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Selecting the key research areas in nano-technology field using technology cluster analysis: A case study based on National R&D Programs in South Korea

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Abstract

In the early 21st century, Korean government issued a policy recommendation that Korean public research institutes should select strategic research fields to concentrate their resources, based on a careful review of the various strategic R&D factors. The government has emphasized the "selection and concentration" strategy for the efficient use of R&D resources and as a way to increase the national competitiveness of Korea. This paper suggests a method, a "Technology Cluster Analysis," for selecting the strategic research areas, mainly targeting large, multi-disciplinary and long-term programs. The technology cluster analysis groups near technologies together based on key indicators. In this study, the method is applied to national R&D programs in the nano-technology field. Fifty-six nano-technologies are analyzed and grouped into three main clusters based on the survey data from 180 experts. Technological distances and correlations among individual technologies are depicted by hierarchical dendrogram. Three main clusters in nano-technology field are found and termed *nano-materials*, *nano-devices*, and *nano-bio*. These three clusters are expected to be the core technology clusters in nano-technology field in South Korea.

Keywords: Technology cluster analysis; Nano-technology; Core technology areas; Proximity index

1. Introduction

The national competitiveness of Korea in the 21st century hinges on the effective distribution and utilization of limited resources based on the strategy that guides the policy makers to specify target technology fields. Korean government and research institutes alike have exerted their concentrated efforts to develop world-class technologies by carefully examining future economy, market outlook, technological trends, and the current level of science and technology. In an effort to respond to such a demand, Korean government has introduced the 'selective focus and concentration' strategy where a great portion of national R&D resources are distributed primarily to the areas of strategic importance according to future strategic needs, technological competitiveness, and national growth/development agenda. One of the challenging issues in this regard is to locate the core areas of research on which national R&D investment efforts are to be exerted. Such areas should be those of great importance in enhancing industrial competitiveness of Korea and those which will create enormous market demand in the future at the national level. They should also represent the promising technologies, best utilizing human resources with a high potential of success, which make commercial links to the existing technologies and products possible (Tassey, 1997).

Although many prior studies (Shehabuddeen et al., 2006) have focused on various technological prospects in an effort to find effective R&D mechanisms, in particular regarding national innovation systems of Korea (Lee, 2004; Lee and Park, 2005; Chung, 2001), studies to estimate promising future technologies based on the trends in technological complexity and convergence are scarcely few. Furthermore, the system of technology estimation and forecasting, which can be used to identify and plan core researches, is not yet well established. This paper is an attempt to rectify such a situation. The current study

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suggests the ‘technology cluster analysis’ as a method to select key fields of research, and applies it to the national-level R&D initiatives to derive important areas of research. We utilize the method to estimate the structure of R&D in the field of nano-technology and classify various sub-technologies into meaningful groups for R&D concentration.

The method of identifying core research fields is comprised of three steps: (1) classifying technologies according to their purposes, (2) conducting a survey for a relevant group of researchers and scientists on the similarities and differences among sub-technologies, and (3) performing the technology cluster analysis. This research focuses especially on the technology cluster analysis step, where we group together those technologies with similar patterns of technological changes. We believe that the results can be used to assist planning for major research projects or to devise policies for different fields of technology. This research aims at applying the methodology to selecting core technologies in the nano-technology field in order to identify important sub-technological categories within the nano-technology field.

This paper is structured as follows. Next part deals with the basic concepts of technology cluster analysis along with a short introduction to the related past studies. We then conduct a study applying the technology cluster analysis to the nano-technology field. Our findings are presented at the end with possible implications of the findings.

2. Research method: technology cluster analysis

Researchers in technology management have utilized two different methodologies to estimate technological distance and proximity. One is to perform bibliometric studies such as citation analysis and patent mapping based on a set of objective data, also called bibliometrics, including academic papers, patent materials, and researcher’s information; the other is to perform cluster analysis using survey data with questionnaires that tap into the researchers’ knowledge base.

