developed countries [28]. Hence, patents are generally used along with other parameters of R&D output such as publications [33].

Human resource development is another key factor affecting the efficiency of a national R&D program. The number of students who have graduated with a master's degree or doctoral degree can be a parameter for human resources development [13, 20, 22], In addition, Feng et al. [11] mentioned awards as an R&D output variable for measuring performance. Awards can be used to measure the impact of research and positively affect a research career within the scientific community.

Lee et al. [22] measured and compared the performance of six national R&D programs of Korea with two input parameters and ten output parameters by using the DEA. The two input variables are the amount of funds and the number of researchers on a project. The ten output variables are the number of domestic SCI papers, domestic non-SCI papers, international SCI papers, international non-SCI papers, domestic applied patents, domestic granted patents, foreign applied patents, master's degree students, and doctoral degree students graduated. Wang and Huang [36] obtained the relative efficiency of R&D activities across 30 countries with R&D capital and manpower as inputs, and patents and academic publications as outputs. Several studies have suggested that DEA-type approaches appear to emerge as an analytical tool for investigating the complex relationship between inputs and outputs in science and technology systems [18]. In this study, R&D efficiency of BT and NT areas in basic research programs are measured by using project support periods and the amount of funds as input parameters, and the number of publications, the IF, the number of applied patents, the number of proceedings papers, and the number of graduate-level degrees as output parameters.

3 DEA models

The output-oriented BCC model used for this study evaluates the efficiency of DMU_o (o=1,…,n) by solving the following linear program model [8] as shown in Eq. (1).

$$
\begin{aligned}
&\text{virtual input} = v_1 x_{1o} + v_2 x_{2o} + \cdots + v_m x_{mo} \\
&\text{virtual ouput} = u_1 y_{1o} + u_2 y_{2o} + \cdots + u_s y_{so} \\
&\eta_B = \frac{virtual\ input}{virtual\ ouput} \\
&\max_{\eta_B,\lambda} \eta_B
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
&\text{subject to} \\
&X\lambda \le 0 \\
&\eta_B y_o - Y\lambda \le 0 \\
&e\lambda = 1 \\
&\lambda \ge 0
\end{aligned}
$$

where $X = (x_i) \in R^{m\times n}$ and $Y = (y_j) \in R^{s\times n}$ are data sets given for *m* input parameters (i = 1, 2, …, m) and *s* output parameters (j = 1, 2, …, s), respectively with *n* DMUs (n = 1, 2, … o, …). $\lambda \in R^n$ represents the non-negative vector for the weights of input and output parameters and *e* is a row vector with 1.

The obtained DEA results could be utilized to determine the problems of the current evaluation process operated by NRF. These problems are described in Section 5. The DEA method as a non-parametric approach has some advantages in terms of evaluating the relative efficiency of R&D activities over other parametric methods. First, DEA does not require the user to prescribe weights given to each parameter of input and output, and it also does not require prescribing the functional forms needed for statistical regression approaches [8]. Second, it deals with the simultaneous occurrences of several inputs and outputs. These attractive features have inspired a number of authors to apply DEA techniques to assess academic R&D efficiency [36]. However, a key problem of DEA is its heavy reliance on the accuracy of the data; that is, there is no allowance for measurement errors [36]. Another problem is related to discrimination that may arise, such as when there are a relatively large number of variables compared to the number of DMUs, which in extreme cases may cause the majority of observations to be defined as efficient [1]. Some studies [4, 12, 36] have applied environmental factors such as the enrollment rate of tertiary education, PC density, and the index of English proficiency to improve the reliability for the DEA analysis. In this study, the problems are resolved by using 1,382 DMUs for BT and 664 DMUs for NT along with two inputs and five output parameters.

