Development of Performance Criteria and Indicators for Government-Sponsored R&Ds: Assessing Different R&D Stage and Field Aspects

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Abstract

Since the performance evaluation of government-sponsored R&D relies mainly on the evaluation by experts, it is difficult to analyze objectively the outcomes of R&Ds. Despite the fact that government-sponsored R&Ds contain the projects belonging to varied fields and in different stages of development, evaluation measures reflecting these natures are hardly seen in practice. To address this gap in research, it is necessary to develop the performance criteria/indicators reflecting the characteristics of government-sponsored R&D.

In this study, we aimed to develop common performance criteria/indicators reflecting the characteristics and goals of large-size government-sponsored R&D programs, and individual performance criteria/indicators reflecting the characteristics of each research field. Using optimal majority rules, criteria and indicators reflecting the characteristics of R&D, fields were selected from a pool garnered from literature reviews. By using the Delphi method, criteria/indicators reflecting the characteristics of R&D stages were newly developed. Based on the analysis, a matrix of common and individual performance criteria/indicators suitable to evaluation of government-sponsored R&D program were newly constructed.

Keywords: government-sponsored R&Ds, R&D stages, R&D fields, performance criteria, performance indicators

1. Introduction

Since the government-sponsored R&Ds consume a large amount of national resources, man-power, and time, and since the outcomes and impacts of projects are widely spread over society, it is essential to analyze how much value was created through the project and whether the project was effectively performed (Lee et al., 1996; Coccia, 2001; Heo et al., 2008). Recently, the necessity of government R&D performance analysis and evaluation has been heavily emphasized due to the increased awareness of the importance of maximizing R&D impacts by effectively utilizing limited government resources (Hong et al., 2009).

Performance analysis of R&D plays a key role in providing information regarding the effectiveness of R&D, the feasibility of assets/resources allocation of R&D and any additional information necessary for planning and conducting new R&D projects or programs (Brown & Svenson, 1998; Coccia, 2004). Especially, the evaluation of government R&D has been moving toward putting more focus on its results and government has continuously worked to improve effectiveness of R&D by allocating and adjusting R&D budgets based on the results of R&D evaluation (Yoon & Kang, 2003; Heo et al., 2008; Chien et al., 2009). Thus, in order to evaluate R&D projects based on its outcomes, the development of scientific and objective performance indicators to analyze results of government sponsored R&D is critical.

Currently the performance evaluation of 21C Frontier R&D program relies on expert-analysis and

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qualitative evaluation methods that lack objectivity to meet the needs of objective evaluation reporting (Kostoff, 1995). Furthermore, the R&D program consists of various sub-projects belonging in different stages and fields; the consideration of distinctive characteristics of outputs from various fields and stages are not reflected in the current evaluation framework. Thus, it is necessary to develop guidelines and evaluation criteria/ indicators that reflect the distinctive nature of each Frontier R&D project and consider the characteristics of differing R&D fields and stages.

This study aims to satisfy the need for creating specific R&D criteria/ indicators that reflect both the characteristics of the fields and their stages of development. The main objective was reached by using domestic and international literature reviews to understand the evaluation structure of government-sponsored R&D and subsequently, a pool of performance criteria/indicators, capturing the common characteristics of the government-sponsored R&D, was created. Second, an optimal majority rule was used to analyze criteria/indicators from the pool. Third, the Delphi method was employed as a supplementary method to capture the important, but uncovered, criteria/indicators from the pool. Based on the analysis results of both techniques, criteria/indicators were identified to evaluate the government-sponsored R&D.

In section 2, the nature of government-sponsored R&D evaluation, types of R&D results, domestic and international R&D evaluation cases are analyzed to obtain the insights concerning the evaluation of government-sponsored R&D. In section 3, the research framework for this study is introduced. In section 4, the research framework is applied to the actual R&D case in Korea. Finally, in section 5, the conclusion is made and any implications identified in this study are discussed.

2. Literature Review

2.1 Understanding of Government-Sponsored R&D and its Evaluation Process

The government-sponsored R&Ds are projects with a large-scale fund conducting research on various interrelated topics rather than on one specific topic for a long period of time (Lee, 2005; Song et al., 2008; Hong et al., 2009). More specifically, government-sponsored R&D is the process to acquire necessary and important strategic technologies through basic, applied and development research (Chien et al., 2009). Government-sponsored R&D may be regarded as a national strategy or plan to accomplish technology innovation by concentrating technologies and resources onto a single place and conducting collaborative research rather than initiating various individual research.

