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Analysis of Investment in Nanotechnology Using DEA

Seung-Chul Yoon · Heung-Kyu Kim†

School of Business Administration, Dankook University

DEA를 활용한 나노기술의 투자분석

윤승철 · 김흥규†

단국대학교 경영학부

This study aims to objectively measure the efficiency of nanotechnology R&D programs by systematically evaluating the inputs and outputs of nanotechnology R&D activities and to find implications for improving the efficiency of nanotechnology R&D programs.

Data on input factors such as R&D investment, R&D manpower, R&D period, and output factors such as paper, patent, and commercialization for R&D projects which started from 2008 or afterwards and ended by 2011 are gathered through National Science and Technology Knowledge Information Service, which are used for efficiency evaluation.

In this study, we analyzed R&D efficiency in detailed technology units in depth. The process taken in this study is as follows.

First, the basic statistics of input and output factors to compare and analyze R&D investment, R&D manpower, R&D period, paper, patent, and commercialization status by technology unit are analyzed.

Next, DEA models are utilized to derive the overall efficiency, pure technology efficiency, and scale efficiency by conducting the efficiency evaluation for each technology unit, from which implications for strategic budget allocation are derived. In addition, partial efficiency evaluation is conducted to identify advantages and disadvantages of each technology unit. In turn, cluster analysis is performed to identify similar technology units, from which implications for efficiency improvement are derived.

Keywords : NT(Nanotechnology), R&D Investment, R&D Performance, R&D Efficiency, R&D Strategy

1. Introduction

We have promoted scientific knowledge through R&D activities and this knowledge has enabled the production of goods or services that are not previously possible. In addition, R&D activities are the basis for productivity improvement on the enterprise side and sustainable economic growth on the national level [5].

For this reason, the government has invested a lot in R&D. The government's nanotechnology R&D investment has continued to grow in size. It was 451.9 billion KRW in 2008, 513.5 billion KRW in 2009, 544.1 billion KRW in 2010, and 607.5 billion KRW in 2011 [13].

In order to enhance long-term national competitiveness, quantitative expansion of R&D investment is important, but it is also important to improve efficiency in terms of quality. In particular, if the national economy is in a difficult situation as now, the efficiency of R&D project is urgently needed.

The purpose of this study is to evaluate the efficiency of nanotechnology R&D projects and to provide implications for strategic budget allocation to enhance the efficiency of nanotechnology R&D projects.

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† Corresponding Author : heungkyu@dankook.ac.kr

2. Literature Review

2.1 Measurement of R&D Performance

The results of national R&D projects are largely divided into theses, patents, commercialization, manpower training, and infrastructure [6]. The results of R&D projects are divided into primary performance and secondary performance as well. The primary outcome basically refers to papers, patents, and commercialization. Secondary outcomes include cost reduction, increasing sales, and improving quality.

These 'output' and 'result' can be thought of as the output of R&D activities and commercialization of R&D outputs. In other words, the direct achievement from R&D activities can be regarded as output. In general, in order to generate economic profit from R&D outputs, commercialization process is necessary. The commercialization process will result in economic performance of R&D activities.

It takes a considerable amount of time to track papers, patents, and commercialization, which are direct results of such R&D activities. For example, in the case of theses, it usually takes one to three years from submitting to publication. In the case of patents, it usually takes three to five years for applications and registrations. In the case of commercialization, it also takes considerable time, usually from months to years.

2.2 Nanotechnology Classification

Nanotechnology is a technology that identifies nanometer-scale atomic and molecular phenomena and manipulates and controls the structure and components of materials at that level. Nanotechnology can be applied to all industries such as machinery, chemistry, bio, energy, electronics and information communication. It is considered as a revolutionary technology for human civilization and is expected to play a leading role in the 21st century knowledge-based society [9, 10].

Nanotechnology can be broadly divided into four categories : 'nanodevices and systems', 'nanomaterials', 'nanobiotechnology', and 'nano-based processes' [13]. First, 'nano devices and systems' are regarded as a source technology that can secure competitive advantage in the market. Next, 'nanomaterial' is a field that includes nanoparticle material and optical nanomaterial, and is evaluated as an application technology having a large economic impact. Next, 'nanobiotechnology' is a fusion of nanotechnology and biotechnology. Finally, 'nano-based process' is a source technology with strong publicness that helps strengthen industrial competitiveness. These four technical fields can be further divided into 22 detail technical fields [13] as shown in <Table 1>.

