

Measuring the Quality of Research Performance by Relative Rank-normalized Impact Factor (R^2nIF)

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Abstract

Due to the recent rapid increase in the size of investment into R&D in Korea, the performance evaluation of government R&D programs has become an important issue in the evaluation and establishment of policies on R&D. Although the results of R&D are produced in a wide range of forms in accordance with the purpose of the R&D, in most cases, these results are primarily in the form of research papers or patents. Accordingly, the analysis of papers and patents is the most fundamental means of evaluating the research performance.

This article attempted to analyze the qualitative status of government R&D programs in Korea and the world through an evidence-based approach with the SCI papers. A new qualitative measurement indicator for the SCI papers, namely the Relative Rank-normalized Impact Factor (R^2nIF), which enables comparison between each field of research, between each country and to global standards, was developed by compensating the limitations of the qualitative indicators that various research groups have been using.

The results in the R^2nIF analysis of government R&D programs showed that although the government R&D programs of Korea have been making contributions towards the enhancement of the qualitative level of SCI papers to a certain extent, the qualitative separation from the global standard still remains substantial, and is particularly large in the fields of Bio-science and Computer science.

It is anticipated that the R^2nIF developed in this paper can be appropriately applied to the majority of performance analysis and evaluation for which the collection of citation information is impossible.

1. Introduction

In common with the rest of the world, Korean Investment into science and technology is increasing in order to enhance national competitiveness. The total government R&D budget of Korea in 2008 was 34.4981 trillion Korean Won (₩), which is a 10.2% increase from the previous year, and the proportion

of the R&D budget in comparison to the GDP at 3.37% was ranked 4th in the world. The R&D budget of the government increased drastically from ₩3.7 trillion in 1999 to ₩12.3 trillion in 2009, and is planned to be expanded continuously at an annual average of 10.7% until 2012. With such an increase in the size of investment into R&D in Korea, interest in research performance is rising. Accordingly, the

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government has established the legal foundation for the efficient management of government R&D programs' performance by enacting the "Law on performance evaluation and performance management of government R&D programs".

Performance evaluations of government R&D programs have become one of the most important topics in the evaluation and establishment of policies on R&D. In most cases, research papers and patents are the most fundamental means of measuring research performance since the results of research are manifested in the forms of papers or patents. Accordingly, the number of SCI papers published, the number of patent applications and registrations, the citations and the SCI Impact Factor (IF) of journal are often used in R&D program evaluation. However, these performance indicators of SCI papers and patents used in most evaluations of R&D programs are only tools to measure the quantitative performance rather than the quality of research, and have limitations in properly reflecting the intrinsic characteristics of each of the research fields. Numerous researchers are developing qualitative measurement indicators in order to overcome such limitations, and the National Research Foundation (NRF) of Korea has analyzed the qualitative characteristics of SCI papers by using a qualitative measurement indicator referred to as the modified rank-normalized Impact Factor (*mrnIF*)¹⁾. However, these qualitative measurement indicators continue to have the limitation that comparative analysis between country and with global standards is impossible.

Accordingly, this paper will propose a new qualitative measurement indicator (Relative Ranking-normalized Impact Factor, *R²nIF*) that can overcome the limitations of the existing qualitative indicators. In addition, we examined the qualitative status of government R&D programs in overall research performance within Korea and the world by applying this indicator to the performance analysis of Korean government R&D programs.

2. Relevant Researches

R&D program evaluation can be divided largely into peer review that represents a qualitative evaluation and quantitative indicator evaluation. Of these, although the peer review does not produce an objective quantification, it is considered to be the most effective method of evaluating R&D programs, pointed particularly qualitative research performance. However, numerous researchers have pointed out the following problems of this method.

Kim, I. M. (2002) pointed out as a problem of peer review the loss of some universal and valid objectivity and fairness when using the subjective judgments of human beings which are influenced by surrounding circumstances. Kostoff (1995) presented the following 6 problems of peer review. Firstly, if the major field of study of the evaluator does not precisely coincide with the corresponding field, then, evaluation results can become distorted. Secondly, the rate at which scientists and engineers receive research grants is much higher in traditional research fields than newly emerging ones. Thirdly, there is a higher probability of receiving a research grant regardless of the qualitative level of the contents of research as there may be halo effect on well-known researchers and research institutions. Fourthly, each evaluator's judgment is subjective, and can be subject to different interpretations and standards of evaluation. Fifthly, substantial consent and consistency between evaluators on the premises used in peer review are required. Sixthly, the cost and time required for peer review is quite substantial.

In order to overcome the aforementioned disadvantages of peer review, many researchers have put much effort into developing quantitative analytic methods. Prichard (1969) developed a new concept referred to as the "bibliometric", and this has become the origin of measurement indicator evaluation and analysis. Measurement indicators for the qualitative analysis of SCI papers using bibliometric include the citation frequency and SCI Impact Factor (IF). Firstly, qualitative analysis using the number of citations began

1) Pudovkin, A. I. (2004); Heo, J. E. (2008)

from the belief that quality of a paper is manifested through its citation by peer scientists (Garfield, 2001). Because most papers cannot be cited by other papers immediately after publication in journals, the average number of citations in a 5-year cycle is frequently used in citation frequency analysis. The comparative indicator for qualitative level of the Center for Science & Technology Studies (CWTS) of Lieden University in Netherlands is one of the cases in which the number of citations in 5-year cycle is used. CWTS carried out analysis of the qualitative level by categorizing the number of citations in 5-year cycle of a particular group as outstanding if it is greater than other groups by 1.2 fold, average if it falls in the range of 0.8~1.2 fold, and inadequate if it is less than 0.8 fold. However, there is a serious limitation in using the extent of citation in a 5-year cycle in analysis or evaluation of performance in that there are difficulties in collecting the information on the number of citations since the majority of papers subjected to analysis and evaluation of performance have been published more recently than 5 years. Accordingly, most of the reports on the analysis and evaluation of performance is employing indirect analysis methods by using the SCI IF rather than direct analysis by using the number of citations.

While the number of citations indicates the impact of individual papers, the SCI IF mainly indicates the influence of the journal itself. The SCI IF of an academic journal is computed by dividing the number of citations in the standard year of all papers published in the corresponding journals during the most recent 2 years, with the exception of the standard year, by the number of papers. However, many researchers have been presenting problems with the SCI IF for the qualitative analysis of papers for a comparative analysis between research fields, made impossible because of the deviation in SCI IF between the research fields which has not been accounted for (Sen, 1992; Marshakova-Shaikovitch, 1996; and Seglen, 1997, etc). For example, a direct comparison of SCI IF between 'Mathematics' for which there are a smaller number of academic journals and low overall SCI IF and 'Bio-science' for which the number of academic journals and SCI IF are higher, may lead to unfair

analysis as it does not consider differences between the research fields at all.

