Intrinsic Characteristics of Basic Research: With Focus on Horizontal Knowledge Transfer

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Abstract
The paper studies the intrinsic characteristics of basic research. Its main purpose is to prevent a negative side effect, which is the possible distortion of the characteristics and the role of basic research, when both the reinforcement of innovation system efficiency and the promotion of basic research are pursued simultaneously. Furthermore, the study clarifies the role of basic research. Methodologically, we conduct a questionnaire survey and a paper citation network analysis. It turns out that the intrinsic characteristics of basic research can be explained by the uncertainty of reaching basic research results and the horizontal knowledge transfer. Our study also suggests that it is desirable to set the role of basic research, as the expansion of knowledge stock through both horizontal and vertical knowledge transfer, differently from that of applied research in the innovation systems.

1. Introduction

Basic research, which is considered the source of knowledge creation, has been studied by various experts, including Pavitt (1990) and Salter and Martin (2000), since its importance was first mentioned by Bush (1945). Bush emphasized the importance of basic research by explaining that basic research creates general knowledge such as laws of natural phenomenon, knowledge of which provides methodology for further problem solving. He asserted that finding the precise answer to a specific problem is the function of applied research. Therefore, he mentioned that the roles of basic research and applied research are different. Since main function of basic research is to create general knowledge, it may become distanced from technology, in contrast to applied research. By mentioning that basic research plays the leading role in technological advancement, Bush once again emphasized its importance. In discussions about the economic contribution of basic research Pavitt(1990) asserted that although basic research may exert the influence on technology through the direct transfer of knowledge, it more commonly acts as an input factor for other processes or plays the role of the starting point of innovation. He did this by quoting from David et al (1988) that, “the outputs of basic research rarely possess intrinsic

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economic value. However, they are critically important inputs to other investment processes that yield further research findings, and sometimes yield innovations". In addition, he explained that the linkage between basic research and technology is, at least, accomplished in a complex 4-dimensional structure, and that the effect, which basic research has on technology, is due to the combination of extensive knowledge and is highly diversified, ranging from gradual progress to groundbreaking technology that opens a new era. In addition, the effect of basic research on technology is accomplished not only through the direct transfer of knowledge, but also through methodology and devices. Lastly, the transfer of knowledge is accomplished mainly by people participating in activities such as meetings and thereby transferring knowledge. Therefore, Pavitt asserted that policy supporting the "selectivity and concentration" of basic research, results from a misunderstanding of the nature of basic research. Salter and Martin (2000) emphasized the following 6 aspects of the social contribution of basic research, including long-term economic effects: increasing the stock of useful knowledge, training skilled graduates, creating new scientific instruments and methodologies, forming networks and stimulating social interaction among experts, increasing the capacity for scientific and technological problem-solving, and creating new firms.

Due to a recognition of the aforementioned social contributions of basic research, the advanced countries, such as the USA, Japan, or OECD members as a whole, are reinforcing their investment in basic research as their economies enter into a knowledge-based structure. OECD (2001) proposed to policy makers that a higher priority must be placed on basic research in order to further promote innovation and to expand the knowledge stock. The USA (2005, 2008), well aware of the need to expand investment into basic research to reinforce national competitiveness, has been significantly expanding and will further expand their support of up-and-coming researchers and high-risk high-return basic research over the next 10 years. Similarly Japan put a high emphasis on basic research in its 3rd Basic Plan for Science and Technology 2006-2010, and is assertively pursuing support for basic research in order to create an extensive diversity of knowledge and to become a source of radical innovation. Likewise the EU established the European Research Council in order to enhance the creativity of European basic research in 2005.

Furthermore, in addition to the expansion of public research support for basic research, efforts have also been taken to improve the efficiency and effectiveness of R&D activities. This is because the expansion of support for public R&D does not automatically ensure performance and there is also a need to reinforce responsibility in public spending. Therefore advanced countries are implementing performance evaluation systems for R&D programs. For example the USA is implementing the Government Performance and Results Act with the goal of improving the efficiency and effectiveness of all government programs, including R&D. Also the UK is implementing the Public Service Agreements in order to clarify and properly evaluate the details of each task, performance targets and the responsibilities of all government departments. Likewise, Korea is also doing its best to improve the efficiency, effectiveness and responsibility of its public institutions by introducing the Basic Act on Evaluation of Government Tasks. These, or similar, performance management systems are also applied to R&D programs, and basic research is not an exception. Under the current conditions, in which international technological competition is getting more severe and technological lifecycles are becoming shorter, basic research is playing more the role of a compositional element within the innovation system rather than having an autonomous existence. Therefore, continuing efforts to enhance its efficiency and effectiveness may cause problems.

The globally accepted definition of basic research is "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view", as stated in the OECD Frascati manual (2002). In other words, only the research undertaken for the purpose of the "acquisition of knowledge" of various phenomena and observable facts rather than for the purposes of a "specific application" is understood as basic research.

As stated above, the performance management systems aim to enable innovation systems to operate efficiently by increasing the productivity of R&D. The application of these management systems may however be problematic in the case of basic research. For example, because the result of basic research is the "acquisition of knowledge" the method of measuring productivity consistently is unclear. In addition, even though basic research has quite different characteristics to applied research, basic research is generally grouped into R&D along with applied research and development. As a result, a distortion of the role of basic research may occur when the role of R&D within the innovation system is described without correctly understanding the characteristics of basic research.

This study aims to present the role of basic research within the innovation system by understanding its intrinsic characteristics. Firstly, the study identifies the role of R&D in the innovation system, as described by the linear, chain-linked open innovation models, and examines how a performance management system aimed at the enhancement of efficiency can distort the role and characteristics of basic research. Secondly, a questionnaire survey of researchers and network analysis, into the intrinsic characteristics of basic research, was carried out and the results presented. The questionnaire survey examined the areas, timing and methods of utilization of the results of basic research. The network analysis was conducted into the relations network of paper citations using the Science Citation Index Expanded Paper DB of Thomson. As a research paper may be considered as the primary result of basic research and the citation of a paper as knowledge transfer, the relations network of a paper's citations can be considered as its knowledge transfer network, the result of the basic research. In this way, it is possible to understand the intrinsic characteristics of basic research through an analysis of the mechanisms of its utilization and the transfer of its results. Based on this understanding, the study further aims to present the role performed by basic research which is undertaken for the purpose of the "acquisition of knowledge" within the innovation system, unlike applied research or developments that are carried out for the purpose of a "particular usage".

2. Models of the innovation system and roles of basic research

The characteristics of the representative models of the innovation system, including the linear model, the chain-linked model and the open innovation model, are examined in this chapter. Furthermore, the role of R&D, and in particular the role of basic research, in each of the innovation system models is discussed. Moreover, the possibility of the distortion of the role of basic research, particularly from side effects of efforts to improve of the efficiency of innovation, is discussed.