Therefore, nanotechnology can be said to be an economical and environmentally friendly technology that manufactures nanostructures, devices or systems while minimizing the loss of resources consumed in the environment. Next, from academic perspective, it can be said to be a combination of disciplines or technologies in various fields such as mathematics, physics, chemistry, medicine, electronics, and materials, which is used for the analysis, manipulation and application of atomic and molecular phenomena. In addition, from industrial perspective, it can be said to be a technology that can substitute existing market or create a new market because it is a technology that goes beyond the limit of existing technology, not just an extension of existing technology.

<Table 1> Nanotechnology Classification

sub-area	technology unit
nano devices and systems	variable wavelength optical device technology, nano devices and systems, other nano devices and systems technology, nano photonics technology, nano electronic device technology, nano information storage technology
nanomaterials	nanomaterial, nanomaterial technology (focusing on nano powder material, optical nano material, high performance synergy material, catalyst, environment and functional material), other nanomaterial technology
nanobio-technology	nano-bio material synthesis and analysis technology, nanobiotechnology, other nanobiotechnology, medicine delivery system
nano-based process	interface or surface nanostructuring technology, nano-based process, other nano-based process technology, nanomaterial technology, nano new functional molecular synthesis technology, nanometer measurement technology (less than 100 nm), nanopatterning process technology, nano chemical process technology, atomic and molecular level material manipulation technology

2.3 DEA

DEA has been applied to the relative efficiency evaluation of various fields since the publication of the related paper including VRS (Variable Returns to Scale) model in 1984, starting with CRS (Constant Returns to Scale) model in 1978.

DEA is divided into various models according to the assumptions such as input oriented or output oriented, CRS or VRS. In DEA, the distance between observed observations and production frontier is regarded as inefficiency. In this case, when the distance is fixed to the input (output), it can be measured by the degree to which the input (output) falls to the production frontier, that is, the input (output) oriented.

VRS model assumes a set of producible sets that satisfy only free disposability and convexity from all observations, and then the inefficiency is measured as the distance between the observed observations and the production frontier. Here, free disposability means that when inputs and outputs are producible, a combination of inputs and outputs with more inputs or fewer outputs is also possible. The convexity also means that if any two input · output combinations are producible, the linear combination of the two can also be produced.

In input oriented model, technological efficiency is calculated by decreasing the proportion of input element usage while maintaining the output level, while in output oriented model, technological efficiency is calculated by increasing the proportion of output production while maintaining input level. Both models have the same value under CRS assumption, but the value is different under VRS assumption. The choice of input oriented or output oriented models is not a problem in econometric estimation. Although it is not applicable to all industries, it is reported that there is a tendency to select input oriented models over output oriented models because the selection of inputs is a major decision variable. However, it is desirable to use output oriented model to increase output by using fixed resources such as R&D activities. In other words, if input elements are controllable, then input oriented model is selected. If controllable elements are output, then output oriented model is selected.

The initial model of the DEA assumes CRS. In other words, no matter how small the scale is, it is assumed that the amount of input and output can be reduced by a certain ratio and become efficient if it is equal to the efficient DMU (Decision Making Unit) ratio scale. However, in general, the larger the scale, the more efficient or inefficient it becomes, which implies CRS assumption is not satisfied. Therefore, the larger the difference in scale between the DMUs to be compared, the more VRS assumption must be considered. In other words, we must determine whether the inefficiency of the DMU is due to the inefficient operation of the DMU itself or due to the unreasonable situation in which the DMU is operating. This scale efficiency can be derived from the efficiency of CRS model and VRS model. The CRS model is validated under the situations where the DMU being evaluated is operating at the optimal production scale, while the VRS model is suitable for situations where the optimal production activity is not achieved due to constraints such as financial conditions.