Past research in bibliometric studies has focused primarily on computing the technological distances between industries, mainly utilizing patent data (Jaffe, 1986; Verspagen, 1997; Yun, 1999). For example, a recent study by Jaffe and Trajtenberg (2002) addressed a number of issues related to aggregate citation frequencies at industry level. Their findings provide useful information on the major differences in citation patterns among R&D fields. Despite various positive methodological competences, prior studies have been performed mainly at industry level or national level and are not quite suitable for estimating technological distances among more detailed, specific technologies within the same technological field. A different method is therefore needed to conduct a fine-grained, specific analysis on technological proximity.

We believe that a more effective method is to perform a survey-based technology cluster analysis, which utilizes the specialists’ knowledge base on specific technologies. The survey method allows us to investigate the cognitive insights of the respondents regarding the current status of the inter-relationships among the target technologies and future trends of technological changes, which cannot be found in bibliometric data. Previous study that utilized survey method for technology cluster analysis includes Ronde (2001). Ronde (2001) conducted a survey on 98 specific technologies of biotechnology in France and, based on the cluster results, came up with three important technology groups. Ronde’s study was intended to identify core fields of biotechnology research at a national level. The characteristic of this study is in general closer to that of Ronde (2001) in that it identifies important technology groups in the newly emerging nano-technology field for national-level R&D projects.

Technology cluster analysis is a clustering method that groups together diverse technologies with similar characteristics based on technological distance or proximity. Technology cluster analysis can be used effectively in planning R&D programs for emerging technologies like nano-technology. When policy makers and R&D planners design national R&D programs in emerging technology fields, they may consult other nations’ previous experience. However, benchmarking approach usually works only to a certain limit. The technological growth path of a nation is likely to differ from that of other advanced nations because of differences in technological endowment, economic and technological growth strategies, national policies and agenda. Under such circumstances, policy makers and planners should gather experts’ opinions extensively and construct a list of emerging technologies to be developed. Then, they can create various R&D programs based on the structured list of technologies.

Technology cluster analysis can contribute at this stage. Technology cluster analysis can be used to identify core research areas both in private and public sectors and both at national and organizational levels. While technology development strategy should be constructed by top-down fashion in private sector and at organizational level, the gathering process of experts’ opinion is much more emphasized for the national R&D programs. Because the philosophy of technology cluster analysis is related to building a cognitive mapping based on experts’ opinions, it is more useful in planning national R&D programs. It is particularly so in planning R&D programs in emerging technology fields, as we are short of information on patents and academic papers. In this case, technology cluster analysis can act as a substitute for citation analysis and patent mapping.

Meanwhile, an important contribution that the current study may have over and above the previous studies is that, while the prior studies showed planar results in identifying the technology groups, the current study provides a comprehensive structure of the technological relationships by analyzing the proximity of individual technologies.

3. Selecting the core research areas in nano-technology field

As the US, Japan, and European nations are aggressively investing in emerging and disruptive nano-technology, Korean government has also started the 'National Nanotechnology Initiative' in July 2001, and is currently promoting its R&D projects. According to the initiative, only the high-potential areas of nano-technology that could guarantee world-level competitiveness would be selected and focused on. Under this principle, nanomaterial, electronic device, computer memory device, and atomic logic device, and so forth, were selected as core technologies. Individual research organizations are also concentrating their efforts to develop new nano-spin device technology, and bio-microprocessor technology. Under the pressure of competition, the key to a success would lie in how each country find the right application to focus on in order to survive through international competitions (Wonglimpiyarat, 2005).

Main procedures for core area selection are comprised of classifying important specific technologies in the nanotechnology field, grouping them into clusters that share similar innovation patterns, and completing a graph that organizes them in a systematic way. And the results of this method can prove to be a useful source at this point for establishing nano-technology policies and implementing future development plans. This is because analysis of each technology groups' characteristics based on the procedures mentioned above, could improve the efficiency of research projects.

3.1. *Purpose-based classification of nano-technology*

In order to estimate the technological distance based on survey data, technological space needs to be well defined. Considering that the purpose of this study is to identify core research areas of nano-technology for future national R&D projects, detailed nano-technology list regarding potential competence of national nano-technology development system and nano-technology innovation system should be analyzed. Therefore, a list of nano-technologies that meets the purpose of this study should be prepared through a comprehensive review ofnational level nanotechnology classification schemes.