2.1 Linear model

The Linear model asserts that research, development, production and marketing are carried out sequentially and vertically as follows: once knowledge stock is accumulated through scientific research, development occurs by applying this scientific knowledge, and then the developed results are commercialized and eventually sold through marketing activities. Research within the linear model is further distinguished into basic research and applied research. Basic research is undertaken for the purpose of acquisition of knowledge rather than for a particular usage, and applied research for the purpose of a particular usage or for the discovery of solutions to particular problems by utilizing the scientific knowledge produced. Therefore, the relationship between basic research and applied research is stipulated as a relationship that progresses sequentially. The linear model is an innovation system model that has been accepted widely since the Second World War (Kline and Rosenberg, 1986), and presented in accordance with the viewpoint that "science leads to technology and technology satisfies market needs" (Gibbons et al., 1994). The linear model is conceptually very simple and easily explains the justification for public support in case of market failures. In addition, the linear model explains the situation quite well from a macroscopic perspective. Therefore, even though it was introduced quite some time ago, it has established itself as a fundamental concept of numerous other innovation models that were proposed since its introduction. Each stage of the linear model is a preparatory stage for the immediately following stage. Therefore, research must take the role of knowledge production for development, and must eventually bring economic effects through product manufacture and marketing. Considering that in this model basic research is undertaken for the purpose of the "production of knowledge", this knowledge produced by basic research only becomes meaningful if it is applied and further developed by being transferred directly to the next stage. In this study, the process of knowledge transfer to the next stage is referred to as the sequential or vertical knowledge transfer method. Assuming that R&D is related to technology, technology to industry and industry to economy, the vertical knowledge transfer method of the linear model, as the fundamental framework that forms the basis for the innovation model, is in fact very important. Knowledge can achieve an economic ripple effect only if it is transferred to the next stage.

However, the one-sided vertical knowledge transfer method has limitations when used alone to explain the innovation model. If the knowledge generated in basic research is not utilized, because of a failure to feed into the next stage, then this knowledge is considered useless, as the innovation process of the linear model stops at that stage. If one were to improve the efficiency of innovation as described by the linear model, the sequential and vertical system of transfer from research to marketing would be linked even more strongly. Moreover, this would lead to the efforts to narrow the vertical distance between all stages. Knowledge not transferred to the next stage, acts as an obstructing factor that causes further vertical distance between research and development. Thus, the efficiency of innovation increases, when "knowledge carried over to the next stage" also increases. And that is the shortcoming of the linear model. The linear model differs from the reality of innovation because it is too simple. The weaknesses of the linear model were highlighted by Kline and Rosenberg (1976) in detail. They pointed out that the existence of defectiveness and failure in the process of learning which creates innovation, proves that feedback and re-attempt are essential in an innovation system. In other words, a model, such as the linear model, in which knowledge transfer occurs only in one direction which excludes feedback and re-attempt, cannot fully explain the innovation system. Therefore, Kline and Rosenberg proposed the chain-linked model as an alternative to the linear model.

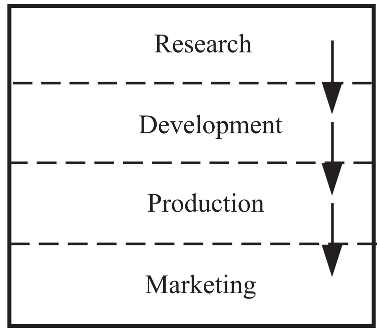

Figure 1 Linear model (Kline and Rosenberg, 1986)

2.2 Chain-linked model

The chain-linked model more realistically advances the linear model in which 4 stages, namely, research, development, manufacturing and marketing, are carried out in sequential and vertical manner. According to the chain-linked model, a foundation of knowledge through research must be accumulated first. Then, the market-sided five elements, including the potential market, invention and/or production of analytic design, detailed design and test, redesign and production, distribution and market, interact like a chain on this knowledge foundation.

The simple method of sequential and vertical knowledge transfer in the linear model is advanced in the chain-linked model. This model explains that knowledge and information interact somewhat freely between the elements of innovation. Feedback is given at each of the stages, which represent the five elements of sequential innovation. For example, in case of a problem in the last stage related to product launch in the market, information about this problem is fed back to each previous stage. Thus a large proportion of the knowledge transfer process included in the chain-linked model in this way cannot be explained by the linear model. Further, research and knowledge directly interact at each stage of innovation.

For example, commercial research is carried out to solve problems occurring at any stage. Unlike the linear model, in which "knowledge" gained as results of basic research, is applied and developed through direct transferred to the next stage, the chain-linked model explains that knowledge accumulated through scientific research turns into the foundation of innovation, and represents the concept of the "accumulated knowledge of science".

In the chain-linked model, the roles of basic research and applied research are not distinguished in detail. However, the role of basic research, which aims to "acquire knowledge", can be interpreted as expanding the "accumulated knowledge of science", while applied research, aimed at a "particular utilization", is focused on commercial research to solve problems that occur at any of the market-sided innovation stages. If one wishes to improve the efficiency of innovation in the chain-linked model, one must stimulate interaction between each of the elements. The feedback delivery between the five market-sided elements is a significant effort. However, where roles of basic research and applied research are not strictly distinguished, efforts to improve efficiency manifest as efforts to strengthen the vertical linkage between the research stage and five market-sided elements, that is to narrow the vertical distance between them. This ultimately has the potential side effect of putting more value on the activation of applied research undertaken with the aim of a "particular utilization" rather than on the further expansion of the "foundation of accumulated knowledge of science".

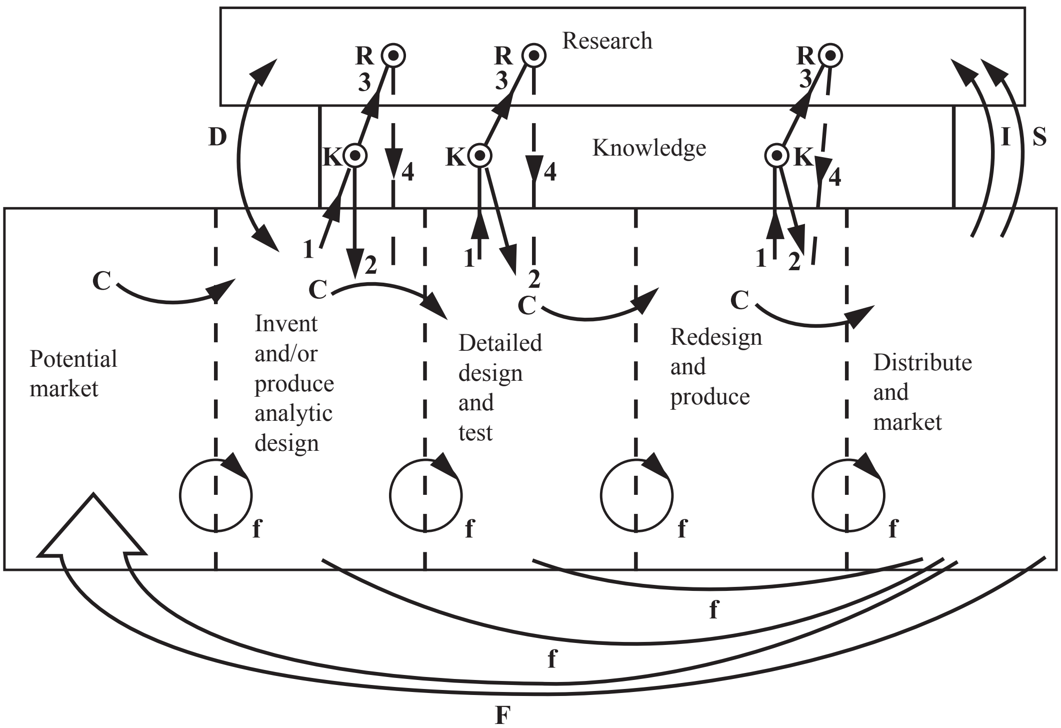

Figure 2 Chain-linked model showing flow paths of information and cooperation (Kline and Rosenberg, 1986)

Symbols on arrows:
C = Central chain of innovation
f = Feedback loops
F = Particularly important feedback
K-R = Links through knowledge to research and back. If a problem is solved at node K, link 3 to R is not activated. The return link from research (link 4) is problematic, therefore represented by a dashed line
D = Direct link to and from research in case of problems in invention and design
I = Support of scientific research by instruments, machines, tools, and procedures of technology
S = Support of scientific research by gaining information directly and by monitoring outside work. The information obtained may apply anywhere along the chain

In other words, in spite of the fact that the chain-linked model is more advanced and expanded than the linear model, there are aspects of basic research which remain unexplained by vertical knowledge transfer alone.