2.4 Efficiency Evaluations of R&D Projects

Eilat et al. [3] conducted a DEA for the purpose of demonstrating a methodology for constructing and analyzing an efficient, effective, and equitable risk portfolio of interactive R&D tasks. Using a model incorporating Balanced Scorecard concept in DEA, a methodology for an integrated R&D portfolio analysis considering effectiveness, efficiency, and homogeneity was proposed.

Guan et al. [5] conducted DEA for 182 innovative firms in China with the aim of identifying the relationship between technological innovation capacity and competitiveness. As a result, only 16% of companies are operating effectively, and there are a number of companies with inconsistencies between organizational innovation capacity and competitiveness. 70% of the ineffective firms are in DRS (Decreasing Returns to Scale), and the remaining 30% are in IRS (Increasing Returns to Scale) status.

Kocher et al. [8] measured the productivity of leading economics research using DEA. The research was conducted in 21 OECD countries. The results of the papers published in the top 10 journals of economics from 1980 to 1998 are measured as output, and R&D expenditure was measured as input. With CRS assumption, only the United States has emerged as an efficient country, and, with VRS assumption, the United States, Ireland, and New Zealand are located at efficient frontier. With the exception of the United States, all countries are in IRS status, which suggests that increasing their R&D activities has the potential to increase their efficiency.

Wang and Huang [12] used DEA to measure the relative efficiency of R&D activities by country. The R&D stock and manpower are considered as input. The papers and patents are considered as output. The main results show that less than half of the countries are performing R&D activities efficiently, and more than two thirds of countries are in IRS status. Also most of the countries turn out to have a stronger position in publishing the papers than patent applications.

Lee et al. [11] conducted DEA for evaluation and comparison of heterogeneous government R&D projects. The efficiency of the 6 R&D projects was assessed through DEA, and the results are compared through Kruskal-Wallis analysis and post hoc Mann-Whiteny U analysis. The results of this study provide the following implications in policy formulation of national R&D projects. Restricted resources enable efficient resource allocation based on the performance ranking of R&D projects. As a result, more investment should be made for projects that are being efficiently operated, and if the improvement is not supported by projects that are ineffectively managed, the investment should be stopped or the investment should be reduced.

Hsu and Hsueh [6] proposed policy implications in Taiwan's government R&D project by using DEA after controlling the impact of external factors. In this process, the amount of necessary improvement in input is calculated to be efficient. The next regression analysis revealed the effect of operational characteristics such as size of beneficiary, industry to which beneficiary belongs, and government support ratio of beneficiary's R&D budget on the amount of necessary improvement. As a result, it is suggested that the upper limit of the share of the government support in the R&D budget of the beneficiaries is needed to reduce the waste of the budget.

3. Analysis Method

3.1 Analysis Unit

In this study, the government's 2,176 R&D projects related to nanotechnology, which started from 2008 or afterwards and ended by 2011, are analyzed. This is because, as of 2016, the National Science and Technology Knowledge Information Service has tracked and examined the performance up to 2014, and the duration for R&D outputs are considered for up to three years.

As mentioned above, R&D expenditure, R&D manpower and R&D period are set as input factors, and research papers, patents, technology fees or practical use are set as output factors in most researches on efficiency evaluation of R&D projects. R&D costs and R&D manpower can be considered as typical input factors in estimating the efficiency of R&D, and R&D period is also considered as an important input factor. In particular, R&D expenditure is the foundation of national science and technology activities, and is a fundamental resource that enables rapid growth or sustained growth of the nation. In addition, papers and patents can be regarded as a representative output factors for academic achievement and technology development. Here patents can be an important indicator of creative output factors not observed in knowledge production. In addition to the papers and patents, we used commercialization as economic performance. On the other hand, it takes a long time for the economic performance of R&D to take place due to the nature of R&D activities, so it is not easy to judge the economic performance of each individual project. As a result, this study looked at the number of process improvement or product development as commercialization.

In this study, there are three input factors: government R&D investment, R&D manpower, and R&D period. Government R&D investment is measured by the grants made by the government (unit : billion KRW), and R&D manpower is measured by the total researcher (unit : M/Y), and R&D period is measured by total R&D period (unit : month). For the output factors, the number of articles published in the SCI journals, the number of patent applications and registrations (domestic and international weighted), and the number of process improvement or product development are considered. In the case of patents, the qualitative difference in the research outputs was considered by applying different weights according to domestic patents and international patents are used. For instance, the weight for international registration was almost twice as high as that for domestic registration [11].