There are three candidates of nano-technology list in Korea. The first is the 'National Nano-Technology Initiative' co-submitted by Ministry of Science and Technology, Ministry of Industry and Resources, and other related government branches in July 2001. The second is a list produced jointly by the Ministry of Science and Technology and KISTEP (Korea Institute of Science and Technology Evaluation and Planning) in December 2001 in an effort to condense the 110 technologies to 67 due to redundancy in certain contents. The list contains 56 nano-technologies with a priority rating attached to each technology. Finally, the last one is a nano-technology list in the National Technology Roadmap (NTRM).

Table 1
Strategic standards for identification of top 56 technologies

Detailed strategic standards	Points
Strategic importance	30
Level of technological development	15
Possibility of technological development	20
Versatility	5
Economic effect	20
Technological and social effect	10

We selected the second list (56 technologies) as the testing sample for the current study due to the following reasons. As for the first list, despite its wide-ranging and well-sorted contents, the list includes too many subtechnologies which do not fit for the purpose of the current research; the list includes a number of technologies for which Korea absolutely lags behind. Due to these reasons, there is an analytic difficulty in using it as it is in this study. The NTRM nano-technology list is found to be redundant, because all of its contents are included in the other two. This list also suffers from the lack of systematic classification scheme. In contrast, the second list has a number of advantages over the other two. Fifty-six high-priority nano-technologies in the list are selected based on six strategic standards as shown in Table 1. The selection criteria carry different weights, among which 'strategic importance' is assigned with the highest weight. In the current study, we analyze 56 nano-technology lists to identify technology clusters.

Nano-technology clusters produced from the '56 top-priority nano-technologies' provide important policy implications. By carefully inspecting the structure and the contents of each cluster, researchers may obtain vital pieces of information on the similarities and differences among specific nano-technologies; policy makers can also use the information for the selection and management of R&D projects (see Appendix A for the list of 56 technologies).

3.2. *Contents of questionnaire*

We use the structured survey to build up the data for core research area selection. The questions should be structured in such a way that they lead to efficient and effective answers by the participants and promote more participation. Survey questionnaire can take different formats, but it usually falls in two types according to the form of answers: *n*-point likert scale method and co-nomination method. As Ronde (2001) demonstrated, *n*-point likert scale method asks the respondent to choose an answer among the *n*-points. In this method, *N* means that the respondent knows the technology most and one means no knowledge on the technology. Because, under this method, the participants are asked to go through pain-taking process of checking every question, it could be appropriate only for mail questionnaires but not for e-mail.

Table 2
Survey questionnaires

Check the technologies you know well in the list.
• "The technologies you know well" means that • The technologies you have studied in performing projects before • The technologies of which the papers and specialized reports you can read and comment • The technologies you plan to research in the future R&D projects

Co-nomination method requires filling in the answer sections only for the relevant questions, so it is a useful method in identifying a pool of specialists for a certain area (Nedeva et al., 1996). For example, for a question such as "who specializes in nano-photonics area?," only a handful of respondents may answer positively; these respondents naturally form a specialist group. This method has a similar logical structure as the co-occurrence method which analyzes how many times the same key words are used in academic papers of similar but different fields. Because this method is simple, it can be effective for e-mail questionnaires. We utilize the co-nomination method, using the specific contents in Table 2. Whether or not an expert knows a designated technology is on the primary focus of the questionnaire. As the criteria of knowledge about the listed technologies, we used three dimensions, project experience before utilizing the technology, familiarity of the scientific outputs from the technology, and future intention of use.

3.3. Selection of participants

We sent out the survey to 600 experts listed in the nano-technology specialist data produced by the Korea Institute of Science and Technology Evaluation and Planning (KISTEP). Roughly 90 of the list are from the industry, 150 are from the research sector, and 360 are from the academic sector. Although the academic circle outnumbers the other expert parts, since nano-technology is a relatively new field, the unbalance is understandable. We attempted to fully utilize the answers from the industry and research sectors, thereby emphasizing the questions geared toward them. E-mail questionnaires were sent to the 600 participants and 180 experts (30% response rate) responded. These 180 responses mean a volume three times more than the 56 technologies that need to be analyzed, so it seemed enough to conduct the technology cluster analysis.