2.3 Open innovation

Thirdly, the open innovation model (Chesbrough, 2003), which has been receiving the spotlight recently, is analyzed. The main feature of the open innovation model is to create new markets by expanding the interactions between the research projects, enabled by breaking down the boundary between internal and external domains of R&D activities. This is expected to maximize the efficiency of R&D. In this model, the activities in all forms including joint research, technology transfer and outsourcing are possible thanks to the interactions between research projects. In addition, interactions between research projects are principally possible regardless of the project's type, whether basic research, applied research, development, manufacturing or marketing. Therefore the knowledge transfer path of the chain-linked model has been further expanded, allowing an increased possibility of knowledge transfer as well as an equivalent increase in innovation opportunities.

However, when the overall aspects of the open innovation model are examined, highly definitive directionality is manifested, which pursues the aggressive maximization of efficiency including the creation of new markets. This is the advancement from research to the market through development. In other words, the basic framework of the open innovation model is the same as that of linear model. The difference is that the open innovation model encourages interactions between research projects. However, even these interactions, when viewed from a general perspective, lead to enormous sequential and vertical flow towards the market. Although Figure 3 and Figure 4 appear to express itself horizontally, it is basically only a 90° rotation of the Figure 1. The expression "vertical" is appropriate from a stepwise perspective). The improvement of innovation efficiency in the open innovation model is manifested as efforts to shorten the overall length of the sequential and vertical flow that undergoes the process of research, development and (new) marketing. Ultimately, the research stages of open innovation are similar to those of the linear model but with the difference that it is composed of detailed stages rather than the sequential two stages of basic and applied research. Thus, in the open innovation model efforts to increase efficiency and quantity of "knowledge carried over to the next stage" could have the side effect of reducing basic research aiming to "accumulate knowledge".

3. Intrinsic Characteristics of Basic Research

In the previous chapter, we discussed the role of basic research and the possibility of side effects arising from the distortion of its role caused by efforts towards the "reinforcement of efficiency of innovation" in the linear, chain-linked and open innovation models. Under circumstances, in which the expansion of investment into basic research and efforts for the improvement

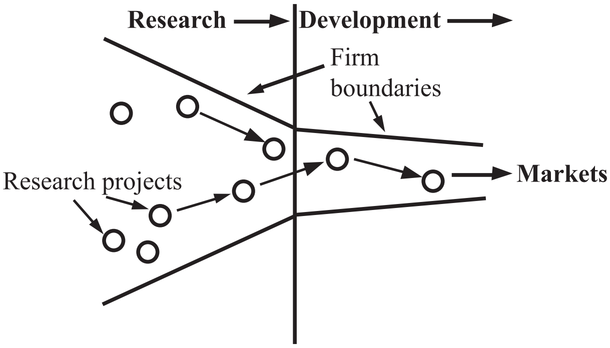

Figure 3 Closed innovation model (Chesbrough, 2003)

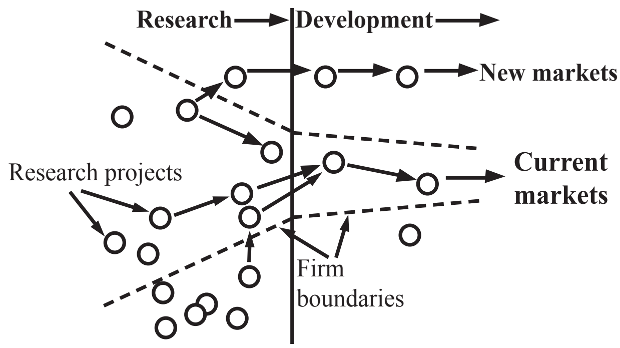

Figure 4 Open innovation model (Chesbrough, 2003)

of the efficiency of the innovation system are being simultaneously pursued, side effects that distort the role of basic research could occur. This distortion could not only hinder expansion of knowledge stock, but also impart influence on overall aspects of the innovation system. Therefore, in order for both the expansion of investment into basic research and efforts to improve the efficiency of innovation system to coexist, it is necessary to distinguish and clearly present the role of research, which is currently both too simple and too comprehensive. The difference between basic research aimed at the "acquisition of knowledge" and applied research aimed at "particular utilization" must be properly clarified. For this purpose, this chapter includes a description of the characteristics of basic research.

Firstly, we carried out an experts-oriented questionnaire survey on when, how and in which area the results of basic research were utilized. The questionnaire survey on the experiences of researchers provided clues as to the mechanism of knowledge transfer generated from basic research. The survey results were used to analyze the utilization of basic research results and particularly the uncertainties surrounding their application. Secondly, we carried out a bibliographic analysis of publications in order to more objectively and statistically study the mechanisms of knowledge transfer and further develop insights derived from the previous step. We studied the mechanism of knowledge transfer using the citation relationships between the fields of papers that can be considered as direct products of basic research. Citation relations are analyzed by applying the network analysis method. The uncertainty of basic research results and the outcome of the network analysis on paper citation relationships verified through the results of questionnaire survey signify that the expansion mechanism for knowledge stock by basic research cannot be properly explained by the simple vertical knowledge transfer method. In other words, the analysis implies that not only the vertical knowledge transfer but also the horizontal knowledge transfer method is highly significant. Such a discovery reveals that the current tendency of expressing the fundamental framework of innovation only through the vertical knowledge transfer method must be modified. In this chapter, the results of the questionnaire survey and network analysis of paper citation relationships are closely examined, and the significance of both the vertical and the horizontal knowledge transfers in the innovation system are discussed in order to understand the intrinsic characteristics of basic research.

3.1 Questionnaire survey results: Uncertainty in the process of utilization of results of basic research

A questionnaire survey was carried out with researchers as subjects in order to study the characteristics of basic research. Questionnaires were distributed electronically to 2,350 researchers currently involved in national R&D projects, out of which 161 subjects responded. The questionnaire was designed to analyze basic research, particularly its success or failure at its conclusion, the areas of utilization of its results, the ways its results were utilized and the time taken for its results to be utilized. 32% of respondents answered that they usually perform basic research, 41% applied research, and 26% development. 1% of respondents performed basic research and applied research together. 91% of respondents stated that they have utilized the results of their own basic research and 94% the results of basic research undertaken by other researchers. In this part, subjects were instructed to consider not only the originally anticipated results but also all the other incidental results of the basic research. We requested the subjects to include incidences of utilization in R&D in totally different areas (thus not limiting them to following the simple framework of the linear model that stipulates progress from basic research and applied research to development).