<Table 3> Weights by Patent Type

patent type	weight
domestic application	0.06
domestic registration	0.26
international application	0.12
international registration	0.56

<Table 2> Input and Output Factors

factor		how to measure
input	R&D investment	grants from the government (unit : KRW in billions)
	R&D manpower	total researcher (unit : M/Y)
	R&D period	total R&D period (unit : month)
output	paper	number of articles published in SCI journals
	patent	number of patent applications and registrations (domestic and international weighted)
	commercialization	Number of process improvements or product developments

3.2 Efficiency Evaluation Using DEA

In the efficiency evaluation using the DEA model, the benchmarking path of each DMU, that is, the improvement direction, and the performance goal can be presented when the number of DMUs is not large. However, since it is difficult to apply these analytical methods when the number of DMUs is large, it is appropriate to group similar entities and present improvement directions and performance goal at the group level. Therefore, in this study, efficiency evaluation was conducted in detailed technology unit rather than individual R&D project, and the improvement direction in detailed technology unit was suggested.

The reason why the analysis unit of this study is not the four major technology units but the detailed 22 technology units is that each of the four major technology units has many projects with different characteristics. In fact, in the field of 'nano devices and systems', 'nano information storage technology' and 'variable wavelength optical devices' are different from each other in details, so it is difficult to know the nature of R&D in each field. Therefore, in this study, the efficiency evaluation was conducted for each detailed technology unit.

On the other hand, DEA can be influenced by the number of DMUs that are subject to efficiency evaluation and the number of factors selected by input and output factors. If the number of DMUs is too small compared to the number of input factors and output factors, the efficiency of all DMUs can be 1, which means that all the DMUs to be evaluated may be evaluated as efficient. As representative studies related to the discrimination power of the DEA model, Banker et al. [1] verified that the number of DMUs to be evaluated should be more than three times the sum of the number of input factors and the number of output factors, Boussofiane et al. [2] argued that the number of DMUs to be evaluated must be at least twice the product of the number of input factors and the number of output factors, and Fitzsimmons and Fitzsimmons [4] asserted that the number of DMUs to be evaluated should be at least twice as large as the sum of the number of input factors and the number of output factors. However, these studies are also conclusions derived from specific situations where the nature of the data used for the analysis is different. Therefore, there is no absolute criterion, and it can be used for reference purposes only when considering the number of DMUs and the number of input and output factors. In this study, the number of DMUs is 22, which is more than three times the number of input and output factors. Therefore, there should be no problem.

In this study, input oriented DEA model is used rather than output oriented DEA model. This is because the input factors can be controlled rather than the output factors. Because of the nature of R&D activities, there is a high likelihood of failure and performance is unclear, so controlling performance is not easy. Also, in this study, the net efficiency was measured using the DEA model of CRS assumption, and the pure technology efficiency was measured by using the DEA model of VRS assumption. The two are compared to calculate the scale efficiency. Based on these results, the direction for improving the efficiency of the detailed technology unit and allocating R&D budget is suggested.

4. Results and Implications

4.1 Basic Statistics

<Table 4> shows the basic statistics of input and output factors for 2,176 projects starting from 2008 and ending by December 2011. The average government R&D investment was 197 million KRW, the R&D manpower was 8.14 persons, and the R&D period was 16.95 months.

<Table 5> shows the basic statistics of input and output factors for each detailed technology unit, which was calculated from 2,176 projects starting from 2008 and ending by December 2011. The average number of articles published was 1.48, with patents and commercialization being 0.13 and 0.43 respectively.