In order to overcome the aforementioned limitations of SCI IF analysis, many researchers have proposed a diverse range of qualitative measurement indicators. In particular, Pudovkin (2004) proposed an indicator referred to as the rank-normalized Impact Factor (*rnIF*) that only utilizes the ranking of SCI IF within a field rather than using the SCI IF. The method proposed by Pudovkin can simply and effectively compensate for the limitations of the SCI IF by means of the following equation (Equation 1).

$$rnIF_j = \frac{(N - R_j + 1)}{N} \quad (\text{Equation 1})$$

Here, *rnIF_j* is the rank-normalized Impact Factor of an academic journal (*j*), *N* is total number of journals for the JCR category to which a journal (*j*) is assigned, while *R_j* is the SCI IF ranking of a particular journal (*j*) within the JCR category. In order to compute *rnIF*, information outside that provided by the Journal Citation Reports (JCR) is not needed. *rnIF* presumes that academic journals in different fields but with a similar status within their respective fields have the same qualitative level. If *rnIF* has value of *x*, then it signifies that an academic journal with $(1-x) \times 100\%$ has superior SCI IF than the academic journal with a value of *x*.

In addition, Sen (1992) suggested the following normalization procedure: $SnIF_j = \frac{IF_j}{maxIF} \times 10$, where *IF_j* is the SCI IF for journal (*j*), *maxIF* is the maximal SCI IF for the JCR category to which journal (*j*) is assigned. Marshakova-Shaikovitch (1996) also suggested a similar normalization: $MnIF_j = \frac{IF_j}{av5maxIF} \times 100$, where *av5maxIF* is the weighted average of the top five SCI IF values in the JCR category, to which the journal (*j*) pertains. The National Research Foundation (NRF) developed a modified rank-normalized Impact Factor (*mrnIF*) to overcome the limitation that the *rnIF* value of the lowest ranking journal for each field relies on number of journals within a field, and allocated integer values in the range of 1~5 on the basis of *mrnIF* (Heo, Jeong Eun et al, 2008).

However, the aforementioned measurement indicators (*rnIF*, *mrnIF*, etc) based on the SCI IF ranking

within a field continue to have the limitation that comparative analysis for each country and with the global standard is impossible. Accordingly, in this article, a new qualitative measurement indicator (R^2nIF) that can overcome the limitations of the existing rank-normalized Impact Factor will be proposed. Furthermore, the current status on the scientific and technological ripple effects of government R&D programs will be accurately diagnosed by utilizing this indicator for the performance analysis of government R&D programs.

3. Analytic Method

3.1 Analytic Model

This article aims to analyze the quality of SCI papers generated from the Korean government's R&D programs. Therefore, the most accurate method would be to investigate and analyze the number of citations of individual papers. However, since this study is on papers published between 2006~2008, analysis of the qualitative level of papers through a citation survey of individual papers is not possible, and it is deemed that numerous performance analyses or performance evaluations would also be subjected to the same limitations. Accordingly, in this study, the method of indirectly analyzing the qualitative level of papers by using the SCI Impact Factor (IF) of journals in which the papers are published has been employed.

As mentioned above, the problem is that there is room for controversy over the fairness of comparing the SCI IF between other research fields since the SCI IF of journals displays substantial differences between each research field. In order to solve these problems, we have developed new qualitative measurement indicator that enables the comparative analysis between other research fields and countries based on the method of compensating the limitations of the SCI IF proposed by Pudovkin *et al.*.

In this article, SCI papers published in the academic journals listed in the JCR database that provides information on SCI IF were chosen up as subjects. The rank-normalized Impact Factor ($rnIF$) was introduced to compensate for the deviation in the

SCI IF between research fields. In order to allocate the SCI IF ranking for each field, it was necessary to categorize the academic journals in each field. The model proposed by Pudovkin *et al.* and the model utilized by NRF (National Research Foundation) categorized the research fields by using the JCR categories (categorization of 175 JCR by Thompson). However, when such a categorization method is employed, there are several fields with less than 20 academic journals within a field, thereby presenting problems in computation of the ranking of journals. Accordingly, in this article, analysis was carried out by employing the method of categorizing journals with National Science Indicators (NSI) standard fields. The NSI standard fields are given in Table 1 below.

After having categorized journals with NSI standard fields, the rank-normalized Impact Factor ($rnIF$) of each journal was allocated in accordance with Equation 2 on the basis of the SCI IF information using the 2007 JCR version and the method proposed

Table 1 NSI standard fields

Main Categories	Standard Field
Engineering and Computer	Computer Science
	Engineering
	Materials Science
Physics, Chemistry and Earth Science	Chemistry
	Geosciences
	Mathematics
	Physics
	Space Science
Bio-science	Biology & Biochemistry
	Immunology
	Microbiology
	Molecular Biology & Genetics
	Neuroscience & Behavior
Medical Science	Pharmacology & Toxicology
	Clinical Medicine
Agriculture, Biology, Environmental Science	Agricultural Science
	Environment/Ecology
	Plant & Animal Science
Multidisciplinary	Multidisciplinary
Social Science	Economics & Business
	Social Science, general
	Psychiatry/Psychology

by Pudovkin.

$$rnIF_j = \frac{(N - R_j + 1)}{N} \quad (\text{Equation 2})$$

N : Total number of journals in the corresponding field

R_j : SCI IF ranking of journal (j) within the corresponding field

Then, the modified rank-normalized Impact Factor ($mrnIF$) was computed in order to overcome the characteristic of $rnIF$ that it relies on the number of journals within a field. Since the lowest value of $rnIF$ for each field relies on the number of journals within a field, values of $rnIF$ were standardized with a minimum value of 0 and a maximum value of 100 through the following Equation 3.

$$mrnIF_j = 100 \times \frac{(N \times rnIF_j + 1)}{(N-1)} \quad (\text{Equation 3})$$