3.1.1 Evaluation of success or failure of basic research at the end of research

Subjects were asked about the evaluation of their basic research at the end of the research. 81% claimed the research as successful in Figure 5. However, 15% replied that they obtained unexpected incidental results rather than the results intended originally. Approximately 4% evaluated the research as failure.

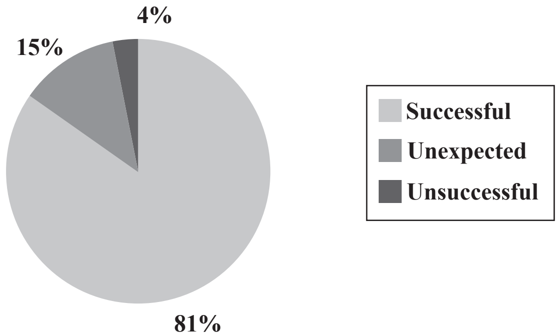

Figure 5 Evaluation of the results at the end of research (survey results)

The respondents further replied that, in spite of the fact that approximately 19% of the results were either incidental or even considered as a failure, they are being further utilized in various fields. This may be the first evidence that the method of vertical knowledge transfer alone is insufficient to explain of the benefits of basic research.

3.1.2 Areas of utilization of results of basic research (path of knowledge transfer)

Subjects were asked about the area in which the results of their basic research were utilized. In Figure 6, 71% of them replied that the results were used in the same academic discipline. 14% stated that they were utilized by being transferred between intermediary academic categories, while 8% responded that they were utilized by being transferred between main academic categories. Thus in approximately 22% of cases, the knowledge generated from basic research has been utilized by being transferred to a proximal academic discipline or to other academic domains. This result signifies that the probability of knowledge generated from basic research encountering the knowledge of other domains is approximately 22%. Knowledge transfer to other domains is the starting point of interdisciplinary research. Thus it was proved that the series of processes including knowledge transfer to a diverse range of domains, the expansion of knowledge stock and the creation of interdisciplinary research, can be regarded as benefits of basic research.

This is the second piece of evidence that application of the method of vertical knowledge transfer only is insufficient when trying to explain the benefits of basic research. However, since this percentage is based only on the questionnaire survey, more accurate and objective analytical data are needed to determine a more precise ratio of knowledge transfer between areas. Therefore, the paper citation network analysis between different fields of science and technology was carried out and is explained in the following chapter.

3.1.3 Utilization ways of basic research results

Lastly, subjects were asked about the ways of utilization of basic research results. The largest proportion of the respondents in Figure 7, 45%, pursued already-planned applied research or development research on the basis of the results. However, quite a high proportion of the subjects, 31%, also carried out new applied research or development research in directions suggested by the results. Furthermore, 22% of the respondents carried

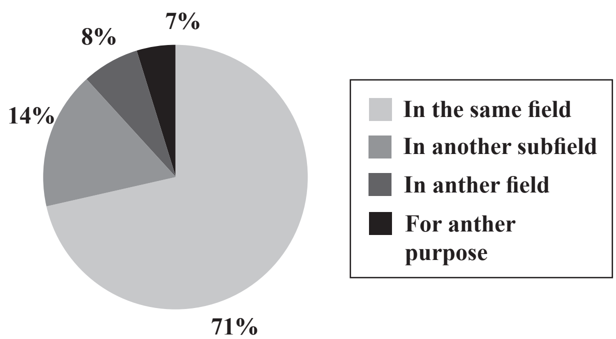

Figure 6 Fields of application for basic research results (survey results)

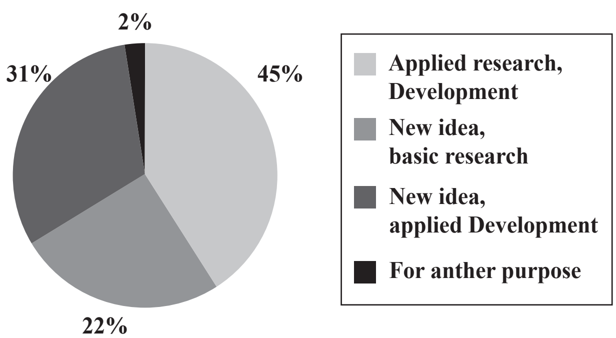

Figure 7 Utilization ways of basic research results (survey results)

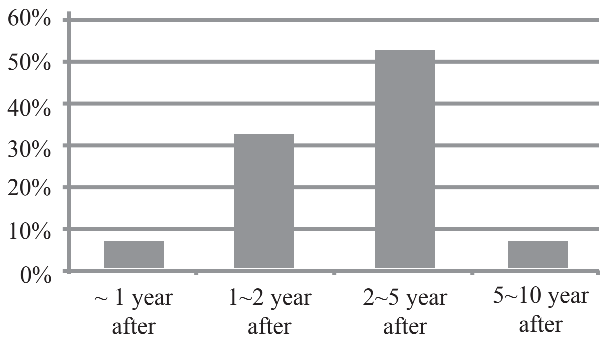

Figure 8 Time required for the results of basic research to be utilized (survey results)

out new basic research by obtaining ideas from the results. That means that although the results of the basic research are often utilized in succeeding research that was already planned, they also provide opportunities for new, originally unplanned research activities. This confirms that basic research plays very important role in the expansion of knowledge stock. Although basic research may not be vertically linked with applied research or the development stage immediately upon its completion, it elevates the level of potential economic and social contribution by expanding knowledge stock through the generation of new knowledge. This implies that the process of knowledge transfer is not simple, but is accomplished through a complicated multi-staged process. This is the third piece of evidence that the application of the vertical knowledge transfer method only is insufficient for the explanation of the benefits of basic research.

3.1.4 Time required for the results of basic research to be utilized

Subjects were also asked about the time taken for the results of basic research to be utilized. 53% of the respondents reported a time frame of 2 to 5 years, 33% a time frame of 1 to 2 years, 7% a time frame of less than one year and 7% a time frame of 5 to 10 years as shown in Figure 8. Thus it is evident that there is a time lag before the utilization of results of basic research.

Based on the survey results, it can be pointed out that in order to properly understand the benefits of basic research we need to understand the utilization of its results and its generation of knowledge transfer. Since basic research is not conducted for the purpose of a particular application, it suffers from built-in uncertainty and thus has a higher probability than applied research or development that results other than those anticipated will be obtained. However, based on the survey results, it was possible to find out that incidental results, which differ from the anticipated results, and even results that are considered failures, have an applicable value to further research. In addition, it was possible to find out that the results of basic research play a substantial role in the generation of interdisciplinary research by being transferred to and used in other science and technology areas. We confirmed that the knowledge transfer doesn't only pass vertically to the next stages as planned prior to the execution of the basic research, but also plays the role of introducing new ideas to researchers, thus being the starting point for new research. Further, the researchers questioned responded that these series of processes take approximately 2~5 years before the results of basic research are utilized.