<Table 4> Basic Statistics of Input and Output-1

	input		
	R&D investment	R&D manpower	R&D period
avg.	1.97	8.14	16.95
std. dev.	4.91	10.29	9.32

<Table 5> Basic Statistics of Input and Output-2

technology unit	input			output		
	R&D inv.	R&D man.	R&D per.	pap.	pat.	com.
variable wavelength optical device technology (8)*	0.99	7	18.25	2.25	0.17	0
nano devices and systems (162)	2.43	8.8	14.56	0.93	0.17	0.26
other nano devices and systems technology (86)	1.14	8.08	15.9	1.13	0.06	0.71
nano photonics technology (31)	1.3	8.48	19.26	2.77	0.22	0.13
nano electronic device technology (70)	1.34	8.7	19.87	3.13	0.17	0.04
nano information storage technology (11)	0.99	5.36	17.55	3.36	0.09	0
nano material (538)	1.26	7.13	15.52	0.72	0.07	0.52
nanomaterial technology (focusing on nano powder material, optical nano material, high performance synergy material, catalyst, environment and functional material) (426)	1.67	7.98	18.68	1.82	0.12	0.45
other nanomaterial technology (146)	1.63	8.86	18.94	2.2	0.11	0.44
nano-bio material synthesis and analysis technology (43)	1.44	7.79	20.7	2.72	0.14	0.12
nanobiotechnology (76)	1.65	9.03	16.45	0.61	0.22	0.71
other nanobiotechnology (20)	1.56	12.95	20.1	2.85	0.01	0.1
medicine delivery system (31)	1.87	9.19	20.84	5.52	0.42	0.06
interface or surface nanostructuring technology (44)	0.96	4.68	15.11	0.55	0.04	0.52
nano-based process (281)	4.69	10.33	16.57	1.63	0.23	0.32
other nano-based process technology (91)	0.97	5.92	15.11	0.43	0.06	0.62
nanomaterial technology (16)	0.67	4.63	22.06	1.25	0	0
nano new functional molecular synthesis technology (5)	2.41	13.6	23	1.4	0.02	1.6
nanometer measurement technology (less than 100 nm) (36)	5.24	9.97	15.31	3.81	0.07	0.39
nanopatterning process technology (24)	1.28	7.17	16.96	0.54	0.1	0.92
nano chemical process technology (19)	0.72	6.16	15.05	0.26	0.01	0.26
atomic and molecular level material manipulation technology (12)	3.22	5.75	13.92	2.83	0.05	0.42
average (2,176)	1.97	8.14	16.95	1.48	0.13	0.43

*denotes the number of R&D projects.

<Table 6> Efficiency Evaluation-1

	average	number of efficient DMUs	number of in efficient DMUs
CRS efficiency	0.83	7(32%)	15(68%)
VRS efficiency	0.94	6(27%)	16(73%)
SE	0.89	5(23%)	17(77%)

4.2 Efficiency Evaluation

As a result of the efficiency evaluation for the technology unit, the average value of the CRS efficiency is 83%, of which the number of efficient DMUs is 7 (32%), the average value of the VRS efficiency is 94%, of which the number of efficient DMUs is 6 (27%). The average value of the scale efficiency (SE), which was obtained through dividing the VRS efficiency by the CRS efficiency, was 89%, of which the number of scale efficient DMUs is 5 (23%).

In terms of the efficiency of each technology unit, it can be seen that ‘other nano device and system technology’, ‘nano information storage technology’, ‘nanobiotechnology’, ‘medicine delivery system’, ‘nano new functional molecular synthesis technology’, ‘nano measurement technology (100 nm or less)’ and ‘nanopatterning process technology’ have been highly efficient. On the other hand, the efficiencies of ‘nanomaterial technology’ and ‘nanocomposite process technology’ are the lowest at 54%, and it is urgent to improve their efficiencies.

<Table 7> Efficiency Evaluation-2

technology unit	CRS efficiency	VRS efficiency	SE
variable wavelength optical device technology	0.76	1	0.76
nano devices and systems	0.73	0.99	0.73
other nano devices and systems technology	1	1	1
nano photonics technology	0.82	0.84	0.97
nano electronic device technology	0.76	1	0.76
nano information storage technology	1	1	1
nanomaterial	0.68	1	0.68
nanomaterial technology (focusing on nano powder material, optical nano material, high performance synergy material, catalyst, environment and functional material)	0.74	1	0.74
other nanomaterial technology	0.75	1	0.75
nano-bio material synthesis and analysis technology	0.68	0.7	0.97
nanobiotechnology	1	1	1
other nanobiotechnology	0.65	0.66	0.99
medicine delivery system	1	1	1
interface or surface nanostructuring technology	0.94	0.98	0.95
nano-based process	0.84	1	0.84
other nano-based process technology	0.9	1	0.9
nanomaterial technology	0.54	0.77	0.71
nano new functional molecular synthesis technology	1	1	1
nanometer measurement technology (less than 100 nm)	1	1	1
nanopatterning process technology	1	1	1
nano chemical process technology	0.54	0.77	0.71
atomic and molecular level material manipulation technology	1	1	1
average	0.83	0.94	0.89