Basically, DEA models can be divided into the CCR model and the BCC model on the basis of the assumption of the return to scale [7]. The CCR model [5] is one of the most basic DEA models and assumes constant returns to scale while the BCC model [2] assumes variable returns to scale. In general, R&D efficiency can be demonstrated as increasing or decreasing returns to scale [3, 32]. Therefore, the BCC model is employed in this study. DEA models are further classified into two models: output-oriented and input-oriented. The output-oriented model focuses on maximizing outputs while the input-oriented model attempts to minimize inputs. The output-oriented model is used in this study because the objective of R&D programs in Korea is to increase outputs rather than decrease inputs, especially in BT and NT areas. Other methods of classification include the radial input oriented model, the radial output oriented model, and the additive model (in which both inputs and outputs are optimized) based on the projection of inefficient DMUs onto the frontier [27].

4 Data collection

4.1 R&D programs

This study considers four national basic research R&D programs to collect both input and output data. These programs aim to support individual or groups of excellent researchers. Three programs are individual programs and one program involves group study. The total number of projects (DMUs) to be analyzed in both the BT and NT fields is 2,046, as shown in Table 1. Program A consists of two subcategories: individual study and collaboration study of 2 to 3 researchers. Researchers are encouraged to work on interdisciplinary research individually or collaboratively in the fields of NT and BT. Program B as individual study is the most popular program for researchers in Korea and the average competition rate is 10 to 1 due to a large research fund and high selection opportunity for more extensive research. The program identifies and strengthens strategically outstanding university laboratories that have the core technology to extend the national competitiveness in terms of industries developing new products. It also encourages efficient utilization of science and technology resources of industries, academics, and research institutes. Program C supports individual researchers and aims to increase their competitiveness in creative innovation, securing new core technologies to create new business, developing a creative research culture, and cultivating next-generation researchers who can emerge as worldwide research leaders in NT and BT areas. Finally, Program D supports a large group of 10 to 15 researchers for interdisciplinary collaborations between industry and academia. By supporting highly-experienced research teams at various universities, this program contributes to enhancing the cultivation of human resources, technology transfer, exchange of research outputs and outcomes in academies and global cooperation. The program emphasizes creative basic research to ensure the exploration of basic theory and knowledge that leads to outstanding publications and the development of advanced technologies. This program has been very successful in terms of publications, applied patents, and human resource development. Table 2 presents the major features of four programs.

Table 1: Description of four programs

Program	Field	Number of Projects	Support Period	Funding
A	BT	824	3-yr basis, Maximum 6 years	$85,000/yr for individual study $170,000/yr for collaboration study
	NT	317		
B	BT	239	3-yr basis, Maximum 9 years	$254,000/yr, only individual study
	NT	176		
C	BT	36	Maximum 9 years	$254,000 to $678,000/yr, only individual study
	NT	44		
D	BT	283	Maximum 7 years	$847,000 to $1,271,000/yr per group
	NT	127		
Total	BT	1,382		
	NT	664		
	total	2,046		

4.2 Performance Variables

Among many input and output variables, two variables from inputs and five from outputs are selected to measure the efficiency as shown in Table 3. These variables are the key parameters for all researchers and the government because the researchers need the continuous support from the government and the government needs to determine the number of budgets to be allocated to the basic research area every year. In all types of project evaluations performed by the NRF, their needs are fulfilled by consideration of these parameters. The first input variable is the total number of funds invested in a project that varies on the basis of the R&D program.

In this study, the output data are obtained from 2005 (since the performance monitoring system of NRF was first operated) to 2010 for researchers to input reliable data. If a researcher starts a six-year project in 1999, he/she completes the project in year 2005. Only outputs in 2005 are assumed as accurate data. According to this lag between support periods and the output measurement period, Eq. (2) is established for the support period ratio per project as the second input variable. The denominator is the duration of a project; that is, the length of support period, and the numerator is the number of overlapped support periods with output measurement periods.

$$Support\ period\ ratio\ /\ project\ =\ \frac{support\ periods\ overlapped\ with\ output\ measurement\ period}{completion\ year\ -\ beginning\ year} \quad (2)$$

For example, if the support period of a project in program A is set from 2001 to 2007, then the number of years overlapped with output measurement periods becomes 3 (2005 through 2007). Thus, the support period ratio is equal to 0.5.