3.4. Cluster analysis

Since 180 experts responded the questionnaires on 56 nano-technologies, we can construct a 180×56 expert-technology matrix (X) consisting of 0 and 1. X matrix can be regarded as a matrix that shows 180 specialists' knowledge on 56 technologies in the form of binary value. In order to look closely at the relationship between technologies I and J, proximity index was assigned to these columns, and based on this index we conducted a hierarchical cluster analysis. The proximity index is defined as follows:

$$P(i,j) = \frac{N(I \cap J)}{N(I \cup J)},$$

$N(I \bigcap J)$ is the number of experts that know both I and J technologies well, and $N(I \cup J)$ represents the number of those who know I or J. The proximity index is a number between 0 and 1, according to the definition. The closer the number is to 1, the greater the similarity becomes, while the similarity is the lowest at 0. If we conduct the index-based hierarchical cluster analysis on X matrix, we can classify n-number of technologies into several important groups (Anderberg, 1973). Because 180 people responded to 56 technologies, we created a 180×56 expert-technology matrix and using a statistics program, conducted the cluster analysis.

4. Results

4.1. Important results of survey

Out of the total 180 respondents, 17.8% (32 persons) belonged to the industry, 25.6% (46 persons) to the government-funded research institutes, 56.8% (102 persons) to the academia. Such distribution can be seen as exemplary, for it shows clearly the contour of domestic nano-technology research and corresponding distribution of human resources. In terms of organizational affiliation, 17 companies, 12 research organizations, and 43 universities are represented, showing a wide range of public/private participation. Survey participants also show a wide range of specialties such as physics, chemistry, biology, medicine, chemical engineering, electronic engineering, mechanical engineering, and environmental engineering.

The participants marked 7.27 of the 56 technologies on the average as their specialty or technology of familiarity, which means they know around 13% of the technologies very well. If we separately count the number according to industry, academia, and research sectors, industry researchers checked 7.34 on the average, academic researchers 6.94, and government-funded institutes' researchers 7.98, as the fields of their specialty. So the government-funded institutes' researchers seemed to cover broader nano-research area than the academic researchers. Average check per technology was 23; this means that on the average each technology has 23 (12.8%) persons out of 180 researchers specializing in it.

Some of the popular technologies with more check marks include nano-powder material, interface/surface nano-structurization technology, chemical process, nano-measurement, nano-information storage technology, Quantum point, and Quantum line. The top 15 technologies have an average of 39 (21.7%) specialists. Especially, if a technology was co-nominated with other technologies

Table 3
Top 15 technologies with the most check marks

No.	Technology title	♯ of experts
18	Nano-powder material	61
22	Interface/surface nano-structurization technology (metallic and ceramic)	58
25	Chemical process (sol–gel, electric chemistry and colloid process)	55
15	Nano-measurement (smaller than 100 nm, including synchroton)	41
2	Nano-infomation storage technology	39

with highest frequency, it means that the particular technology is the most important among the identified technology cluster. The details of top five technologies are as shown in Table 3.

Some of the technologies with the least number of specialists include nano-mesoscopic system, lithographic equipments, medical type development, nano-link logic, high frequency electronic material, and functional device group in single chip. The lower 15 technologies have an average of 8.7 (5.4%) specialists. If a technology was least frequently co-nominated with other technologies, it means that the particular technology most likely remains as a residual technology rather than being included in the core technology cluster.

4.2. Three main clusters as core research areas

After computing the proximity index, we then linked the technologies together according to the index scores. For example, technology no. 3 (nano-bio chip and bio device) and technology no. 11 (nano-bio sensor and artificial senses) had the closest numbers in the proximity index. So they were the first to be clustered, and next closest were technologies no. 18 (nano-powder material) and No. 28 (technologically processed materials: for environment and chemical industry) and so on. As the result of technology cluster analysis, 42 technologies were grouped into three important clusters forming nano-material-related cluster (A), nano-device-related cluster (B), and nano-bio-related cluster (C) as shown in Table 4.