<Table 8> Causes of Inefficiency

technology unit	scale inefficiency	pure technology inefficiency	optimal efficiency
variable wavelength optical device technology	○		
nano devices and systems	○		
other nano devices and systems technology			○
nano photonics technology		○	
nano electronic device technology	○		
nano information storage technology			○
nanomaterial	○		
nanomaterial technology (focusing on nano powder material, optical nano material, high performance synergy material, catalyst, environment and functional material)	○		
other nanomaterial technology	○		
nano-bio material synthesis and analysis technology	○		
nanobiotechnology		○	
other nanobiotechnology			○
medicine delivery system	○		
interface or surface nanostructuring technology	○		
nano-based process	○		
other nano-based process technology	○		
nanomaterial technology	○		
nano new functional molecular synthesis technology			○
nanometer measurement technology (less than 100 nm)			○
nanopatterning process technology			○
nano chemical process technology	○		
atomic and molecular level material manipulation technology			○
total	13	2	7

4.3 Implications

In this study, the cause of inefficiency for each technology was determined by comparing VRS efficiency and SE. In addition, the results of the CRS efficiency for each technology unit are used to explain how the output changes as the size of the input increases.

In case of inefficiency technology unit, the cause is more from scale inefficiency rather than pure technology inefficiency. Therefore, the direction for improving the efficiency of R&D is as follows. First, the increase in the R&D budget is necessary for the IRS. In the case of the CRS, it is desirable to maintain the current R&D budget. On the other hand, in the case of DRS, the reduction of R&D budget is necessary.

In this study, the DEA model is constructed with 3 input factors and 3 output factors. For the output factors, papers, patents, and commercialization are considered. On the other hand, when the efficiency of each of the output factors is considered, the advantages and disadvantages of each technology unit could be identified. Therefore, this study also constructs the VRS partial efficiency model, which takes each of the output factors in the previous DEA model as new output factors.

Cluster analysis was conducted based on the paper efficiency, patent efficiency, and commercialization efficiency, from which technology units are classified into three clusters. Cluster 1 is a group with higher efficiency than the average in all parts of the paper, patent, and commercialization. On the other hand, cluster 2 is a group with the paper efficiency somewhat higher than the average, the patent efficiency similar to the average, and the commercialization efficiency lower than the average. Finally, cluster 3 is a group with the paper efficiency lower than the average, the patent efficiency somewhat lower than the average, and the commercialization efficiency higher than the average.

Cluster 1 has the paper efficiency of 95% (very high), the patent efficiency of the 94% (very high), and commercialization efficiency of 84% (high). Therefore, R&D strategy for technology units belonging to cluster 1 should be estab-

<Table 9> Returns to Scale

technology unit	IRS	CRS	DRS
variable wavelength optical device technology	○		
nano devices and systems			○
other nano devices and systems technology			○
nano photonics technology	○		
nano electronic device technology			○
nano information storage technology		○	
nanomaterial			○
nanomaterial technology (focusing on nano powder material, optical nano material, high performance synergy material, catalyst, environment and functional material)			○
other nanomaterial technology			○
nano-bio material synthesis and analysis technology			○
nanobiotechnology		○	
other nanobiotechnology	○		
medicine delivery system		○	
interface or surface nanostructuring technology			○
nano-based process			○
other nano-based process technology			○
nanomaterial technology	○		
nano new functional molecular synthesis technology		○	
nanometer measurement technology (less than 100 nm)		○	
nanopatterning process technology	○		
nano chemical process technology	○		
atomic and molecular level material manipulation technology		○	
total	6	6	10

lished in order to continuously strengthen competencies based on high efficiencies.