Unlike the conventional research conducted in private sectors, the government-sponsored R&D possesses the following characteristics. First, it comprises various sub-projects with different missions but closely interrelated to each other (Lee, 2005; Hong et al., 2009). Since sub-projects have different objectives and conduct research in different fields, decision- makers face difficulty understanding the nature of all sub-projects and must check the progress of projects (Kostoff, 1995). Thus, it is necessary for decision-makers to understand the interrelations among each sub-project and to present qualitative characteristics of R&D results in quantitative form.

Second, since several sub-projects are conducted at various stages in different fields, it is important to understand the characteristics of different R&D stages and fields (Yoon & Kang, 2003; Lee, 2005, Hong et al., 2009). R&D is generally divided into three stages - basic research, applied research and development research. Basic research pursues neither application nor commercial purposes, but only improvement of knowledge. Applied research also pursues improvement of knowledge, but it also pursues realistic application and commercial purposes during process. Finally, development research pursues improvement or creation of materials, devices, products, systems and processes by using data obtained from basic and applied research. Although the proportion of basic, applied and development stages in R&D varies among different R&Ds, government-sponsored R&D included all three R&D stages (Chien et al., 2009).

Moreover, a government R&D project contains sub-projects in various fields (Hong et al., 2009).

Especially in Korea R&Ds are classified into one of six research fields (generally called 6T, MOST, 2004) defined and based on its core research focus. Since government-sponsored R&Ds have varied aims and reflect different characteristics of three distinct R&D stages and six different R&D fields, in-depth knowledge and understanding are key components to analyze the results of government-sponsored R&D.

2.2 Types of Results and Evaluation Criteria of Government-Sponsored R&D

The first step for the R&D evaluation is to make a clear distinction between R&D output and outcomes. The output implies any quantitative and qualitative product generated at the end of the project (Brown & Sevenson, 1998; PREST, 2002). Meanwhile, the outcome implies the effectiveness of R&D caused by direct and indirect outputs (Brown & Sevenson, 1998; PREST, 2002). In addition, R&D results can be categorized into technical performance, economic performance and social performance. Technical performance refers to the case when benefits by the development of related technologies are obtained through outputs/outcomes of research. Economic performance refers to the case when a financial gain is obtained through outputs/outcomes of research. Social performance refers to the case when a social ripple effect is obtained through outputs/outcomes of research (Ruegg, 1996; European Commission, 1999; Ruegg and Feller, 2003; Chien et al., 2009).

In Korea, types of large-scale R&D can be classified into evaluation information and evaluation statistics (MOST, 2004). Evaluation information represents papers, intellectual properties, reports, and software, all of which have some scientific values to be used for future research, technology transfer, and commercialization in the future. Evaluation statistics represents royalty, commercialization, human resource development, collaborative research and international collaboration, all of which have some statistical importance to be used for supporting policy objectives.

The concept of government-sponsored R&D results is well-described in much of the literature. In an academic sense, the concept of R&D results is defined as any valuable and open knowledge generated during the process of R&D (Cohen & Levinthal, 1989). DeCotiis & Dyer (1977) classified R&D results into commercial outcomes, technological outcomes, human resource development related outcomes, and science outcomes. Brown & Sevenson (1998) categorized R&D results into outputs and outcomes depending on its effect on commercialization of R&D results. In their definition, outputs include intellectual products from R&D, such as patent, new product or process, publication, knowledge, and outcomes include any specific economic profits from R&D results such as cost-saving and increased sales.

R&D evaluation is generally used for improving the effectiveness and efficiency of R&D operation units by analyzing the critical success factors of R&D, goal accomplishment rates with respect to outputs (Brown & Svenson, 1998). In order to evaluate accurately whether or not the results of the business clearly achieves R&D objectives, evaluation criteria/indicators should be established. Several different evaluation criteria/indicators should be developed to meet the different needs of evaluation, and reflect different characteristics of R&D.