The remaining 14 technologies are either clustered into small groups with two or three technologies, or are ungrouped. The reasons why they were not grouped into main clusters are because (1) there are only few specialists in those fields, and (2) the frequency of co-nomination is low as well.[1]

Table 4
Three main clusters

Technology cluster	Technology nos.
Nano-material-related cluster (A)	4, 33, 13, 55, 35, 22, 36, 18, 28, 25, 26, 48, 29, 47, 30, 7, 53
Nano-device-related cluster (B)	12, 21, 15, 20, 42, 1, 32, 9, 17, 49, 14, 41, 2, 16, 10, 39
Nano-bio-related cluster (C)	3, 11, 8, 31, 56, 6, 23, 5, 45

The hierarchical dendrogram of each cluster is presented in Fig. 1

As we can see in Fig. 1, nano-material- and nano-device-related clusters are with numerous specific technologies, and nano-bio-related cluster is with fewer specific technologies.

One notable finding is that the three main technology clusters match the nano-research areas covered by several national R&D projects for which Korean government has been funding (the Ministry of Science and Technology, 2002). Korean Nano-technology Initiative is being promoted according to five large technological groups, which contain three technological clusters of the results of the current study, nano-environment/energy-related group, and another group additively. Within the cluster structure, individual technologies covered in these clusters also coincide with the technologies of independent research projects with which the government is attempting to promote. Korean government tends to more focus on the three main clusters and nano-environment/energy-related group.

Big programs in emerging technologies should be planned through a carefully designed structural process. In addition, the individual technology should be developed in consideration of technological relatedness to other technologies. From these viewpoints, the results can be utilized more specifically to design big research programs.

5. Conclusions

This study suggested the technology cluster analysis model to be utilized at a national R&D level for identifying core areas of research, and applied the model to nano-technology field. With the data drawn from 180 participants responding to a survey on 56 nano-technology list, three key technology clusters were formed. The technological proximity of each individual technology of each cluster was shown with the dendrograms. The three major technology clusters are nano-material-related cluster, nano-device-related cluster, and nano-bio-related cluster, which exactly match the core technology groups that the national-level R&D programs are currently covering. Furthermore, within a big frame, individual technologies of each cluster are also in line with those technologies

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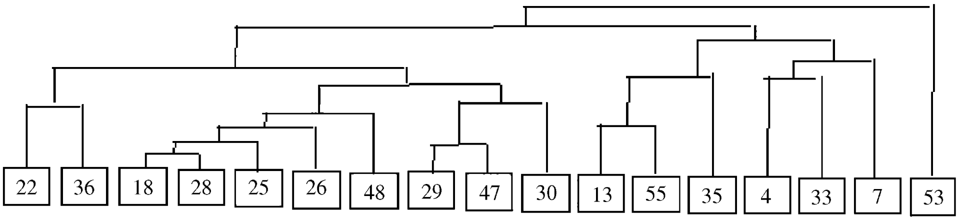
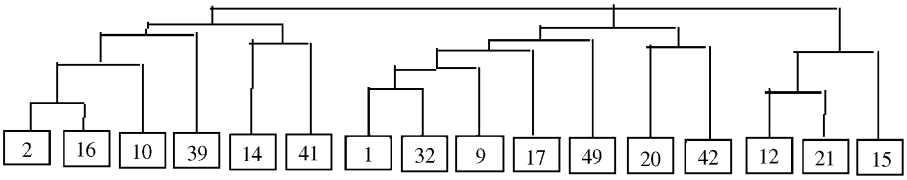
[1] Here, we used hierarchical cluster analysis. The cut-off value was designated by quantum jump interval and experts' opinion.

[Nano-material related cluster (A)]



[Nano-device related cluster (B)]



[Nano-device related cluster (C)]

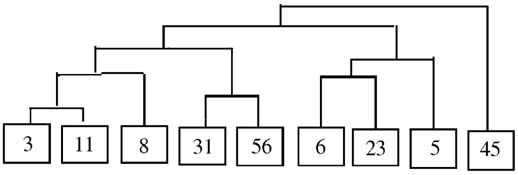


Fig. 1. Hierarchical dendrogram of the three clusters: nano-material-related cluster (A), nano-device-related cluster (B), and nano-bio-related cluster (C).

researched by government-funded institutes and firms. An important contribution of study is that it provides a closer look at the relationships between individual technologies according to their levels.