Cluster 2 has the paper efficiency of 76% (somewhat high), but the patent efficiency of 61% (somewhat low) and the commercialization efficiency of 30% (very low). Therefore, R&D strategy for technology units belonging to cluster 2 should be established in order to induce technology acquisition through cooperation domestic or abroad. This cooperation can be seen from the perspective of open innovation. Open innovation refers to acquiring and transferring technologies, ideas, or knowledge in and out.

Cluster 3 has the paper efficiency of 32% (very low), the patent efficiency of 52% (somewhat low), and the commercialization efficiency of 94% (very high). Therefore, R&D strategy for technology units belonging to cluster 3 should be established in order to expand the base. In other words, only when the base is expanded, the current high commercialization efficiency is expected to continue.

<Table 10> Partial Efficiency

technology unit	paper efficiency	patent efficiency	com. efficiency
variable wavelength optical device technology	1	1	1
nano devices and systems	0.28	0.32	0.89
other nano devices and systems technology	0.14	0.29	1
nano photonics technology	0.65	0.32	0.32
nano electronic device technology	0.33	0.24	1
nano information storage technology	0.91	0.43	0.55
nanomaterial	0.69	0.78	0.25
nanomaterial technology (focusing on nano powder material, optical nano material, high performance synergy material, catalyst, environment and functional material)	0.63	0.46	0.19
other nanomaterial technology	0.18	1	0.96
nano-bio material synthesis and analysis technology	1	1	1
nanobiotechnology	0.96	0.37	0.44
other nanobiotechnology	0.88	1	0.49
medicine delivery system	0.77	0.76	0.76
interface or surface nanostructuring technology	0.24	0.99	0.38
nano-based process	0.41	0.74	1
other nano-based process technology	1	1	0.74
nanomaterial technology	1	0.57	0.1
nano new functional molecular synthesis technology	1	0.95	0.95
nanometer measurement technology (less than 100 nm)	0.34	0.46	1
nanopatterning process technology	0.58	0.58	0.77
nano chemical process technology	1	0.84	0.92
atomic and molecular level material manipulation technology	1	1	0.21
average	0.68	0.69	0.68

<Table 11> Clusters

#	pap.	pat.	com.	technology unit
1	.95	.94	.84	variable wavelength optical device technology, nano new functional molecular synthesis technology, nano-based process, nanomaterial technology, nano materials technology (focusing on nano powder materials, optical nano materials, high performance synergic materials, catalysts, environment and functional materials), nanotechnology (nanotechnology), nano information storage technology, atomic and molecular level material manipulation technology
2	.76	.61	.30	other nanobiotechnology, other nanomaterial technology, nano photonics technology, nano bio material synthesis and analysis technology, nano measurement technology (less than 100nm), nano device and system, nano electronic device technology, medicine medicine delivery system
3	.32	.52	.94	interface or surface nano-structuring technology, other nano-based process technology, other nano device and system technology, nanobiotechnology, nano material, nanopatterning process technology, nano chemical process technology

5. Conclusion

In this study, nanotechnology related national R&D projects are analyzed in terms of direct R&D performance. In other words, the efficiencies for technology units are evaluated, implications for the efficient allocation of R&D budget are drawn, and priorities for technology units are determined.

Meanwhile, the weights of R&D manpower, paper, and commercialization are not considered in the process of efficiency evaluation due to limited data. Even with the same R&D manpower, the R&D performance will vary depending on his or her experience and major field. Also, the quality of the same paper will differ depending on domestic or international, and non-SCI or SCI. Again, process improvements and product developments will have different economic values depending on the case. Therefore, it is necessary to think about how to reflect these matters systematically in the future.

In addition, if policy implications are derived by comparing R&D efficiency with those of the US, Japan, and Europe, which have a lot of R&D investment in nanotechnology, it will help the government to improve the efficiency of nanotechnology related national R&D projects.

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ORCID

Seung-Chul Yoon | http://orcid.org/0000-0001-9929-7016

Heung-Kyu Kim | http://orcid.org/0000-0003-2506-6519