The five output variables include: the number of SCI papers published, the average impact factor (IF) of journals publishing SCI papers, the number of applied patents, the number of papers presented in both domestic and international proceedings, and the number of graduate-level degrees from a project. Academic papers published in journals are widely used to evaluate the performance of researchers since they are the most common avenue for delivering research ideas and outcomes [36]. Griliches [15] indicated that a patent is a good indicator of unobserved inventive output in a knowledge production function. Garg et al. [13] mentioned that R&D funding can provide a thrust to human resources development in various technical and engineering disciplines. Also, R&D funding provides the critical inputs to improve technical education standards in terms of revising or developing course curricula and to establish working linkages with industries, R&D establishments, and the academia in order to foster technological innovation and better utilization of R&D results. The proceeding papers presented in domestic and international conferences give the authors more opportunities to expose their recent research results.

Both input and output data are collected from 2,046 projects in BT and NT areas up to the year 2010. Table 4 presents statistics of input and output variables in the BT and NT areas.

Table 2: Major features of four programs

Program	Major Features
A	- Increase the number of SCI paper - Human resource development - Cultivation of basic research capability in various areas including interdisciplinary area
B	- Strengthen of national science and technology competitiveness mainly through patent application - Excellent paper quality - Excavation and support of excellent laboratory in universities
C	- Cultivating next-generation researchers as a worldwide research leader - Excellent paper quality
D	- Excellent paper quality - Patent applications - Human resource development with interdisciplinary ways

Table 3: Input and output variables

Variables	Descriptions
Input (I1) Budget (I2) Support period ratio	 Total amount of funds allocated to a project Ratio of support period overlapped with output measurement period
Output (O1) SCI papers (O2) Average IF (O3) Applied patents (O4) Proceeding papers (O5) Graduate-level degrees	 The number of SCI papers Average Impact Factor of journal papers published The number of applied patents The number of domestic and international proceeding papers The number of students graduated with master's degree and doctoral degree

Table 4: Statistics of input and output variables in BT and NT areas

Area	Value	Budget (I1)	Support period ratio (I2)	SCI papers (O1)	Average IF (O2)	Applied patents (O3)	Proceeding papers (O4)	Graduate-level degrees (O5)
BT	Max	9509.1280	1	69	28.8530	30	281	54
	Min	10.5880	0	1	0	0	0	0
	Average	519.1192	0.8236	7.0753	3.6770	0.6585	19.8835	4.4233
	SD	795.0267	0.2876	8.2675	2.5378	2.0059	25.4160	5.2003
NT	Max	7329.2750	1	173	17.6755	38	328	42
	Min	15	0	1	0	0	0	0
	Average	757.7223	0.8019	15.6913	2.9774	1.9473	39.4157	5.9262
	SD	1172.5558	0.3143	19.3571	1.9283	4.3504	45.2354	6.0064

5 Analysis results

5.1 Measuring performance R&D programs

The DEA method is capable of mirroring an R&D program's unique characteristics by assigning relatively high weights to inputs and outputs in which each project has strength. An output variable weight for each project is normalized and is compared to observe the relative weight of other variables under each R&D program in the BT and NT fields. The results are shown in Tables 5 and 6. The numbers in parentheses are the rankings under each program. In the case of BT, the number of proceeding papers (O4) has the highest weights in all programs, followed by the number of SCI papers (O1). It should be noted that Program A is a human resource development type, program B is a patent-oriented type, Program C is an excellence paper-quality type, and Program D includes all major goals of interdisciplinary methods. The performances shown by BT related projects somewhat differ from the goals of the programs. Such situation can be explained by two causes. First, the BT related research in Korea is at a germination stage compared to the developed countries. Therefore, it is rare for the researchers to generate excellent patents. Second, the researchers heavily focus on excellent paper generation because they want to pass the intermediate evaluation stage scheduled every three or four years. In Korea, most intermediate and final evaluation stages for projects are based on quantitative measures, especially, the number papers published, regardless of the types of the programs.
The normalized average weights for the NT field show that Programs A and B meet their goals such as human resource development and the number of applied patents. All programs except Program A have the highest weight of the number of applied patents (O3). This result can be explained by the government policy that emphasizes faster commercialization of research outputs from NT areas. Also, the publication related variables such as the number of SCI papers (O1), IF (O2), and the number of proceeding papers (O4) have high weights similar to the results in the BT area. This means that the researchers in NT areas also focus on acquiring continuous support from the government through the number of publications. It might be concluded that the NT area matures theoretically and technically compared to the BT area in Korea.