The technology cluster analysis method suggested a way of grouping innovative activities according to the magnitude of basic knowledge they share. Although the method used had the danger of producing subjective responses, we tried to keep the result more general and objective by conducting a large-scale survey. Therefore, this analysis can be considered a preliminary stage of clearly discerning a promising future. But in order to get a more precise estimation, there needs to be a survey on a larger pool of experts, conducted by the national R&D planning and managing institute. A way to improve the technology cluster analysis is to include experts from more diverse fields of research, thus expanding the technology–expert matrix.

When policy makers and R&D planners design national R&D programs in emerging technology fields, they can gather experts' opinions extensively and construct a structuralized list of emerging technologies to be developed through technology cluster analysis. It is particularly so in planning R&D programs in emerging technology fields, as we are short of information on patents and academic papers. The tool is applicable not only to catch-up countries but also to developed countries such as France (Ronde, 2001) if it deals with emerging technology field.

In selecting core areas of research, unique and creative area of research along with future market size can become an important task. And especially for high-tech fields, studying only comprehensible areas and well-known papers that utilized limited domestic researchers may bind our potential to attain world-class skills. Therefore, in order to supplement such limitations, trend analysis, citation analysis, patent map, and science and technology document analysis should be carried out simultaneously along with technology cluster analysis.

There are several avenues for further research efforts. One important application of technology cluster analysis is to use the method to ascertain the results of citation analysis and patent maps. In this case, we can use the method to complement the results of bibliometric studies in, especially, mature technology fields. We can also compare and contrast the clustering results across different nations. For example, the clustering results of US nano-technologies and that of Korea can be compared. This will provide ample insights in policy making and national R&D planning in the suggested areas of concern.

Appendix A

List of top 56 nano-technologies (Table A1)

Table A1

No.	Technology	No.	Technology
1	Nano-photonics (excluding quantum point, quantum line)	29	Nano-material as chemical catalyst
2	Nano-infomation storage technology	30	Hybrid nano-complex
3	Nano-bio chip and bio device	31	Bio imitating nano-material
4	Nano-molecular synthesis	32	Quantum point, Quantum line
5	Nano-bio substance (including nano-bio catalyst)	33	Micro-emulsion
6	Polymer used in nano-technology	34	Nano-link logic
7	Solar cell	35	Complex layered material
8	Nano-bio movement analysis	36	Magnetic assembling process
9	Fluctuating waves device	37	Nano-device logic/simulation
10	Substance manipulation at atomic/molecular level	38	Hard disk TMR device
11	Nano-bio sensor and artificial senses	39	Nano-tube device
12	Nano-metrology (100 nm standard, including measuring method)	40	Molecular device
13	Hydrogen storage	41	Plasma process
14	Atom-layer thin-film process (including ALE)	42	Equipment for optical process (focusing on semiconductor process)
15	Nano-measurement (smaller than 100 nm, including synchroton)	43	Functional device group in single chip
16	High-density material for recording	44	Medical type development
17	Optical material	45	Nano-detection device (execpt genomics, proteomics)
18	Nano-powder material	46	Spin device
19	Molecular machine	47	Pollution elimination technology (including material and device)
20	Nano-patterning process (lithography, etching process)	48	Nano-structure separating membrane device (transport membrane material, catalytic membrane, bio thin-film material)
21	Microscope injection test	49	Nano-Opitics
22	Interface/surface nano-structurization technology (metallic, ceramic, polymer material)	50	Lithographic equipments (equiments only)
23	Medicine delivery system	51	Nano-mesoscopic system
24	Nano-bonding	52	Quantum computer device
25	Chemical process (sol–gel, electric chemistry, and colloid process)	53	Durable nano-material (corrosion-resistant, heat-resistant, abrasion-resistant material)
26	Material for energy (material for energy generations and storage, excluding solar battery)	54	High-frequency electronic material
27	Atom and molecule transcription and calculation	55	Nano-fiber material
28	Technologically processed material (for environment and chemical industry)	56	Bio-protein configuration material

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