2.3 Foreign Cases on Government-Sponsored R&D Evaluation

According to ASIF (ASIF: Assessing the Socio-economics Impact of the Framework Programme) a research paper published from PRESET in Britain in 2002, the results of R&D can be divided into Direct Impacts and Indirect Impacts based on its nature, and into Short –term outcomes and Long-term outcomes based on the time it takes to generate the R&D results. Moreover, depending on aspects, the results can be classified into science-technological results, economic results and social results. The performance analysis conducted by USA's ATP (Advanced Technology Program) focuses its evaluation on outputs and outcomes belonging in the science-technological dimension and economic dimension as well as on the social ripple effect of the project (Ruegg, 1996;

Ruegg and Feller, 2003). In a case of 5th Framework Programme, one of the major R&D programs in the European Union, various indicators and criteria in the three dimensions that ATP, ASIF used, and as well as in the policy perspective are used to evaluate the results of R&D projects on real-time basis.

Japan's NEDO (New Energy and Industrial Technology Development Organization) evaluates the value of technology related to energy, and industry based on guidelines and the manual set by the ministry of Economics and Industry in Japan (Oh, 2006; Cho et al., 2009). Their major evaluation criteria in post evaluation are dissemination and promotion, publicity and the ripple effect and the business scenario created up to the point of commercialization. Taiwan's NSC (National Science Council) classifies the final output of R&D into Academic achievement, Human resource training, Technology output, Knowledge service, Technology diffusion and service, Derivative benefit; as well, it measures the effectiveness and efficiency of R&D outputs in six dimensions (Chien et al., 2009). The outputs and social ripple effects of R&D projects impact various aspects of society (Chien et al., 2009; Hong et al., 2009).

Especially, government-sponsored R&D contributes to the advance of science and technology through accumulation of scientific knowledge and produces economic-added values through technology transfers and commercialization. Moreover, it has a major impact on social development through supplying highly educated work forces, know-how, and initiating international collaborative R&D. Thus, it is important to analyze how and which R&D results affect what aspect of society and to scrutinize how each aspect of society is influenced by which criteria (Nakamura et al., 2008).

As shown in several foreign cases and previous studies, an evaluation should be able to categorize the results of government-sponsored R&D according to the scientific-technological, economic and social dimensions. Furthermore, performance criteria and indicators should be designed to reflect these three dimensions during performance analysis while reflecting the general characteristics of government-sponsored R&D during the overall evaluation.

3. Research Framework

In this section, the methodology to develop performance criteria and indices for each R&D stage and field are introduced as shown in Figure 1.

3.1 Step 1: Development of Government-Sponsored R&D Evaluation Guidelines and Pool of Criteria

To understand the nature of government-sponsored R&D evaluation, the definition and characteristics of large-scale R&D are analyzed through literature reviews. Based on that, the guideline to evaluate government-sponsored R&D is developed. A two-step approach is used to develop the evaluation criteria and indices for government-sponsored R&D evaluation model. At the first step, the pool of general evaluation criteria/indicators, suitable to evaluate any common results of government-sponsored R&D projects, is constructed. The criteria/indicators included in the pool are extracted from various sources, such as past government-sponsored R&D conducted in Korea and overseas, academic literature, and current government evaluation guidelines. The evaluation criteria/indicators in the pool should be able to evaluate R&D results classified in all three aspects (i.e. Science-technological Aspect, Economic Aspect, and Social Aspect). Once the pool is constructed, the final candidates for evaluation criteria/indicators are selected, and the selected candidates are reclassified into several categories in accordance with their nature. If the indicators/criteria that have similar characteristics are in the pool, the one with the better representation is chosen as the candidate.

3.2 Step 2: Development of R&D Criteria and Indicators Reflecting R&D Stage

To identify the nature of each R&D stage, literature reviews and expert interviews are performed. First, before extracting appropriate criteria/indicators for each R&D stage, a survey questionnaires based on criteria/indicator presented in the pool is created and distributed to the experts group and to each R&D