The process of utilization of basic research results and the process of knowledge transfer generated from basic research cannot be explained with the simple vertical knowledge transfer method only. The results of basic research are directly transferred to a series of innovation stages such as development, manufacturing and marketing for utilization, as explained in the vertical flow that is generally used in the innovation system models. However, the results of basic research as knowledge are also transferred between academic disciplines, and contribute to the expansion of knowledge stock. These aspects need to be focused on in order to understand the characteristics of basic research. These aspects are the features of basic research that are different from the direct effect (knowledge transfer to the applied research and development stage) and indirect effect (cultivation of manpower or development of new methodology, etc.) explained in the existing innovation system models. Although the direct effects of basic research can be measured, it can, as presented in the previous chapter, distort the role of basic research as well as the innovation system as a whole. Although the indirect effects of basic research are important characteristics, they are very difficult to measure and extremely abstract. What we therefore focus on is the role of the results of basic research as a starting point for new research though a transfer to other areas, rather than the commonly understood role of vertical transfer to the next stage. Such processes will be referred to as the horizontal knowledge transfer method.

In simple terms, the horizontal knowledge transfer method represents knowledge transfer to other academic areas. Primarily, this represents the expansion of knowledge stock, and secondly, the convergence of knowledge. As aforementioned, it also explains that the results of basic research present new ideas for further basic research rather than only vertically proceeding to applied research or development as planned. We believe that such characteristics of basic research account for a highly significant portion of the benefits of basic research. Further, the paper citation network analysis was carried out in order to verify this aspect through objective data.

3.2 Paper citation network analysis results: Mechanism of knowledge stock expansion and horizontal knowledge transfer

The main result of basic research is a research paper. Therefore, we carried out a paper citation network analysis between fields of science and technology in order to obtain objective data on the process of utilization of basic research results and knowledge transfer. Studies using the measurement of knowledge transfer through paper citation analyses were attempted in the past (National Science Board, 1998; Narin and Noma, 1985; Meyer, 2002; Rinia et al., 2002, etc.). Although the existing analyses of paper citation between fields or citation relation matrices explain the relationships between any two arbitrary fields, they are limitated in terms of providing a comprehensive understanding of the flow of knowledge in diverse directions through all the fields of science and technology. Therefore in this study, a network analysis of the extent of citation between fields of science and technology was undertaken. In particular, we tried to understand the knowledge transfer in the fields of science and technology in Korea in order to deduce implications for Korean national science and technology policies including the improvement of the efficiency of the innovation system.

The “nodes” of the network have been defined as the fields of science and technology, and “links” of the network as the citation relationships between fields, which have a direction. The centrality of each field and the proximities of fields in the network were analyzed.

3.2.1 Paper citation network (knowledge transfer) between fields of science and technology

The research papers in 1996 and in 2006 authored by Koreans in the Web of Science, and Science Citation Index Expanded (SCIE) of Thomson Scientific Company were analyzed. Two datasets were prepared to assess the differences between the networks of 1996 and 2006. The network was defined as follows.

Table 1 Field categories

	Field category
1	BIOLOGY & BIOCHEMISTRY
2	CLINICAL MEDICINE
3	CHEMISTRY
4	PHYSICS
5	MULTIDISCIPLINARY
6	ENGINEERING
7	MATERIALS SCIENCE
8	MICROBIOLOGY
9	MOLECULAR BIOLOGY & GENETICS
10	IMMUNOLOGY
11	NEUROSCIENCE & BEHAVIOR
12	PHARMACOLOGY
13	PLANT & ANIMAL SCIENCE
14	ENVIRONMENT/ECOLOGY
15	AGRICULTURAL SCIENCES
16	SOCIAL SCIENCES, GENERAL
17	COMPUTER SCIENCE
18	GEOSCIENCES
19	MATHEMATICS
20	PSYCHIATRY/PSYCHOLOGY
21	TELECOMMUNICATIONS
22	ENERGY & FUELS
23	NANOSCIENCE & NANOTECHNOLOGY
24	SPACE SCIENCES

The Web of Science provided the subject category for each academic journal. Further, the service referred to as the "Essential Science Indicator" (ESI) provided 22 field categories. We allocated the ESI categorization for each academic journal by matching more than 190 of their subject categories with the 22 ESI categories. Two particular subject categories (telecommunication and nanoscience & nanotechnology) were difficult to classify into any of the ESI categories. Therefore we established two more specific field categories as research in these fields is carried out very actively in Korea. Thus, the eventual number of 24 field categories (network nodes) was set. These 24 field categories are summarized in <Table 1>. Correspondingly, the same 24 field categories were applied to the references used in the papers. Then, the links were identified between the field of the paper and the fields of the references used in the paper. The direction of the link begins from the field of the reference and ends at the field of the paper, thereby indicating the direction of knowledge transfer. We referred the fields of the references as "knowledge donors" and the fields of the papers as "knowledge acceptors".

In summary, the two paper citation networks for the fields of science and technology in Korea illustrate from which field the knowledge originated (the knowledge donor) and to which field knowledge was transferred and utilized (the knowledge acceptor). It also illustrates the extent of connection or proximity between the fields of science and technology. The results of the paper citation network in the fields of science and technology in 1996 and 2006 are as Figure 9 and Figure 10.

In-degree centrality and out-degree centrality of network for each field of science and technology in 1996 and 2006 are presented in Table 2 and Table 3.

The size of the node indicates the level of in-degree centrality, that is, the knowledge acceptance. A citation relation is indicated with an arrow and its direction represents the direction of the knowledge transfer. The thickness of the arrow is proportional to the frequency of citation. Biology & Biochemistry, Chemistry, Microbiology, Physics and Engineering were the central domains in the network in 1996. Biology & Biochemistry and Chemistry remain as the central domains in the network in 2006, thereby verifying their firm positions as knowledge acceptors. In addition, fields including Clinical Medicine, Materials Science and Physics gained the status of central domains in the network in 2006. These fields were characterized by a high level of both in-degree and out-degree centrality. In other words, fields such as Biology & Biochemistry, Chemistry and Physics, which are the fields of pure basic science rather than fields of applied science, are playing important roles as both knowledge acceptors and knowledge donors, and knowledge transfer to and from these fields occurs very actively

3.2.2 Composition of community in the fields of science and technology (analysis of association between fields)

We applied the composition method, which have high association from the paper citation network into a community. Thus, we composed communities with components that are divided by eliminating the links with high link-betweenness centrality one by one. Since the link-betweenness centrality signifies the number of appearances of a link on the geodesic path of all other node pairs, it can be said that the link with a high link-betweenness centrality carries out the role of a bridge in the network. Therefore, if the link with high link-betweenness centrality is eliminated, then the connection between two components held by such link is divided, thereby thereby composing community of nodes.

Network communities in the fields of science and technology in 1996 and 2006 are composed as shown in Figure 11 and Figure 12.