Table 5: Normalized average weights of output variables for programs in BT field

Program	SCI papers (O1)	Average IF (O2)	Applied Patents (O3)	Proceeding papers (O4)	Graduate-level degree (O5)
A	0.0041 (2)	0.0022 (4)	0.0014 (5)	0.0145 (1)	0.0024 (3)
B	0.0234 (2)	0.0035 (5)	0.007 (3)	0.1004 (1)	0.0049 (4)
C	0.0254 (2)	0.0046 (3)	0.0043 (4)	0.0514 (1)	0.0035 (5)
D	0.0211 (2)	0.0032 (5)	0.0042 (4)	0.0957 (1)	0.0088 (3)

Table 6: Normalized average weights of output variables for programs in NT field

Program	SCI papers (O1)	Average IF (O2)	Applied Patents (O3)	Proceeding papers (O4)	Graduate-level degree (O5)
A	0.0018 (2)	0.0018 (3)	0.0013 (5)	0.0016 (4)	0.0019 (1)
B	0.0014 (2)	0.0012 (5)	0.0015 (1)	0.0014 (3)	0.0013 (4)
C	0.0007 (4)	0.0010 (2)	0.0016 (1)	0.0008 (3)	0.0002 (5)
D	0.0013 (4)	0.0014 (3)	0.0019 (1)	0.0017 (2)	0.0013 (5)

Table 7 shows the results of average efficiency in the BT and NT areas based on the BCC-O model. A Kruskal-Wallis test is executed to compare the efficiency of the four programs. It is concluded that the efficiencies of these four programs are statistically significant with a zero P-value. Through a Mann-Whitney U test, a comparison between the two programs is made. For example, Programs C and D in the BT field showed no difference in terms of average efficiency. Therefore, in the case of BT, the efficiency ranking is C, D > B >A. The efficiency of the NT area projects is greater than that of BT in all programs. In the case of NT, the ranking is D, C > B > A.

Table 7: Comparison of program efficiency from BCC-O model

Program	Number of Projects in BT area	Average efficiency	Number of Projects in NT area	Average efficiency
A	824	0.28202	317	0.3506
B	239	0.4375	176	0.5088
C	36	0.5232	44	0.6304
D	283	0.4678	127	0.6465
Mann-Whitney U-test results : C, D > B > A			Mann-Whitney U-test results : D, C > B > A	

χ^2=251.226, df=3, p=0.000; χ^2=168.233, df=3, p=0.000

Figs. 1 and 2 present the efficiency distributions in BT and NT areas, respectively where the average efficiency of BT is 0.3532 and NT is 0.4677. The efficiencies of most projects in the BT area are shown distributed in the lower part of Fig. 1, regardless of the programs. Only 37 DMUs (2.7%) have excellent efficiency values. In the NT area, the efficiencies are shown distributed in the low or middle part of Fig. 2. 44 DMUs (6.6%) have excellent efficiency values. These results require correlation analysis to determine which variables strongly affect the efficiency in the BT and NT areas by observing the relationships among variables. The correlation analysis results are presented in Tables 8 and 9. In general, a correlation value higher than 0.6 represents relatively high relationships between two variables in R&D project evaluation [25]. The number of SCI papers (O1) and the number of proceeding papers (O4) showed the strongest correlation to each other (0.604 in BT and 0.729 in NT). The correlation between the number of proceeding papers (O4) and the number of graduate-level degrees (O5) is also strong (0.542 in BT and 0.612 in NT).