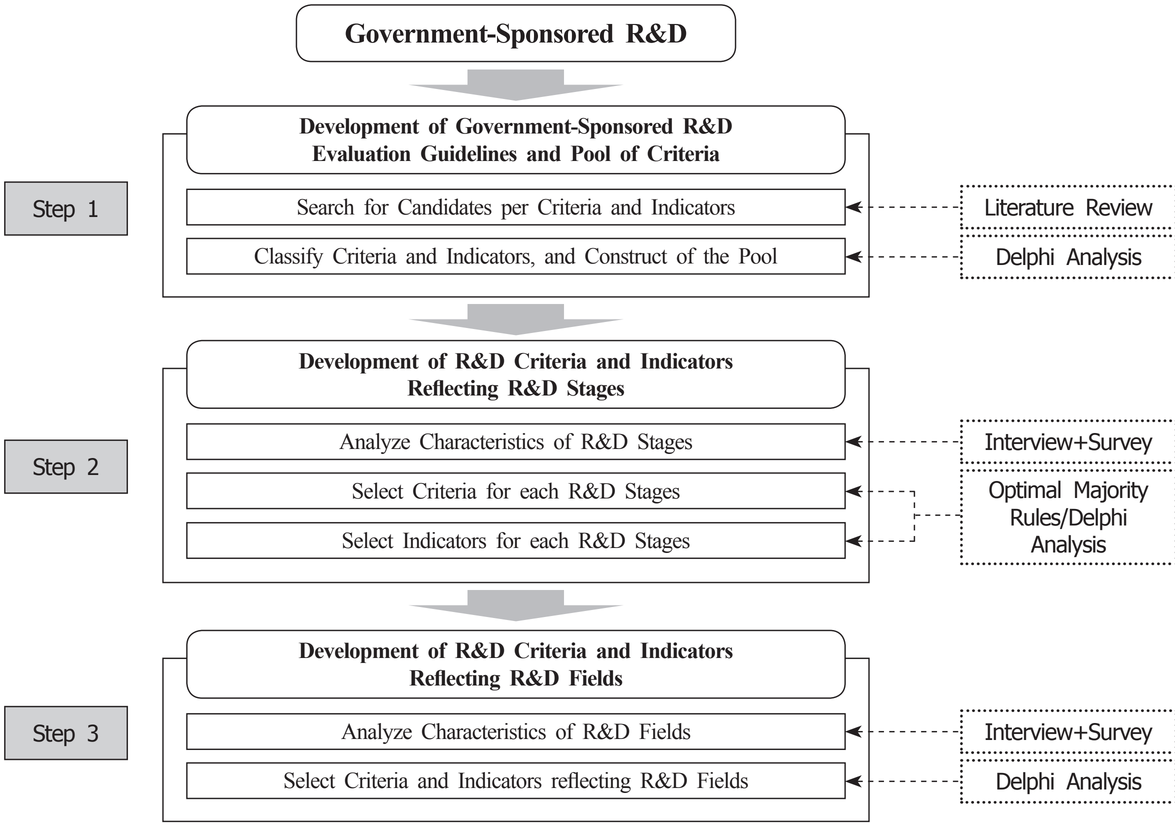

Figure 1 A framework to develop evaluation criteria and indicators for government-sponsored R&D

project administrator keeping mission. The selection of criteria/indicators will be made by a two-step approach.

In the first step, criteria/indicators are filtered based on a pre-determined approval rate. If an approval rate for a criterion/indicator is lower than the pre-determined rate, it is not accepted. If higher, then it is included as the performance criteria/indicators. A pre-determined rate is selected based on an optimal majority rule proposed by Buchanan & Tullock in 1962. When an optimal majority rule is applied to determine an acceptable approval rate, statistical techniques are deployed to compensate for the sample variation of the survey.

In the second step, among criteria/indicators that were not approved by experts but received a sufficient approval rate not to be excluded, are re-considered through the Delphi method (Dalkey & Helmer, 1963). Once evaluation criteria/indicators for each R&D stage are selected through the interview with experts, the detailed evaluation indicators are selected from the pool we made in the Step 1.

3.3 Step 3: Development of R&D Criteria and Indicators Reflecting R&D Fields

To understand the characteristics and different nature of each of the R&D fields, literature reviews and expert interviews are performed. Also, visits to R&D projects offices are made to gather information regarding the current status of project progress and the distinct nature of R&D outputs from each R&D project. Based on results of the interview and the site-visit with the Delphi methods, evaluation indicators/criteria reflecting the characteristics of each R&D fields are selected from the pool. Also any additional criteria/indicators not included in the pool, but representing the distinctive nature of each field is also selected as the indicators/criteria.