In 1996, fields including Material science, Immunology, Geosciences, Agricultural sciences, Telecommunications, Energy & fuels, Space sciences, Psychiatry/psychology, and Nanoscience & nano-technology formed separate communities while the remaining 15 fields formed a single main community. In 2006, the size of the main community grew bigger. Only the Space sciences remained as a separate community while the other 23 fields were bundled together. This can be interpreted as an intensification

Figure 9 Network of paper citations between the fields in 1996

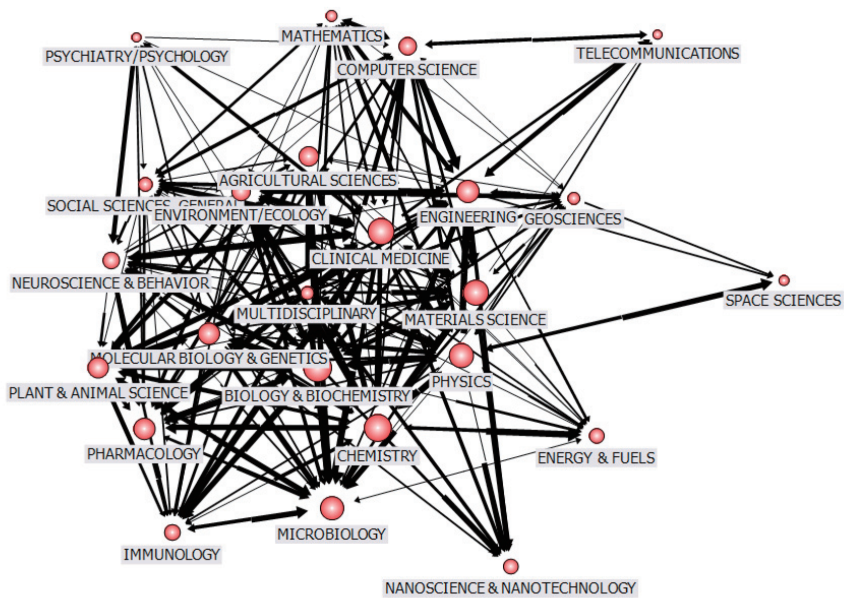

Figure 10 Network of paper citations between the fields in 2006

Table 2 In-degree centrality for each field of science and technology in 1996 and 2006

(in the order of the extent of in-degree centrality in 2006)

	Field Category (as knowledge acceptor)	In-degree centrality 2006	In-degree centrality 1996
1	BIOLOGY & BIOCHEMISTRY	3,474.90	760.8
2	CHEMISTRY	2,471.70	470.2
3	CLINICAL MEDICINE	2,099.00	272.2
4	MATERIALS SCIENCE	2,056.10	288.9
5	PHYSICS	1,987.20	386.9
6	MICROBIOLOGY	1,798.40	414
7	ENGINEERING	1,144.30	306.8
8	PHARMACOLOGY	1,041.10	161.6
9	MOLECULAR BIOLOGY & GENETICS	897	169.9
10	PLANT & ANIMAL SCIENCE	791.1	104.1
11	AGRICULTURAL SCIENCES	692.1	66.3
12	ENVIRONMENT/ECOLOGY	670.2	100.3
13	COMPUTER SCIENCE	544.3	89.7
14	NEUROSCIENCE & BEHAVIOR	526.3	72
15	IMMUNOLOGY	514.9	95.2
16	NANOSCIENCE & NANOTECHNOLOGY	446.5	28.4
17	ENERGY & FUELS	231.5	15.2
18	SOCIAL SCIENCES, GENERAL	228.4	54.8
19	MULTIDISCIPLINARY	217.8	35.2
20	GEOSCIENCES	215.9	34.3
21	MATHEMATICS	208.6	45
22	SPACE SCIENCES	165.8	48.9
23	TELECOMMUNICATIONS	158.2	28.1
24	PSYCHIATRY/PSYCHOLOGY	115.3	5.6

Table 3 Out-degree centrality for each field of science and technology in 1996 and 2006

(in the order of the extent of out-degree centrality in 2006)

	Field Category (as knowledge donor)	Out-degree centrality 2006	Out-degree centrality 1996
1	BIOLOGY & BIOCHEMISTRY	3,809.40	661.7
2	CLINICAL MEDICINE	3,175.40	524.2
3	CHEMISTRY	2,523.00	402.4
4	PHYSICS	2,017.10	435.7
5	MULTIDISCIPLINARY	1,762.00	376.1
6	ENGINEERING	1,293.30	275
7	MATERIALS SCIENCE	1,162.50	175.1
8	MICROBIOLOGY	1,072.10	240.7
9	MOLECULAR BIOLOGY & GENETICS	1,047.70	201
10	IMMUNOLOGY	755.2	92.1
11	NEUROSCIENCE & BEHAVIOR	685.6	81.2
12	PHARMACOLOGY	525.7	109
13	PLANT & ANIMAL SCIENCE	513.8	86.2
14	ENVIRONMENT/ECOLOGY	492.2	55.7
15	AGRICULTURAL SCIENCES	399.1	41
16	SOCIAL SCIENCES, GENERAL	369.3	69.8
17	COMPUTER SCIENCE	367.6	111.5
18	GEOSCIENCES	203.5	33
19	MATHEMATICS	184.7	42.5
20	PSYCHIATRY/PSYCHOLOGY	113	11.8
21	TELECOMMUNICATIONS	81.4	11.8
22	ENERGY & FUELS	72.1	14.2
23	NANOSCIENCE & NANOTECHNOLOGY	40.3	9.4
24	SPACE SCIENCES	30.7	0.2