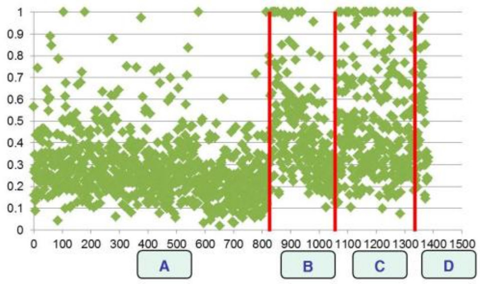

Fig. 1: Efficiency distribution of BT projects

No. of DMUs	1,382
Average efficiency	0.3532
SD	0.2051
Maximum efficiency	1
Minimum efficiency	0.01823
Total number of simplex iterations	21,332
No. of efficient DMUs which efficiency is 1	37 (2.7%)

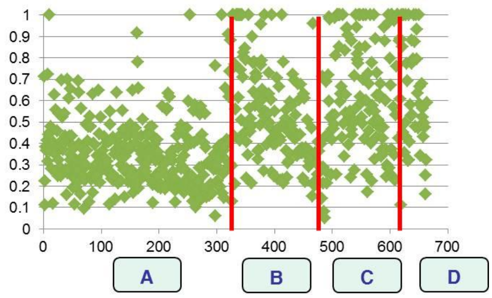

Fig. 2: Efficiency distribution of NT projects

No. of DMUs	664
Average efficiency	0.4677
SD	0.2381
Maximum efficiency	1
Minimum efficiency	0.0491
Total number of simplex iterations	16,418
No. of efficient DMUs which efficiency is 1	44 (6.6%)

Table 8: Correlation analysis among variables in the BT area

Divide		Budget (I1)	Support period ratio (I2)	SCI papers (O1)	Average IF (O2)	Applied patents (O3)	Proceeding papers (O4)	Graduate-level degrees (O5)
Pearson Statistics	Budget	1	-0.289	0.391	0.195	0.171	0.232	0.317
	Support period ratio	-0.289	1	-0.084	0.035	-0.089	0.019	-0.039
	SCI papers	0.391	-0.084	1	0.009	0.411	0.604	0.476
	Average IF	0.195	0.035	0.009	1	-0.03	-0.037	-0.019
	Applied patents	0.171	-0.089	0.411	-0.03	1	0.373	0.272
	Proceeding papers	0.232	0.019	0.604	-0.037	0.373	1	0.542
	Graduate-level degrees	0.317	-0.039	0.476	-0.019	0.272	0.542	1
P-value (one-side)	Budget	-	0	0	0	0	0	0
	Support period ratio	0	-	0.001	0.095	0	0.235	0.072
	SCI papers	0	0.001	-	0.363	0	0	0
	Average IF	0	0.095	0.363	-	0.131	0.084	0.235
	Applied patents	0	0	0	0.131	-	0	0
	Proceeding papers	0	0.235	0	0.084	0	-	0
	Graduate-level degrees	0	0.072	0	0.235	0	0	-

From the correlation analysis for both the NT and NT areas in Korea, the following features can be extracted with respect to input and output parameters:

1. Input variables

A negative relationship exists between the budget (I1) and project period (I2) in both the BT and NT areas. This result can give rise to the question of whether or not the amount of funding is determined by the project length. In Korea, a longer project period does not necessarily mean more funding is required. Also, neither I1 nor I2 affect any output variables; it may seem that other factors such as building a researcher's reputation and overcoming the tough competitive environment in their institutions would motivate their research efforts.

2. Output variables

As shown in Table 5, O4 has the highest weight value in determining the BT area efficiency. From the correlation analysis, the BT area efficiency is highly correlated with O1 and O5. Therefore, this result shows that more proceeding papers presented domestically and internationally would affect the generation of SCI papers and help the development of new human resources for the BT area.

As shown in Table 6, O3 has the highest weight value in determining the NT area efficiency of programs B, C and D. Along with this output variable, other variables such as O1, O2, and O4 contribute to determine the efficiency. The correlation analysis shows that O3 has relatively stronger relationships with O1, O4, and O5. This means that O3 is regarded as a more critical parameter in the NT area.