4. Case Study

In this study, the evaluation criteria/indicators were developed by following the research framework presented in section 3. The Korean government launched the long-term national R&D program named the 21st Century Frontier Program in 2001 to strengthen the foundation of selective future strategic technologies with huge potential that would improve Korea's national scientific competitiveness to reach the level of advanced countries by 2010. The project aimed to utilize the research potential acquired from previous experiences with national R&D programs, such as the Highly Advanced National Program (G-7 Projects). Besides improving Korea's scientific competitiveness, the project also aims to contribute to the development of the economy by improving national competitiveness, improving public welfare and improving quality of life to match the level of advanced countries, and by creating new industries through the development of future technologies.

The 21st Century Frontier program consists of 16 projects from the ET (Environment Technology), NT (Nano Technology), and BT (Bio Technology) fields with a total available fund of US$ 150 millions. The fund granted to each project was approximately US $ 8 ~ 10 millions and the duration of each project was up to ten years from the initial launch date of the project. Eight projects, four in BT, three in ET and one in NT were terminated in March 2011 and the remaining eight projects are continuously conducting R&Ds. Sub-projects of these 16 projects were also conducted at different stages.

4.1 Analysis on the Nature of Government-Sponsored R&D

Large-scale R&D can be defined as the R&D project conducting research on various interrelated topics rather than on one specific topic for a long period of time. Because of the nature of large-scale R&D, the R&D often produces its output immediately, but most of the outcomes are generally produced throughout that long period of time. Also, the results of R&D impact greatly on society in all aspects. Therefore, the evaluation of large-scale R&D should evaluate not only the science and technological aspects of the project, but also the social and economic aspects.

4.2 Development of the Pool of Evaluation Criteria/ Indicators

Throughout the comprehensive literature reviews on domestic and international journals, and reports, the pool of criteria/indicators that can measure the general results of R&Ds were constructed. The criteria/ indicators in the pool can be classified into 26 criteria and 111 indicators. 26 criteria are classified into science-technological, economic, and social aspects accordingly. The result of criteria classification is shown in Table 1.

Table 1 General pool containing 26 Criteria of government-sponsored R&D

Aspect	Evaluation Criteria
Science-Technological	Publication (1), Rewards (2), Patent (3), Technology Advancement (4), Industry-Academia Collaboration (5), International Collaborative Research (6), Construction of Research Infrastructure (7), Utilization of Research Infrastructure (8), Certificate/Credentials for Standardization (9), Activities for Standardization (10), Facilitation of Standardization Activities (11), International Standardization Activities (12)
Economic	Technology Transfer (13), Commercialization (14), Market Share (15), Increase in Export/Import (16), Market Creation Effect in related fields (17), New Job Creation Effect (18), Improvement on Productivity (19)
Social	R&D Publicity (20), Development of Public Infrastructure related Technology (21), Human Resource Training (22), Quality Improvement of R&D Human Resource (23), International Human Resource Exchange (24), International Collaboration (25), Improvement in Service (26)

4.3 Development of Stage Specific Criteria/Indicators

In order to extract the appropriate criteria for each R&D stage from the pool shown in Table 1, a survey containing the questions related to the appropriateness of each criterion for basic, applied and development stages, was distributed to and answered by 23 R&D experts who had enough background on R&D planning and on actual R&D projects, and by 17 Managers of 21st Century Frontier projects which included two multiple responses from the microorganism genome R&D project. The questionnaires were designed as Yes or No questions asking whether each criterion was appropriate for each of the three R&D stages.

As explained in the section 3, a two-step approach was used to select criteria for each R&D stage. The optimal majority rule used in the first step adopts an approval rate that can minimize time, opportunity costs, exclusion risks, and inclusion risks associated with decision-making. Exclusion risk is defined as the risk that essential criteria/indicators are not selected in the evaluation matrix. Inclusion risk is defined as the risk that unnecessary criteria/indicators are selected and included in the evaluation matrix. In reality, it is difficult to estimate accurately the approval rate minimizing these factors. Thus 75% is set as the approval rate which approximately 8 out of 10 people agree on. If the criterion/indicator receives an approval rate of 60% or less we regarded that as not receiving enough consensus from the experts even though the number is more than half. Thus, the approved rate used for selection is 75% or 0.75; the approved used for exclusion is 60% or 0.6.