N : Total number of journals in the corresponding field

$rnIF_j$: $rnIF$ of journal (j) in which paper is published

However, as mentioned above, the $mrnIF$ also continues to have the limitation that it does not allow comparative analysis between countries or at the global level. Therefore, in this article, the Relative Rank-normalized Impact Factor (R^2nIF), with additional factors to the $mrnIF$ which enable international comparison, is developed and used in analysis. R^2nIF is an indicator that compares the $mrnIF$ of a paper to be analyzed with the $mrnIF_{Global\ average}$ of the same research field as shown in Equation 4. For example, R^2nIF of a paper published in the 'Physics Review Letters' in 2008, which is a journal under the category of 'Physics', can be computed by dividing the $mrnIF_j$ of 'Physics Review Letters' (=97.035) by $mrnIF_{Global\ average}$ of the field of 'Physics' (=68.715) in 2008.

$$R^2nIF_j = \frac{mrnIF_j}{mrnIF_{Global\ average\ of\ the\ same\ research\ field}} \quad (\text{Equation 4})$$

To compute the R^2nIF , the $mrnIF_{Global\ average}$ of each of the 22 NSI standard fields must be computed for all the papers in the world. Information on the number of papers in each journal is necessary to compute the $mrnIF_{Global\ average}$ for each NSI Standard Field. This data was extracted from the Science Citation

Index Expanded (SCIE) Database held by KAIST. The $mrnIF_{Global\ average}$ for the field of 'Physics' in 2008 can be easily computed by applying Equation 5. The $mrnIF_{Global\ average}$ computed using the number of papers (N_i) and the $mrnIF_i$ information for each journal is shown in Table 2.

$$mrnIF_{Global\ average(2008)\ of\ the\ physics} = \frac{\sum_{i=1}^n (mrnIF_i \times N_i)}{\sum_{i=1}^n N_i} \quad (\text{Equation 5})$$

N_i : No. of papers in the i^{th} journal in 2008 under the category of 'Physics' in 2008

$mrnIF_i$: $mrnIF$ of the i^{th} journal under the category of 'Physics'

Then, the R^2nIF_j of each paper is calculated by dividing the $mrnIF_j$ of the publishing journal by the $mrnIF_{Global\ average}$ of the same research field, and is shown in Table 3. Allocating R^2nIF_s to each paper in this way, the quality of SCI papers generated with government R&D support was analyzed in comparison to global standards.

3.2 Limitations of Analysis

We would like to mention the limitations of performance analysis using R^2nIF_j as employed in this article. Firstly, in order to analyze the qualitative characteristics of SCI papers generated from government R&D programs, it would be most accurate to calculate the $rnIF_j$ for each journal after classifying all journals into the 'Science and Technology Standard Category' set by the 'National Science & Technology Council'. However, this is impossible in reality due to the enormous amount of work it would involve. Accordingly, the NSI standard field was used in this analysis. In addition, if a journal is repeated in more than one NSI standard field, then, the average $rnIF_j$ was used.

Table 2 Global average of $mmIF$ for each NSI standard field (2006-2008)

NSI Standard Fields	$mmIF_{\text{Global average}}$		
	2006	2007	2008
Agricultural Sciences	71.727	71.381	72.261
Biology & Biochemistry	65.200	65.046	64.644
Chemistry	68.122	68.180	68.182
Clinical Medicine	65.802	65.861	65.509
Computer Science	67.987	69.022	68.622
Economics & Business	67.749	67.866	73.543
Engineering	73.044	73.807	73.544
Environment/Ecology	66.233	68.167	67.454
Geosciences	69.138	67.947	70.168
Immunology	60.468	61.956	61.663
Materials Science	75.359	76.497	76.994
Mathematics	67.858	67.045	66.059
Microbiology	63.240	63.116	63.016
Molecular Biology & Genetics	62.330	62.247	62.164
Multidisciplinary	74.368	75.250	74.934
Neuroscience & Behavior	65.608	65.971	65.975
Pharmacology & Toxicology	61.114	61.152	60.642
Physics	67.482	68.482	68.715
Plant & Animal Science	68.200	68.494	69.083
Psychiatry/Psychology	65.593	65.979	65.459
Social Sciences, general	68.992	69.847	68.413
Space Science	74.347	77.368	72.938

Table 3 Example of computation of R^2nIF of SCI paper (2008)

Paper	Journal	NSI Standard Field	SCI IF	$mmIF$ (A)	$mmIF_{\text{Global average('08)}}$ (B)	R^2nIF (A/B)
Chemical tools for functional studies of ...	Chemical Society Reviews		13.082	99.424		1.458
Assay of diazinon pesticides in cucumber ...	Microchimica Acta	Chemistry	1.959	68.300	68.182	1.002
Effects of anonaine on dopamine biosynthesis ...	Molecules		0.940	39.193		0.575
Current status of ENSO prediction skill in ...	Climate Dynamics		3.961	98.118		1.398
Does the restoration of an inner-city stream in Seoul ...	Theoretical and Applied Climatology	Geosciences	1.674	70.353	70.168	1.003
Two-dimensional waveform inversion of multi-component ...	Geophysical Prospecting		0.731	31.529		0.449
Choice of neighbor order in nearest-neighbor ...	Annals of Statistics		1.944	94.316		1.428
Weighted Poincare inequality and heat kernel estimates ...	Mathematische Annalen	Mathematics	0.877	67.789	66.059	1.026
List-coloring the square of a subcubic graph	Journal of Graph Theory		0.503	33.263		0.504

Table 3 Example of computation of R^2nIF of SCI paper (2008) (cont'd)

Paper	Journal	NSI Standard Field	SCI IF	$mmIF$ (A)	$mmIF_{Global}$ average('08) (B)	R^2nIF (A/B)
Combinatorial patterns of histone acetylations ...	Nature Genetics	Molecular Biology & Genetics	25.556	99.170		1.595
Basal c-Jun N-terminal kinases promote mitotic progression ...	Cell Cycle		3.314	60.996	62.164	0.981
Adaptive response to GSH depletion and resistance to ...	Molecular and Cellular Biochemistry		1.707	26.556		0.427
Anisotropic behaviours of massless Dirac ...	Nature Physics	Physics	14.677	99.191		1.444
Miniaturization of a Fresnel spectrometer	Journal of Optics A-Pure and Applied Optics		1.752	68.733	68.715	1.000
Time-dependent Wigner distribution function ...	Physica Scripta		0.946	40.431		0.588
A subhalo-galaxy correspondence model of galaxy biasing	Astrophysical Journal	Space Science	6.405	93.333		1.280
The high activity of 3C 454.3 in autumn 2007 ...	Astronomy & Astrophysics		4.259	80.000	72.938	1.097
Enhanced luminosity of young stellar objects in cometary globules	Astrophysics and Space Science		0.834	31.111		0.427

4. Analysis of Qualitative Characteristics by Using the Relative Rank-normalized Impact Factor (R^2nIF)

4.1. Comparison of Each Country by R^2nIF

Among the key countries, the Relative Rank-normalized Impact Factor (R^2nIF) of the SCI papers of the USA was the highest in 2008 at 1.066, with the U.K. and Germany also illustrating high values of 1.044 and 1.015, respectively. In comparison, the R^2nIF of SCI papers of Korea in 2008 was 0.924, which is below the global average of 1.0, as were Japan and Taiwan with a figure of 0.947 and 0.966 respectively. The qualitative level of SCI papers in Korea is, however, slightly higher than newly industrialized countries such as China and India.