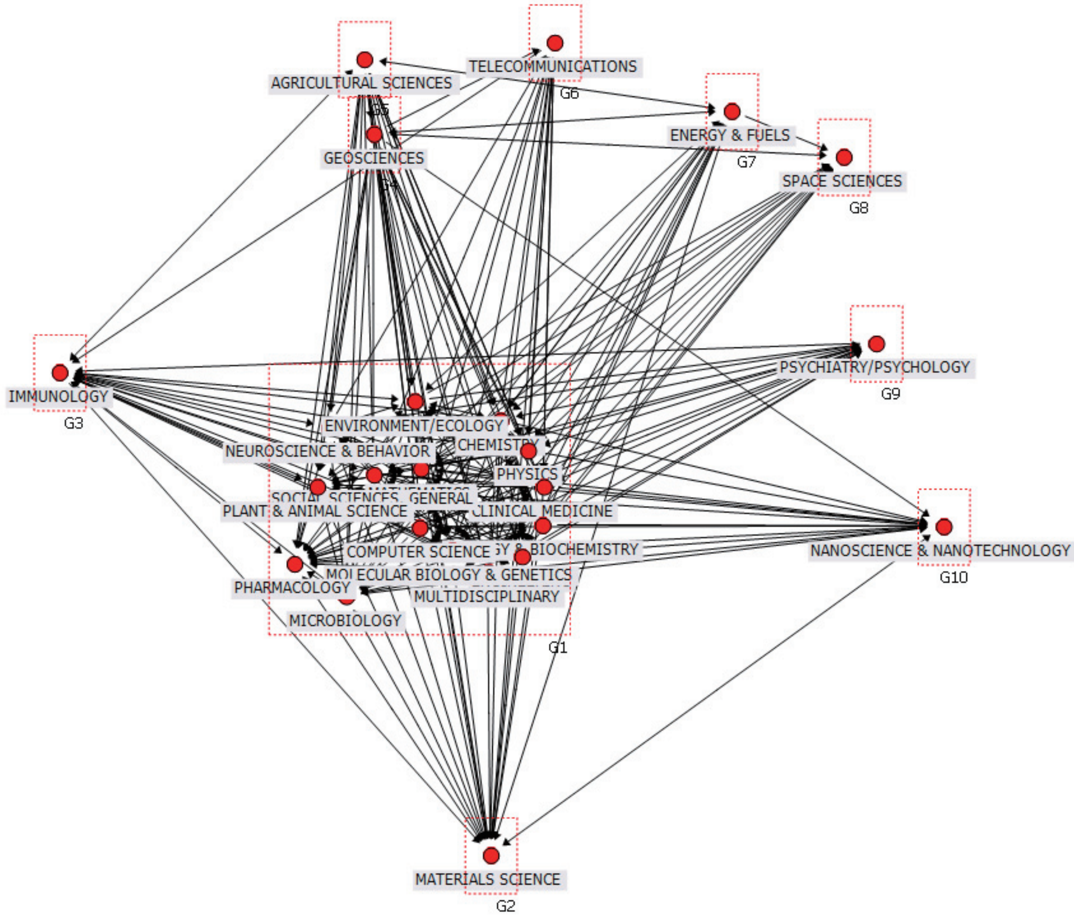

Figure 11 Network community in 1996

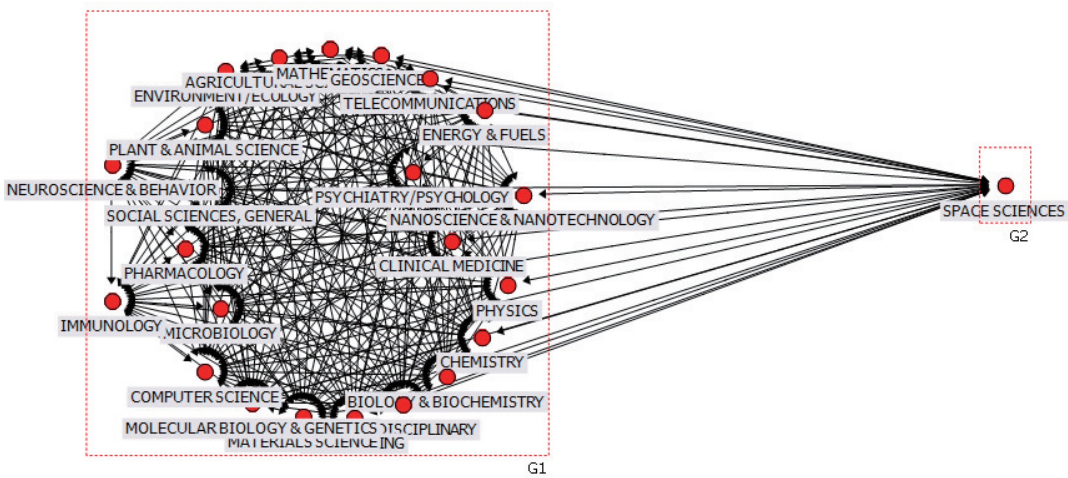

Figure 12 Network community in 2006

of the association between the fields with gradually increasing ambiguity of the field boundaries along with very active horizontal knowledge transfer between the fields. In particular, in the current era, in which multi-disciplinary research is being encouraged, the horizontal knowledge transfer between the fields of science and technology is important, as it can, among other things, provide incentives to create new academic fields. The birth of a new academic field signifies the birth of a new knowledge system. The birth of a new knowledge system can be seen as having the largest ripple effect of all events of knowledge creation. Ultimately, although horizontal knowledge transfer may have both a low level of immediate utilization and a low level of contribution towards the innovation system, it may result in the birth of a new knowledge system with a large ripple effect and radical innovation.

A field that deserves more focus is Nanoscience & nanotechnology, which is known to be a promising field as well as representing an interdisciplinary technology field. Similarly, the number of research papers in the nano-field in 1996 was too few to categorize it as a complete academic discipline and it was not included in the mainstream community due to a very low level of out-degree centrality. However, by 2006, the number of papers as well as the in-degree centrality and out-degree centrality of this field increased enormously, enabling it to be included in the main community. It is thus obvious that a new emerging field has matured into a complete field within science and technology.

3.2.3 Time lag (referencing timing)

In this part, the time taken for papers to be cited was analyzed. The time taken for a paper to be cited can be also interpreted as the time needed for knowledge transfer to occur. The time difference between the publishing year of the paper and the publishing year of the paper's reference was computed for both 1996 in Figure 13 and 2006 in Figure 14. This time lag was computed for the cases of citation within the same field (gray circle), for the cases of citation in other fields (black circle), and for all citations (white circle).

According to Figure 13 and Figure 14, the statistical time lag in the citation of papers in 1996 was approximately 3 years. Citations within the same field and to other fields appeared to exhibit approximately the same time lag. On the other hand, in 2006, the time lag to the peak citation frequency in the same field was 2 years, a slight increase in the speed of knowledge transfer in comparison to 10 years earlier. This was in contrast to citation in other