Since the survey uses the samples to estimate the true mean value of population, adjustment from sample to population is needed. For example, one criterion with a sample approval rate of 75% and variability of 30% can have a range of true population approval rate between 45% and 100%. In fact, the approval rate of true population can be totally different from that of the sample, and it can distort the result. In order to compensate for the variability existing in samples, we adopted the idea of confidence interval from the statistics. The 95% Confidence intervals for basic and applied R&D are shown in Figure 2. Based on our 95% Confidence interval analysis results, we included the criteria if the value of the approval rate from the sample was higher than 62.5% because, depending on the sample, the true approval rate of population can be higher than 75%. By the same logic, we excluded the criteria/indicators from the matrix if the value of the approval rate from the sample was lower than 47.5%.

The Delphi method was used in the second step to

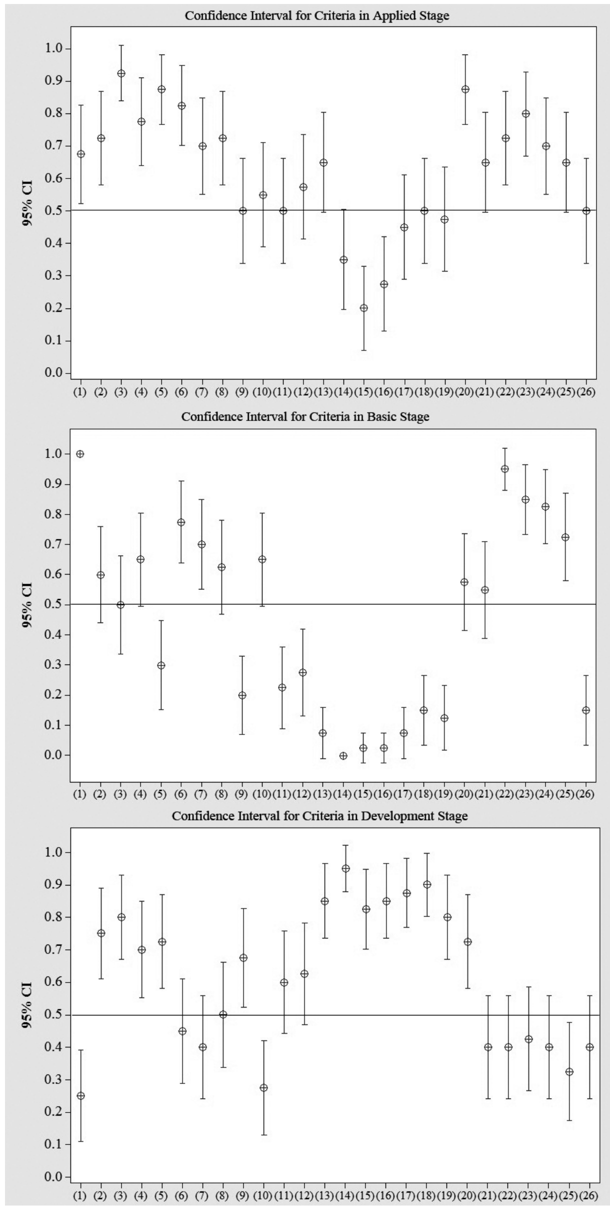

Figure 2 Confidence interval for criteria in basic and applied stage

determine whether or not the criteria with an approval rate between 62.5% and 47.5% should be included in the matrix.

Table 2 represents criteria developed for reflecting characteristics of each R&D stage. Criteria are classified as either output criteria or outcome criteria. The output criteria for the basic stage include Publication, International Collaborative Research, Construction of Research Infrastructure, Human Resource Training, International Human Resource Exchange, and International Collaboration. The outcome criteria for the basic stage include Quality Improvement of R&D Human Resource. The output criteria for the applied stage include Academia Collaboration, International Collaborative Research, Construction of Research Infrastructure, Technology Transfer, R&D Publicity, Human Resource Training, International Human Resource Exchange, and International Collaboration. The outcome criteria for the applied stage consist of Technology Advancement, Utilization of Research Infrastructure, and Quality Improvement of R&D Human Resource. The output criteria for the development stage contain Rewards, Patent, Industry-Academia Collaboration, Technology Transfer, Commercialization, and R&D Publicity. The outcome criteria for the development stage include Technology Advancement, Increase in Export/Import, Market Creation Effect in related fields, New Job Creation Effect, and Improvement on Productivity. Also, a number of final criteria and indicators were 19