Table 9: Correlation analysis among variables in the NT area

Divide		Budget (I1)	Support period ratio (I2)	SCI papers (O1)	Average IF (O2)	Applied patents (O3)	Proceeding papers (O4)	Graduate-level degrees (O5)
Pearson Statistics	Budget	1	-0.338	0.491	0.131	0.359	0.308	0.269
	Support period ratio	-0.338	1	-0.017	0.166	-0.072	0.038	-0.021
	SCI papers	0.491	-0.017	1	0.081	0.462	0.729	0.585
	Average IF	0.131	0.166	0.081	1	0.001	-0.033	-0.055
	Applied patents	0.359	-0.072	0.462	0.001	1	0.425	0.467
	Proceeding papers	0.308	0.038	0.729	0.033	0.425	1	0.612
	Graduate-level degrees	0.269	-0.021	0.585	-0.055	0.467	0.612	1
P-value (one-side)	Budget	-	0	0	0	0	0	0
	Support period ratio	0	-	0.332	0	0.032	0.163	0.298
	SCI papers	0	0.332	-	0.019	0	0	0
	Average IF	0	0	0.019	-	0.494	0.2	0.077
	Applied patents	0	0.032	0	0.494	-	0	0
	Proceeding papers	0	0.163	0	0.2	0	-	0
	Graduate-level degrees	0	0.298	0	0.077	0	0	-

DEA results could be utilized to determine the problems of the current evaluation process operated by NRF. O4 is important to determine the efficiency of BT related projects, while O3 affects the efficiency of NT related projects. However, MEST is the main funding source of interest in other output variables as well at the initial, intermediate, and final performance evaluation stages. For example, O1 is the most critical parameter utilized in all processes of selection, review, and evaluation of research projects, although different R&D programs have their own assessment standards. Therefore, this study uses DEA projection to make these BT or NT projects highly efficient, i.e., efficiency = 1. Tables 10 and 11 present the projection results. As shown in Tables 10 and 11, all of the BT or NT projects require much higher performances in all output variables. The highest improvement is required for O3 in both fields. Especially, the BT area needs to improve O2. These results are also illustrated in Figs. 1 and 2. In the case of input variables, a longer project period does not require more funding. This means that the R&D policy for the BT and NT areas needs to be re-established in Korea.

As shown in Table 2, all programs except Program A have the identical goal, i.e., excellent paper quality achievement. However, DEA projection results show that the goal has not yet been accomplished. As stated earlier, NRF's main duty is to strengthen the research capability of the basic research area. However, some dilemmas occur at the research project evaluation stage. The NRF's evaluation process is mainly adapted from the NSF (National Science Foundation) process of USA, particularly the peer review process in the basic research area. However, Korea's peer review process differs from that of USA or other developed countries. Because Korea's research area is very narrow compared with other developed countries, factional strife occurs in the peer review processes. As a result, a researcher needs to form a clique for the purpose of project selection under tough competition. This environment can mean poorly prepared proposals are awarded funding. Another problem arises with evaluation standards. For example, the evaluation standard for selecting new projects in program B is shown in Table 12. All of the points are divided into two parts: the research plan and the researcher's capability. Despite an even allotment of points by the two criteria, peer reviewers often decide that a researcher's capability is far more important than the research plan. Also, the researcher's capability can be mainly judged by his/her past research output (mainly the number of SCI papers and the number of applied patents). Furthermore, research output is mainly evaluated in quantitative ways rather than in a qualitative manner. As a result, after reviewers have debated research proposals in a corresponding review panel, they select several outstanding projects on the basis of available budgets, but they first decide the entire score given to a project based heavily on the researcher's capability, while the sub-criteria are graded later. In many cases, researchers who have built their reputation on various political, social, and academic aspects have a greater possibility of proposal acceptance. Therefore, a substantive review would not be possible in most evaluations. Efficiency improvement could be realized only after reforming these evaluation processes.