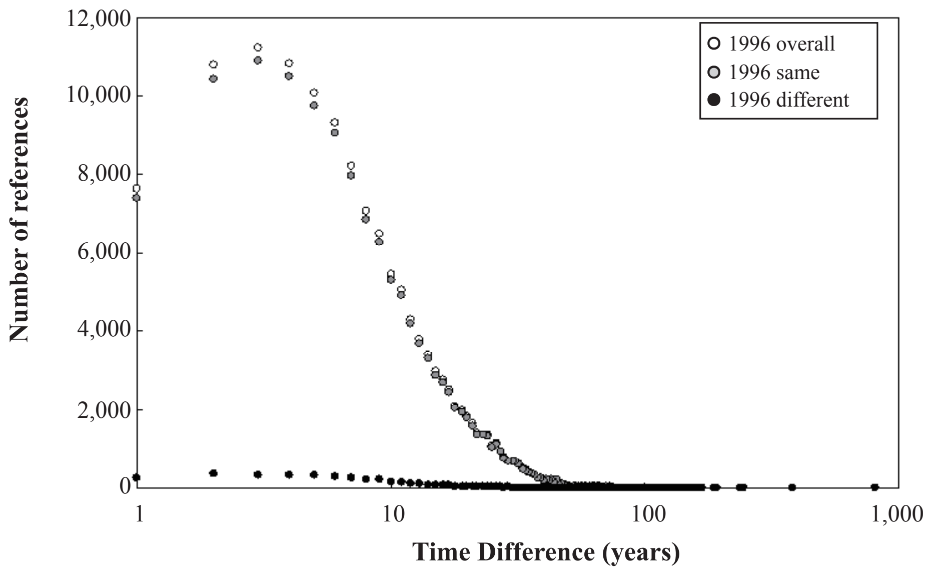

Figure 13 Time lag for referencing in 1996

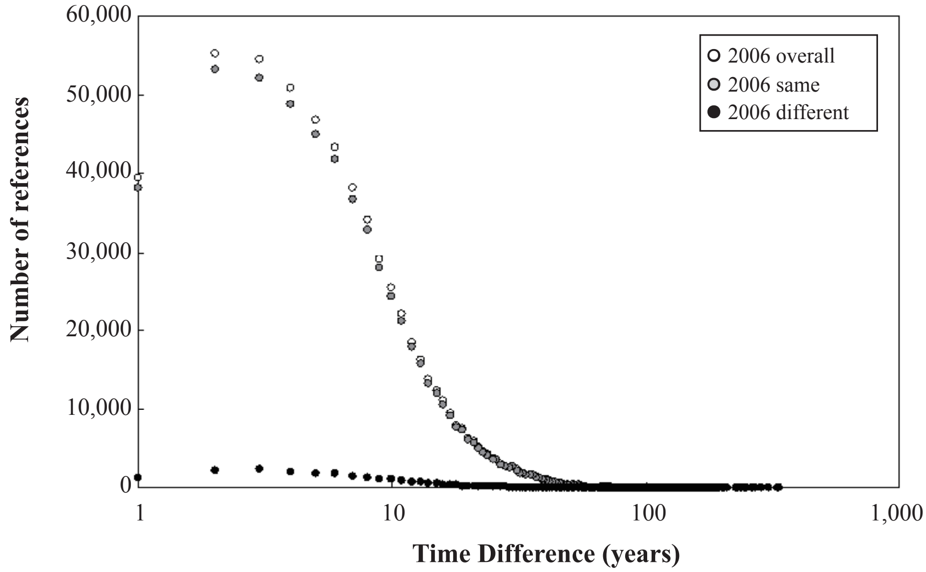

Figure 14 Time lag for referencing in 2006

fields in 2006, where a time lag of more than 3 years was most frequent. This signifies that the speed of horizontal knowledge transfer (knowledge transfer to other fields) is somewhat slower than the speed of knowledge transfer within the same field.

3.3 Implication: Horizontal knowledge transfer

Efforts to reinforce the efficiency of innovation systems can be explained by answering the following questions: "How fast is the knowledge transfer to the next stage?" and "How active is the association between the stages of research, development, manufacturing and marketing?" They can be rephrased as "How close is the distance between the stages of research, development, manufacturing and marketing?" Therefore, to evaluate the effectiveness of R&D programs, measurements are made of whether, and to what extent, the results of research have been transferred to the development stage, and whether, and to what extent, the results of the development stage have been transferred to the market through the manufacturing stage. However, as mentioned above, there is an uncertainty when utilizing basic research results since basic research aims to "acquire knowledge" rather than pursue immediate practical goals. Therefore, it is not possible to conclude that the effectiveness of the research is high just because the research managed to produce the anticipated results. Even if the research results had an outcome that was not anticipated or the research was even deemed to have been a failure, it may have a great ripple effect later. Therefore application objectivity need not and must not be emphasized for basic research. If efforts to improve the efficiency of the innovation system influence the basic research, then they can actually exert pressure to produce short-term results from basic research. This may reduce the uncertainty of basic research's results, which is one of its most important characteristics. The uncertainty of basic research results guarantees its creativity. Therefore, if the uncertainty of the basic research results are eliminated, then there is a concern that the creativity of basic research may be lowered, ultimately leading to lower quality results. Whereas in the case of applied research and development, it can be desirable to evaluate whether the planned results have been produced and utilized as planned, in the case of basic research, a different approach must be followed.

Among the characteristics of basic research that were analyzed in the previous chapter, we should pay high attention to the horizontal knowledge transfer method. If the planned results of basic research are obtained and then progressed into applied research and development, then the role of basic research can be understood easily with the vertical knowledge transfer method and can be explained by various innovation system models. However, we must always acknowledge the uncertainty of basic research results. Even when the planned results are not obtained, the other intrinsic roles of basic research must be remembered, such as expansion of knowledge stock, provision of new ideas for further R&D, and knowledge transfer to other fields of science and technology. This aspect is not possible to explain using the various innovation system models, such as the linear, chain-linked and open innovation models, that utilize the vertical knowledge transfer method as the fundamental framework. Therefore, we decided to refer to this aspect as the "horizontal knowledge transfer method". The overall creativity of the researchers can only be guaranteed if the same level of importance given to the vertical knowledge transfer method is also given to the horizontal knowledge transfer method, which, unlike the vertical knowledge transfer method, provides ideas for further R&D. Along with the uncertainty of basic research results, the horizontal knowledge transfer method has an enormous effect on the improvement of the level of basic research quality and the speed of expansion of knowledge stock. In the era of multi-disciplinary research, in which the associations between fields are continually increasing and the boundaries between fields are becoming increasingly blurred, such an understanding of horizontal knowledge transfer becomes even more important. Therefore, when reinforcing the efficiency of the innovation system, the distinct role of basic research must be understood differently to the role of applied research which is aimed at a "particular application" and is thus appropriate for the vertical knowledge transfer method. It is particularly desirable to acknowledge the role of basic research in the expansion of knowledge stock through horizontal knowledge transfer, in addition to vertical knowledge transfer.

4. Conclusion

In this study we discussed the possible distortion of the characteristics and roles of basic research when "reinforcement of efficiency of innovation system" and "promotion of basic research" is pursued simultaneously. In addition, it was explained that the role of basic research in the innovation system must be treated differently from that of applied research through analysis of the intrinsic characteristics of basic research. In various existing innovation systems, research does not properly distinguish basic research from applied research. Therefore, both basic research, aimed at the "acquisition of knowledge", and applied research, aimed at a "particular application", are situated within the innovation system as an element referred to as just research.

The innovation system is composed of research, which is an element that creates knowledge stock, development on the basis of this knowledge stock, and market-sided innovation elements such as production. However, efforts to improve the efficiency of the innovation system are accomplished by narrowing the distance between each of the innovation elements through active knowledge transfer between them. In other words, it aims to activate vertical knowledge transfer. In doing so, pressure to produce short-term application results for utilization in the next stage is also exerted on basic research, which may result in the unfavorable side effect of the distortion of the characteristics and the role of basic research. To prevent such a side effect and to clarify the role of basic research, the intrinsic characteristics of basic research must be understood. In this study, the questionnaire survey and paper citation network analysis were carried out to understand the characteristics of basic research. The analysis elucidated two intrinsic characteristics of basic research, namely the uncertainty of the basic research results and the horizontal knowledge transfer.

The uncertainty of basic research results were discussed previously along with the indirect effects of basic research. The desired horizontal knowledge transfer method cannot be explained in the majority of innovation system models that just follow the vertical knowledge transfer method as their fundamental framework. However, the horizontal knowledge transfer method can maximize the creativity of basic research by, for example, giving birth to new fields of science and technology. This birth of new knowledge systems is fundamentally different from the generation of fragmented knowledge. It is the process which creates the highest ripple effect of all methods of knowledge creation and can become a matrix of radical innovation. In addition, the perspective gained from the horizontal knowledge transfer method can help enormously to improve of the quality of basic research and the speed of expansion of knowledge stock by fostering the creativity of researchers and by not emphasizing the short-term applications of their results. Under the knowledge-based economic system in which knowledge creation including creativity and multi-disciplinary research play an important role, not only the existing vertical knowledge transfer method but also the horizontal knowledge transfer method has enormous significance. Therefore, when reinforcing the efficiency of the innovation system, it is necessary to distinguish the role of basic research from that of applied research which is the vertical transfer of knowledge towards a "particular application". It is desirable to define the role of basic research as the expansion of knowledge stock through both horizontal and vertical knowledge transfers. As such, if the role of basic research is considered separately, then the "reinforcement of the efficiency of innovation system" and "promotion of basic research" can coexist without side effects, and the expansion of knowledge stock system can be achieved efficiently in the innovation system.

5.. References

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