Table 2 Final criteria for each R&D stage

Aspect	R&D stage					
	Basic		Applied		Development	
	Output	Outcome	Output	Outcome	Output	Outcome
Science-Technological	Publication, International Collaborative Research, Construction of Research Infrastructure		Publication, Rewards, Patent, Industry-Academia Collaboration, International Collaborative Research, Construction of Research Infrastructure	Technology Advancement, Utilization of Research Infrastructure	Rewards, Patent, Industry-Academia Collaboration	Technology Advancement
Economic			Technology Transfer		Technology Transfer, Commercialization	Increase in Export/Import, Market Creation Effect in related fields, New Job Creation Effect, Improvement on Productivity
Social	Human Resource Training, International Human Resource Exchange, International Collaboration	Quality Improvement of R&D Human Resource	R&D Publicity, Human Resource Training, International Human Resource Exchange, International Collaboration	Quality Improvement of R&D Human Resource	R&D Publicity	

Table 3 Final criteria and indicators

Criteria	Indicators
Publication	Total number of publications in domestic and international academic journals
	Total number of SCI publications
	Total Impact Factor of publications
	ornIF (ordinary normalized Impact Factor)
	Impact Factor per research fund
Rewards	Total number of award-winning conference (Domestic/International)
	Total number of award for outstanding achievements from Public/Private organizations (Domestic/International)
Patent	Total number of patents applied (Domestic/International)
	Total number of patents registered (Domestic/International)
	Registered Patents per research fund
Industry-Academia Collaboration	Total number of Industry-Academia collaboration per research project
Technology Advancement	Narrowness of technological gap
	Development of global leading technology
Construction of Research Infrastructure	Total number of Database (DB) constructions
	Total number of research facility constructions
	Total number of research equipment constructions
International Collaborative Research	Total number of international collaborative research projects
Utilization of Research Infrastructure	Utilization of research facilities
	Utilization of shared equipment
Technology Transfer	Total number of technology transfers incurred
	Total amount of economic profits from technology transfers
Commercialization	Total number of new product development
	Total amount of new product's sales
	Total number of venture establishments
Increase in Export/Import	Total amount of export
	Total amount of import substitution
Market Creation Effect in related fields	Inducement effect of private investment
International Human Resource Exchange	Total number of invited foreign researchers
	Total number of domestic researchers sent abroad
International Collaboration	Total number of international MOUs
Human Resource Training	Total number of trained personnel in related fields
Improvement on productivity	Cost-reducing effect by technology development
New Job Creation Effect	Inducement effect of Employment
R&D Publicity	Total number of publicity on R&D
Quality Improvement of R&D Human Res ource	Quality Improvement of R&D Human Resources

and 35 respectively as shown in Table 3.

4.4 Development of Field Specific Criteria/Indicators

We visited the headquarters of 16 Frontier R&D projects to obtain interviews to understand characteristics, outcomes of each R&D field and to ascertain implications in regard to each R&D stage. The Delphi method was performed to develop the criteria, which best reflects the characteristics of each R&D stage. The criteria may be extracted from the pool we created in the previous step, or be newly created through the expert discussion on implications. Moreover, the distinctive indicators that represent unique characteristics of each field were developed based on the results of interviews with 16 Frontier R&D projects.

In the BT field, Improvements on National Health and Contributions to R&D Infrastructure were added as outcome criteria. Contribution to R&D Infrastructure represents any R&D cost savings due to the sharing of constructed Database or Software developed. Indicators for Contribution to R&D Infrastructure are based on the value of plant/animal resources obtained and the value of information presented on websites. Improvement on National Health represents any improvement on national health by the results of conducted R&D. Indicators for that are the change of Index associated with Health, change of cure rate, and change of primary attack rate.