When the qualitative level SCI papers in Korea is calculated limiting the scope to those with government R&D support, the R^2nIF of SCI papers published in 2008 is 0.934, which is still below the global average, but slightly higher than that of all Korean papers at 0.924. This indicates that government R&D programs are making a contribution towards the improvement of paper quality. However, the annual average R^2nIF of

SCI papers with government R&D support decrease from a peak of 0.942 in 2006, and exhibit a growing gap with average global quality levels. Therefore, further study is needed to establish the cause of failure to improve the quality of SCI papers in spite of the efforts the government has made to increase it. R^2nIF of SCI papers of key countries during 2006–2008 are shown in Table 4.

The results of R^2nIF analysis for each of the NSI standard fields illustrated that Korea has strength in the fields of space science, earth science, material science, and plant & animal science (Table 5). The R^2nIF for SCI papers in these fields in 2008 were 1.107,

Table 4 Average R^2nIF of SCI papers of key countries

Key Countries	2006	2007	2008
Korea	0.862	0.915	0.924
Government R&D	0.942	0.940	0.934
USA	1.071	1.076	1.066
U.K.	1.034	1.046	1.044
China	0.901	0.914	0.896
Germany	0.991	1.014	1.015
Japan	0.914	0.938	0.947
Taiwan	0.926	0.955	0.966
India	0.862	0.874	0.866

1.055, 1.020 and 1.011, respectively, and were higher than the global average at 1.0. In addition, although not many papers were published in the field, papers in the field of ‘multidisciplinary’ had an R^2nIF of 1.080, which is also higher than the global average. In comparison, the R^2nIF for the BT-related NSI standard fields including biology & biochemistry, clinical medical science, immunology, microbiology, molecular biology & genetics, and pharmacology were in the range of 0.8~0.9, thereby displaying a substantial gap with global standards.

Figure 1 shows the results of a comparison of the R^2nIF for each NSI standard field in 2008 with the USA, the UK, Germany, Japan, Taiwan, China and India. In comparison to the USA, the UK and Germany, Korea substantially lags behind in a majority of fields with the exception of a few fields such as space science, material science, earth science and agriculture. In particular, the gap in computer science and BT-related fields (microbiology, molecular biology

& genetics, and immunology) is quite substantial. Korea displays R^2nIF characteristics that are similar to Japan and Taiwan for each field, and when compared to China and India, Korea displays qualitative paper characteristics which are equivalent or superior in most fields, the one exception being computer science where Korea lags behind.

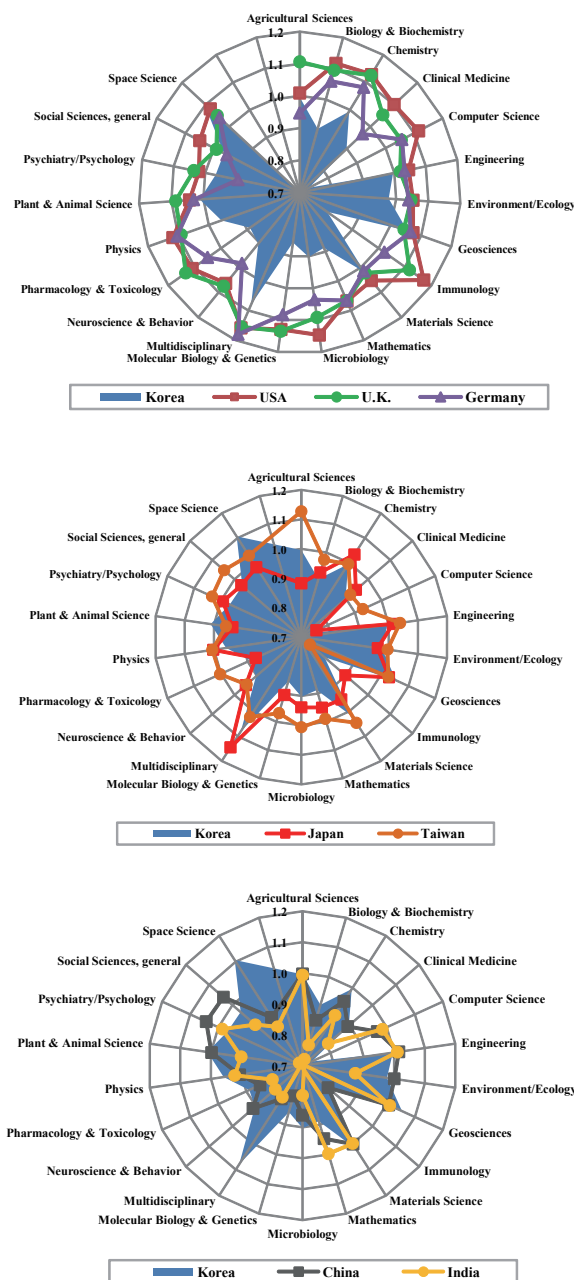


Table 5 R^2nIF of SCI papers of Korea for each NSI standard field

NSI Standard Field	R^2nIF		
	2006	2007	2008
Agricultural Sciences	1.014	1.021	0.996
Biology & Biochemistry	0.902	0.896	0.905
Chemistry	0.994	0.981	0.995
Clinical Medicine	0.900	0.902	0.899
Computer Science	0.737	0.784	0.733
Engineering	0.981	1.002	0.996
Environment/Ecology	0.894	0.910	0.977
Geosciences	1.049	1.061	1.055
Immunology	0.820	0.892	0.804
Materials Science	1.022	0.996	1.020
Mathematics	0.914	0.969	0.887
Microbiology	0.888	0.886	0.902
Molecular Biology & Genetics	0.880	0.872	0.857
Multidisciplinary	1.149	1.071	1.080
Neuroscience & Behavior	0.897	0.910	0.904
Pharmacology & Toxicology	0.901	0.914	0.890
Physics	0.952	0.981	0.958
Plant & Animal Science	1.000	1.008	1.011
Psychiatry/Psychology	1.062	1.002	0.967
Social Sciences, general	0.977	1.064	0.965
Space Science	1.099	1.085	1.107