Table 10: Projection for the entire BT projects

Divide	Budget (I1)	Support period ratio (I2)	SCI Papers (O1)	Average IF (O2)	Applied patents (O3)	Proceeding papers (O4)	Graduate-level degrees (O5)
Initial average	519.12	0.82	7.08	3.68	0.66	19.88	4.42
Projection’s average	422.11	0.78	19.61	11.97	2.79	63.39	12.71
Ratio (%)	81.31	94.36	277.16	325.58	423.18	318.81	287.37

Table 11: Projection for the entire NT projects

Divide	Budget (I1)	Support period ratio (I2)	SCI Papers (O1)	Average IF (O2)	Applied patents (O3)	Proceeding papers (O4)	Graduate-level degrees (O5)
Initial average	757.72	0.80	15.69	2.98	1.95	39.42	5.93
Projection’s average	638.12	0.72	38.97	7.30	5.70	107.10	14.26
Ratio (%)	84.22	89.20	248.32	245.10	292.57	271.71	240.62

Table 12: Project selection standard in Program B

Evaluation Criteria		Points
Excellence of proposed research plan	Research contents and methods	30
	Appropriateness of budget and support period	10
	Utilization and expected effect	10
Capability of researcher		50
Total		100

6 Conclusions and discussion

In this study, the efficiency of BT and NT is measured by using the BCC-O model of the DEA method for more than 2,000 projects within four different R&D programs of Korea. Two input variables and five output variables as shown in Table 3 are considered to determine the efficiency. The efficiency obtained from BCC-O is verified by a Kruskal-Wallis test with a Mann-Whitney U test. From the DEA results, Program C and Program D show the highest performance in the BT and NT areas, respectively. The BT field is based on a high weight given to the number of proceeding papers while the NT field is based on high weights given to the number of applied patents, the number of SCI papers, and the number of proceeding papers. The correlation analysis is used to determine the relationship among variables as shown in Tables 8 and 9. Due to the different features of each field, any comparison of efficiency between each field should be avoided.

Program A shows the lowest performance in both fields. One of the main purposes of Program A is to cultivate the capability of researchers in the fields. However, the results show that most of researchers’ performances are located at a low efficiency level (Figs. 1 and 2) even though their efficiency depends on the number of proceeding papers and the number of SCI papers. This means that Program A requires tight management in the selection and evaluation process for removing low quality projects. A goal of Program B is to strengthen competitiveness through patent applications. This goal is met at a certain level for the NT field in terms of average weights. However, the same goal is not met for the BT field. Such results can be explained by technology maturity of NT in Korea. The technology maturity can be defined by the commercialization speed through applied patents. In Korea, NT is regarded as more matured technology for faster commercialization than BT.

DEA projection results (Tables 10 and 11) show that the overall output values should be improved in all measures. On the other hand, input values can be decreased. This means that the policy for the ultimate promotion of output values needs to be set up towards the direction of tightening control over the evaluation process.

This study has several limitations. First, the BCC-O model is used because R&D projects generally showed their performance in an increasing, decreasing, or complex return to scale. However, Lee and Park [21] suggests that R&D projects also showed constant return to scale. Therefore, the efficiency should be alternatively measured by the CCR model and compared with the results from the BCC model. Second, both environmental factors and statistical noise should be removed for more accurate results. In this study, the environmental factors are not considered. Third, some input and output variables such as the number of researchers, number of awards, and the number of invited talks should be considered to draw more exclusive results. Finally, all of the BT and NT fields should be classified further into detailed areas for micro-analysis in terms of R&D efficiency.

Most researchers in science and engineering fields have mentioned that the Korean government or research support agencies such as NRF should guarantee them more considerable autonomy with respect to project management. However, while Korea’s R&D investment size has a steady growth rate, the R&D efficiency measured for both the BT and NT fields in this study seems to not follow the investment growth rate. In the efficiency projection results, all output values should be improved by as much as 240% to 423% to be at efficiency 1, regardless of what programs are considered. This study can be considered to develop better processes for project selection and many types of evaluation, provided a quantitative method such as DEA could become widely acceptable for researchers.

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