In ET field, environmental credentials/certification was added as a output criterion. It represents any recognition related to environment from public sources such as ISO (International Organization for Standardization), Ministry of Environment in Korea, EPA (Environmental Protection Agency) in USA, and UN (United Nations). Indicators for this criterion are numbers of credential/certification, contents of credential/certification, and areas of credential/certification. An outcome criterion added in ET field was contribution to environment and energy infrastructure. Indicators for this criterion are Energy-saving effect, pollution-reduction effect, and disaster prevention effect, etc.

In NT field, Contribution to Technology Development was added as outcome criteria. It measures how much R&D results from the basic stage contribute to producing of R&D outputs at the applied or development stage. Indicators for this criterion are Registered Patents related to core-technology, number of publications in many world-class journals, and the like. Another outcome criterion in the NT field is Standardization. Indicators are number of proposals of domestic/international standardization, number of accepted domestic/international standardization proposals and activities related to standardization. An output criterion in the NT field selected was a prototype.

5. Conclusions

Recently, the necessity of government R&D performance analysis and evaluation has been heavily emphasized due to the increased awareness of the importance of maximizing R&D impacts by effectively utilizing limited government resources (Hong et al., 2009). In order to evaluate the R&D project based on its results, development of necessary evaluation criteria/indicators is essentially important. Even though the R&D results from different stages and fields exhibit varied characteristics, the traditional R&D evaluation method failed to consider the differences when evaluating the R&D project.

Thus, in this study, we proposed a research framework to develop performance criteria and indictors reflecting the nature of each R&D stages and fields. First, we analyzed the structure of past and present government-sponsored R&Ds to understand the nature of R&Ds. Then we created a pool of evaluation criteria and indicators. Using the optimal majority rule, stage specific criteria and indicators were selected from the pool. Second, by applying the Delphi method, field specific distinctive criteria and indicators were selected. With two stage specific and field specific criteria and indicators developed, the matrix containing universal criteria/indicators to evaluate government-sponsored R&D was formed.

To apply the method in practice, the proposed research framework for government-sponsored R&D

programs was applied to the 21st Century Frontier R&D program supported by a government foundation in Korea. This program was composed of 16 R&D projects from the BT, NT, and ET fields with a total available fund of US $150 million. The size of each program was approximately US $8-10 million and the duration of each program was up to 10 years from the launch date. After removing similarity and redundancy among criteria and indicators, the pool consisted of 26 performance criteria and 111 performance indicators that can analyze the outputs and outcomes of R&D in science-technological, economical, and social aspects based on related works.

In order to extract the appropriate criteria for each R&D stage from the pool, a survey containing the questions related to the appropriateness of each criterion for basic, applied and development stages, was distributed to and answered by 23 R&D experts who had enough background on R&D planning and actual R&D projects, and 17 Managers of 21st Century Frontier projects which included two multiple responses. Nineteen performance criteria and 35 performance indicators that would be used to evaluate government-sponsored R&Ds were finally developed based on the analysis results of both the optimal majority rule and the Delphi method. Based on results of the interview and the site-visit with the Delphi methods, field specific performance criteria/indicators reflecting the characteristics of each R&D field were selected from the pool. Any additional criteria/indicators not included in the pool, but representing the distinctive nature of each field were also selected.

The matrix drawn up in this study would provide a useful guideline to analyze results of government-sponsored R&Ds. It can suggest scientific and objective information to analyze R&D performance based on the evaluation results. Consequently, it enables program managers to see the status of R&D programs at a glance, and to easily compare the evaluation results of various R&D programs in one major R&D program. The matrix in this study can also be applied to the evaluation of other R&D programs in Korea. Government officials may use the results of this study to manage and analyze their R&D programs in the future. Furthermore, the matrix will provide helpful insights for future government-sponsored R&D program planning in Korea. The planner will be able to provide evaluation guidelines or establish expectations for the R&D performance in Post Frontier programs based on the result of this study.

Although we designed the matrix of evaluation indicators with assistance of experts in R&D evaluation and management, the matrix is more appropriate for R&D evaluation from a global perspective. In order to improve the effectiveness of the matrix developed in this study, evaluation criteria and indicators should be performed more discussion to reflect the unique Korean conditions. Also, the matrix developed in this study should be combined with the evaluation model to actually evaluate the performance of Frontier projects in order to validate the effectiveness of the matrix in evaluation of government-sponsored R&D. Further works should be conducted to improve the matrix in order to make our study more valuable.

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