Figure 1 Comparison of R^2nIF for each NSI standard field of key countries (2008)

Table 6 Comparison of qualitative measurement indicators of SCI paper for each category of research institution

Category of research institution	No. of SCI papers			SCI IF			<i>mmIF</i>			<i>R²nIF</i>		
	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
National and Public Research Institutes	295	409	560	2.12	2.03	2.39	56.5	55.9	57.5	0.850	0.838	0.863
Government Subsidized Research Institutes	2,738	2,941	3,181	2.03	2.25	2.25	61.2	65.0	63.3	0.883	0.932	0.909
Universities	6,793	9,557	11,450	2.70	2.58	2.56	66.0	65.3	65.2	0.969	0.949	0.948
Large Enterprises	177	300	363	2.83	2.27	2.25	70.9	67.2	62.8	1.034	0.966	0.907
Small & Medium Enterprises	175	265	269	2.39	2.23	2.04	61.5	63.2	61.6	0.902	0.912	0.888
Others	150	215	205	2.01	2.15	2.05	61.3	58.3	62.0	0.883	0.838	0.887
Total	10,328	13,687	16,028	2.49	2.47	2.47	64.4	64.8	64.4	0.942	0.940	0.934

4.2. Comparison of *R²nIF* for Each Detailed Standard

4.2.1 Comparison of *R²nIF* across categories of research institution

The results of the *R²nIF* analysis broken down by categories of research institution (Figure 2) illustrated that universities have the highest *R²nIF*, and that the qualitative level of all categories of research institution were lower than the global average. Among the categories of research institution, the *R²nIF* of SCI papers published by universities in 2008 was the highest at 0.948, followed by government subsidized

research institutes (0.909), large enterprises (0.907), small & medium enterprises (0.888) and national & public research institutes (0.863). Although the number of SCI papers published by all categories of research institution increased substantially in comparison to the previous year, the *R²nIF*, which is a qualitative indicator, decreased, thereby indicating an urgent need to improve the qualitative aspects. In particular, in the case of universities, although the number of published papers increased enormously (6,793 → 11,450), the *R²nIF* on the contrary decreased from 0.969 in 2006 to 0.948 in 2008 as shown in Table 6.

Figure 3 and Table 7 show the results of breaking

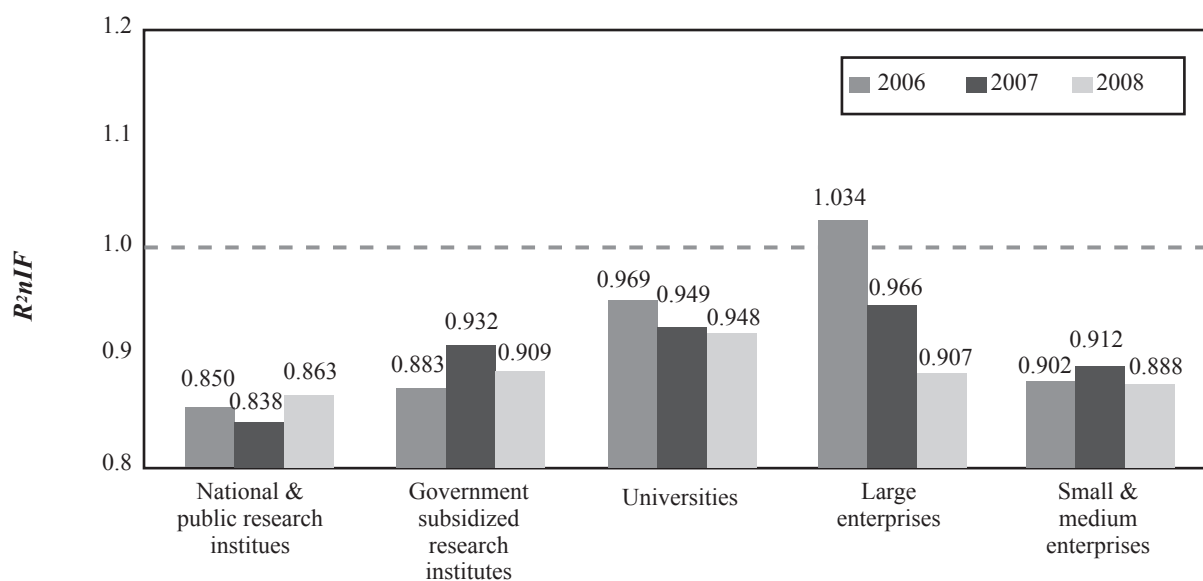
**Figure 2** Comparison of *R²nIF* for each category of research institution

Table 7 Comparison of qualitative measurement indicators of SCI paper for each R&D stage of categories of research institution

Categories		No. of SCI papers			SCI IF			<i>mmIF</i>			<i>R²nIF</i>		
		2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
National and Public Research Institutes	Basic Research	98	167	252	2.22	2.19	2.15	56.6	57.2	56.0	0.861	0.864	0.840
	Applied Research	71	149	225	1.49	1.75	2.82	51.5	55.1	60.9	0.766	0.816	0.914
	Development Research	125	93	73	2.40	2.22	1.93	59.4	54.8	53.6	0.891	0.827	0.803
	Others	1	0	10	0.86	-	2.07	44.9	-	48.3	0.658	-	0.726
	Subtotal	295	409	560	2.12	2.03	2.39	55.6	55.9	57.5	0.850	0.838	0.863
Government Subsidized Research Institutes	Basic Research	826	1,184	1,310	2.63	2.62	2.57	67.2	67.5	65.6	0.980	0.975	0.950
	Applied Research	1,222	1,053	1,076	1.84	2.21	2.13	59.7	64.8	62.2	0.860	0.930	0.894
	Development Research	614	660	703	1.67	1.61	1.88	57.8	60.6	61.2	0.826	0.855	0.866
	Others	77	43	93	1.40	2.88	1.84	47.9	68.2	59.9	0.682	0.978	0.846
	Subtotal	2,738	2,941	3,181	2.03	2.25	2.25	61.2	65.0	63.3	0.883	0.932	0.909
Universities	Basic Research	4,174	5,975	6,999	2.95	2.82	2.86	67.7	67.5	68.1	0.998	0.985	0.995
	Applied Research	1,850	2,551	3,247	2.38	2.35	2.20	63.7	62.7	61.4	0.932	0.908	0.889
	Development Research	728	911	1,101	2.15	1.81	1.78	62.6	60.3	58.6	0.909	0.862	0.837
	Others	41	120	104	1.35	1.18	1.25	57.3	51.1	54.3	0.812	0.713	0.762
	Subtotal	6,793	9,557	11,450	2.70	2.58	2.56	66.0	65.3	65.2	0.969	0.949	0.948
Large Enterprises	Basic Research	15	32	16	2.78	2.60	2.71	65.9	71.2	67.4	0.995	1.040	1.001
	Applied Research	46	83	102	3.44	3.09	3.08	69.1	71.3	63.5	1.033	1.046	0.944
	Development Research	117	185	246	2.59	1.85	1.88	72.3	64.7	62.3	1.040	0.918	0.886
	Others	0	0	0	-	-	-	-	-	-	-	-	-
	Subtotal	177	300	363	2.83	2.27	2.25	70.9	67.2	62.8	1.034	0.966	0.907
Small & Medium Enterprises	Basic Research	10	12	19	3.05	2.38	2.30	56.5	52.0	64.1	0.863	0.789	0.931
	Applied Research	20	37	60	2.21	2.71	2.00	59.3	69.4	58.6	0.872	0.998	0.847
	Development Research	145	216	185	2.37	2.14	2.04	62.1	62.8	62.4	0.908	0.904	0.898
	Others	0	0	3	-	-	1.22	-	-	56.5	-	-	0.789
	Subtotal	175	265	269	2.39	2.23	2.04	61.5	63.2	61.6	0.902	0.912	0.888
Others		150	215	205	2.01	2.15	2.05	61.3	58.3	62.0	0.883	0.838	0.887
Total		10,328	13,687	16,028	2.49	2.47	2.47	64.4	64.8	64.4	0.942	0.940	0.934

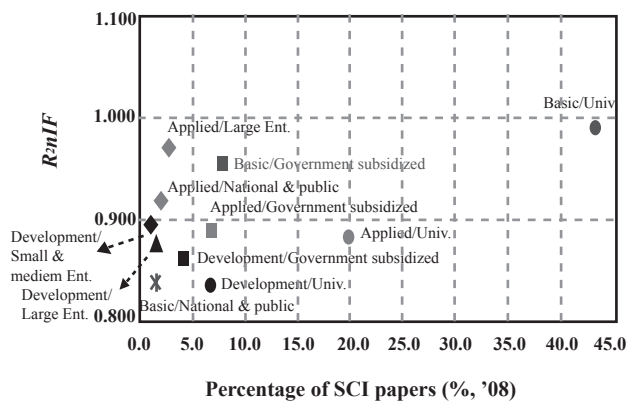


Figure 3 R^2nIF for each R&D stage/ category of research institution (2008)

down the R^2nIF for each category of research institution by each stage of R&D. SCI papers with a high R^2nIF were generated from basic research carried out by universities. Although the R^2nIF of papers published for basic research projects by universities was 0.995 in 2008, close to the global level, the quality of papers of applied research and development research carried out by universities were substantially lower than the global level. In addition, although the R^2nIF for applied research carried out by large enterprises in 2008 was the highest among the categories of research institution at 0.944, this value is still substantially lower than the global level.

Table 8 Universities with high ranking R^2nIF

2006				2007				2008			
Institutions	No. of papers	SCI IF	R^2nIF	Institutions	No. of papers	SCI IF	R^2nIF	Institutions	No. of papers	SCI IF	R^2nIF
POSTEH	404	3.30	1.092	POSTEH	630	2.96	1.055	KAIST	591	3.18	1.062
Ewha Womans Uni.	151	3.72	1.079	Ewha Womans Uni.	190	3.27	1.037	POSTEH	775	3.07	1.054
KAIST	453	2.89	1.057	Yonsei Uni.	645	3.16	1.033	Ewha Womans Uni.	247	3.50	1.048
Seoul Nat. Uni.	1,027	3.21	1.030	KAIST	542	2.88	1.011	GIST	210	2.63	1.029
Yonsei Uni.	452	3.09	1.027	Seoul Nat. Uni.	1,404	2.91	1.002	Yonsei Uni.	822	3.16	1.014
Kyungpook Nat. Uni.	222	3.20	1.011	Hanyang Uni.	418	2.51	0.988	Seoul Nat. Uni.	1,562	3.03	1.011
Korea Uni.	415	2.65	0.984	Sungkyunkwan Uni.	441	2.69	0.984	Sungkyunkwan Uni.	536	2.73	1.004
Sungkyunkwan Uni.	291	2.76	0.984	GIST	191	2.65	0.980	Kyungpook Nat. Uni.	344	2.76	0.963
Chungbuk Nat. Uni.	107	2.54	0.945	Korea Uni.	539	2.46	0.956	Gyeongsang Nat. Uni.	197	2.54	0.957
Chungnam Nat. Uni.	124	2.42	0.941	Chungnam Nat. Uni.	152	2.39	0.938	Seoul Nat. Uni. Hospital	175	3.54	0.933
Ajou Uni.	99	2.82	0.937	Kyungpook Nat. Uni.	248	2.59	0.930	Korea Uni.	576	2.40	0.931
Catholic Uni. of Korea	112	3.20	0.932	Ajou Uni.	127	2.46	0.930	Chonbuk Nat. Uni.	322	2.19	0.929
Hanyang Uni.	305	1.96	0.921	Chonnam Nat. Uni.	187	2.74	0.920	Chonnam Nat. Uni.	270	2.32	0.907
Inha Uni.	215	2.27	0.916	Pusan Nat. Uni.	410	2.35	0.917	Pusan Nat. Uni.	455	2.17	0.905
Chonbuk Nat. Uni.	155	2.22	0.911	Chonbuk Nat. Uni.	225	2.03	0.904	Hanyang Uni.	611	2.03	0.903
Gyeongsang Nat. Uni.	118	2.38	0.909	Konkuk Uni.	146	2.37	0.872	Konkuk Uni.	204	2.37	0.883
Pusan Nat. Uni.	227	2.25	0.904	Gyeongsang Nat. Uni.	194	2.24	0.861	Ajou Uni.	169	2.24	0.880
Chonnam Nat. Uni.	152	2.79	0.899	Chungbuk Nat. Uni.	187	2.02	0.853	Chungnam Nat. Uni.	169	2.16	0.856
Konkuk Uni.	104	2.42	0.898	Kyung Hee Uni.	214	2.22	0.851	Kyung Hee Uni.	259	2.08	0.847
Kyung Hee Uni.	131	2.21	0.850	Inha Uni.	258	1.80	0.831	Inha Uni.	331	1.81	0.833

Note) These are results of analysis that excluded the BK21 performances. For KAIST and GIST, analysis was carried out by excluding the performances generated from institutional subsidies

the R^2nIF for each category of research institution by each stage of R&D. SCI papers with a high R^2nIF were generated from basic research carried out by universities. Although the R^2nIF of papers published for basic research projects by universities was 0.995 in 2008, close to the global level, the quality of papers of applied research and development research carried out by universities were substantially lower than the global level. In addition, although the R^2nIF for applied research carried out by large enterprises in 2008 was the highest among the categories of research institution at 0.944, this value is still substantially lower than the global level.

4.2.2 Comparison of R^2nIF for each institution conducting research

The results of the R^2nIF analysis of SCI papers for each university revealed that Pohang University of Science & Technology (POSTECH), Korea Advanced Institute of Science & Technology (KAIST), Ewha Womans University, Yonsei University, and Seoul National University published papers in renowned academic journals (Table 8). In 2008, the universities

with an average R^2nIF of more than 1.0 included KAIST (1.062), POSTECH (1.054), Ewha Womans University (1.048), Gwangju Institute of Science & Technology (GIST) (1.029), Yonsei University (1.014) and Seoul National University (1.011). In particular, 5 universities including POSTECH, Ewha Womans University, KAIST, Seoul National University and Yonsei University have displayed R^2nIF s that are higher than the global average of 1.0 for 3 years in succession since 2006.

The examination of qualitative characteristics of SCI papers produced by 26 government-subsidized research institutions (under the jurisdiction of the Korea Research Council of Fundamental S&T and the Korea Research Council for Industrial S&T) revealed that the Korea Astronomy and Space Science Institute (KASI) and the Korea Basic Science Institute (KBSI) published papers in well-known academic journals (Table 9). The R^2nIF for KASI and KBSI in 2008 were 1.098 and 1.035, respectively, indicating publishing in journals above the global average, while the R^2nIF for KIST, KRIBB and KRICT in 2008 were 0.982, 0.966 and 0.960, respectively, and lagged behind the global average slightly. In comparison, the R^2nIF for KAERI

Table 9 subsidized research institute with high ranking R^2nIF

2006				2007				2008			
Institutions	No. of papers	SCI IF	R^2nIF	Institutions	No. of papers	SCI IF	R^2nIF	Institutions	No. of papers	SCI IF	R^2nIF
KRISS	96	2.17	1.019	KASI	68	4.32	1.071	KASI	79	4.54	1.098
KASI	74	4.00	1.013	KIST	382	2.45	1.014	KBSI	105	3.09	1.035
KBSI	66	2.58	1.003	KRISS	163	2.06	1.013	KIST	480	2.52	0.982
KIST	334	2.19	0.975	KRICT	132	2.59	1.000	KRIBB	222	3.05	0.966
KRICT	103	2.31	0.973	KBSI	102	2.68	0.993	KRICT	170	2.50	0.960
KIMM	83	1.83	0.962	KIMM	122	1.96	0.954	KIER	92	2.05	0.960
KRIBB	219	3.01	0.937	KRIBB	258	2.72	0.929	KIMS	83	1.79	0.948
NFRI	59	1.46	0.875	KERI	108	1.59	0.919	KRISS	172	2.30	0.938
ETRI	132	1.25	0.801	KIER	70	1.70	0.886	KORDI	91	2.24	0.916
KIGAM	71	1.66	0.746	KFRI	61	1.82	0.861	KIMM	73	1.79	0.912
KAERI	257	1.28	0.735	KORDI	95	1.98	0.842	NFRI	53	1.32	0.904
				KIGAM	93	1.42	0.825	KIGAM	98	1.59	0.855
				ETRI	210	1.41	0.818	ETRI	205	1.63	0.851
				KAERI	315	1.33	0.763	KFRI	58	1.85	0.846
								KERI	88	1.47	0.792
								KAERI	418	1.18	0.705

Note) Arranged in the order of R^2nIF with research institutions that produced more than 50 research papers as subjects

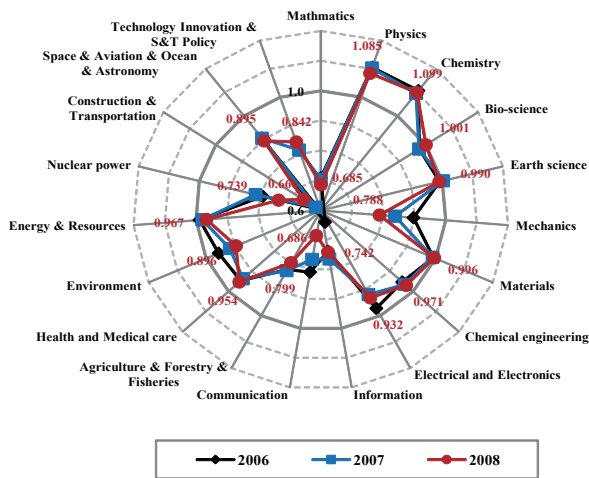


Figure 4 Comparison of R^2nIF for each technological field

and ETRI in 2008 were 0.705 and 0.851, respectively, illustrating a substantial gap with the global standard, thereby requiring qualitative improvements.

4.2.3 Comparison of R^2nIF for each technology field

The examination of the R^2nIF for each S&T standard category illustrated that the qualitative level of SCI papers generated in the fields of physics and chemistry were higher than the global average as shown in Figure 4. The R^2nIF for physics and chemistry in 2008 were 1.085 and 1.099, respectively, showing that the SCI papers were on the average published in journals with a level of citation higher

than the global average. In comparison, the R^2nIF of papers generated from fields including information, communication, agriculture & forestry & fisheries, environment and nuclear power were less than 0.9, thereby continuing to exhibit a substantial deficiency when compared to global standards.

4.2.4 Comparison of R^2nIF for each key R&D program

Table 10 shows the R^2nIF of the top 10 R&D programs in terms of numbers of SCI papers published in 2008. Among the key R&D programs, the R^2nIF of the ‘Creative Research Program’ was 1.131, which is higher than the global average, so it is publishing a large number of SCI papers in qualitatively outstanding journals. In addition, the R^2nIF of SCI papers generated from the ‘21C Frontier R&D Program’ was 1.011, illustrating that its quality of papers is close to the global level. In contrast, R^2nIF of ‘Particular Basic Research Support Program’ that generated the largest number of SCI papers was 0.949, thus failing to achieve the global average. The R^2nIF for the ‘University IT Research Center Cultivation Support Program’ and the ‘Nuclear Power Technology Development Program’ were below 0.7, thereby illustrating an enormous difference when compared with the global standard.

4.2.5 Comparison of R^2nIF for each type of cooperative R&D by universities

Table 10 Comparison of the qualitative measurement indicators of SCI papers for the top 10 programs in terms of number of papers published (2008)

Program Name	No. of papers	SCI IF	R^2nIF
Creative Research	466	4.11	1.131
21C Frontier R&D	971	2.82	1.011
Cultivation of outstanding research center	900	2.79	0.992
Cultivation of outstanding research center <SRC,ERC,MRC,NCRC>	814	2.70	0.988
Development of Foundation Technology (Nano, Bio)	377	3.05	0.986
National Research Laboratory	886	2.56	0.986
Particular Basic Research Support	1,630	2.44	0.949
Public Health and Medical Technology R&D	352	2.92	0.924
Support for Cultivation of University IT Research Center	483	1.18	0.697
Development of Nuclear Power Technology	325	1.18	0.687

Table 11 Comparison of qualitative measurement indicator for SCI papers for each type of cooperative R&D by university (2008)

Category of research institution	Types of cooperative R&D	No. of papers	SCI IF	R^2nIF	
University	Non-execution of international cooperative R&D	Enterprise·University	885	1.92	0.839
		Enterprise·University·Research institute	376	2.52	0.943
		University·Others	53	2.60	0.927
		University·Research institute	175	2.40	0.863
		University· University	2,658	2.27	0.899
		No Cooperation	5,245	2.76	0.980
	Subtotal	9,392	2.53	0.940	
	Execution of international cooperative R&D	University·Overseas Institute	1,700	2.80	1.005

The R^2nIF of SCI papers generated from the projects in which universities participated as the category of research institution were examined for each type of cooperative R&D. As shown in Table 11, the R^2nIF of SCI papers generated from the projects in which universities pursued research jointly with overseas research institutions was 1.005, or in other words these papers were published in academic journals with level of citation that is above the global average. This value is higher than the papers generated from the projects in which universities did not carry out international cooperative R&D (0.940), thereby illustrating that the execution of cooperative R&D by universities in the field of basic science in collaboration with overseas research institutions enhances papers quality. However, further study is needed to be certain how much of the paper quality difference is actually due to the international collaboration since groups able to set up international collaboration may already have an above average research quality.

5. Conclusion

This article attempted to analyze the qualitative status of Korean government R&D programs in comparison to the global standard by proposing and utilizing a new measurement indicator to analyze the qualitative level of papers based on the SCI Impact Factor (IF). A wide range of qualitative measurement indicators that can analyze SCI papers have been developed by numerous researchers. Among these, the SCI IF is the most commonly used in performance

analysis and evaluation. However, the SCI IF has the problem that comparative analysis between technology fields is impossible since it displays substantial differences between each field. Qualitative measurement indicators such as the rank-normalized Impact Factor ($rnIF$) that try to overcome these problems also have the limitation that international comparisons such as between countries and or to a global standard are not possible. Accordingly, in this article, a new qualitative measurement indicator (Relative Rank-normalized Impact Factor, R^2nIF) that enables a comparison with global standards was developed by advancing the supplemented SCI IF indicator ($rnIF$) a step further. R^2nIF is an indicator ($R^2nIF_j = mrnIF_j / mrnIF_{\text{Global average in the same field}}$) computed by dividing the modified rank-normalized Impact Factor ($mrnIF$) of a paper by the global average of the $mrnIF$ in the same research field, and is an enhanced indicator that enables analysis in qualitative comparison with the global level.

The results of the analysis of the qualitative level of government R&D programs by utilizing R^2nIF , which was newly developed in this study, can be summarized as follows. Firstly, although it was revealed that the government R&D programs are making some contributions towards the enhancement of the qualitative level of the SCI papers of Korea, the qualitative level has stagnated. Although the R^2nIF average for all the SCI papers generated from government R&D programs was 0.934 in 2008, thereby falling behind the global average of 1.0, it is slightly higher than the average R^2nIF of all papers generated in Korea, 0.924.

However, it was revealed that the R^2nIF for each year has gradually decreased from the peak of 0.942 in 2006, showing the need for additional detailed analysis and discussions in the future of the reasons for the failure to improve the qualitative level in spite of the recent efforts of the government to enhance the qualitative level of SCI papers. Secondly, the result of a comparison of the qualitative level of papers with those of advanced countries such as the USA, the UK and Germany revealed that the levels are substantially lower in most fields, with a particularly large gap in BT-related fields (such as biology & biochemistry, clinical medical science, immunology, microbiology and molecular biology) and in the computer science field. Thirdly, among categories of research institution, the quality of papers by universities that carry out basic research was found to be comparatively superior. In technology fields, the quality of papers in basic science fields such as physics and chemistry were found to be comparatively superior. Lastly, it was found that the quality of papers generated from international cooperative research was comparatively superior.

As explained above, the new qualitative indicator (R^2nIF) proposed in this article enables the comparison between countries, technology fields and categories of research institution, and it is anticipated that this indicator can be utilized for the identification of areas of strength and weakness of institutions carrying out research including universities and government subsidized research institutes, and in the evaluation of individual papers from R&D programs.

This article has proposed a new measurement indicator that can analyze the qualitative level of an SCI paper. As research performances can manifest themselves diversely according to the nature of the R&D program, there is a need to pursue follow up studies on the qualitative measurement indicator for various types of research performances other than research papers. In particular, patents are an important indicator that can be used to assess technology innovation by country, region, technology and the category of research institution. Therefore, discussion of a qualitative measurement indicator that can internationally compare the technological

and economical values of patents is necessary. For example, supplementing the citation frequency for each patent, the number of patent claims and the patent family size indicator, which are frequently used in qualitative analysis of patents, would enable international comparison. A comparison with the global average for the technological field can be considered. In addition, there is a need to pursue follow-up studies on the development of a customized performance indicator that is appropriate not only for comparison between technological fields but also between each R&D program. For this purpose, a follow-up study to quantify the quality level of research performance which is appropriate for R&D programs, other than by papers and patent, such as by technology transfer, commercialization and cultivation of manpower, is required.

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