Characteristics of ICT-Based Converging Technologies

Pang Ryong Kim

The rising pace of technological change in information and communications technology (ICT) has provoked technological convergence by providing a new mode of diversification. This paper investigates the nature of ICT-based converging technologies by examining comparative empirical evidence on converging versus nonconverging technologies in relation to the following issues: patent application trends, concentration across technologies, the concentration of patenting activity across firms, R&D efforts, and a technology impact index. For this study, a new operational definition of ICT-based converging technology is derived, and a massive quantity of patents, up to around 600,000, is analyzed. This study follows the International Patent Classification as well as the modified European Commission's industry classification system for the classification of technologies and industries, respectively.

Keywords: Patent analysis, homogeneous convergence, heterogeneous convergence, IPC, ICT.

Manuscript received Jan. 17, 2013; revised May 10, 2013; accepted June 3, 2013.

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I. Introduction

Although a patent may not be essentially valuable, a patent claiming an invention with market demand is likely to have economic value because intellectual property rights (IPRs) can stop others from making and offering the same item for sale and can be used to defend a firm's competitive position [1], [2]. The development of new technologies motivates firms to protect their inventions. Patents not only enhance the value of a firm but can also function as bargaining means in managing the firm's strategic alliances [3]. Vermeulen [4] proposed that patenting strategies can be examined from four perspectives: marketing profit, profit source, bargaining power, and industrial control. Although patents do not necessarily cover technologies, inventions based on technological applications combined with analyzing the US patent market, the world's most competitive, can yield some clues about which converging information and communication technologies may be the next heavyweights. According to Hanni and others [5], despite all the discussions on globalization and emerging markets, the increase in the number of IPR studies in the US was greater than in any other country during the period of 1990 to 2009. The authors have indicated the size and significance of the US market according to the global standards as one possible reason for this.

Technological convergence has been regarded as an emerging trend and has received particular attention in the ICT industry [6]. Technological convergence in the ICT sector has been discussed since the early 1970s [7]. Since the 1980s, there have been numerous innovative convergences of heterogeneous technologies to create new products and services, and even new technologies [8]. Important concepts in the research literature build on the notion that new technologies are combinations of existing components and principals. This observation is derived from the perspective that exotic combinations produce the most novel inventions. For inventions that become commercialized, payouts may be especially high. There are numerous examples of important inventions involving technological convergence abound [9], [10].

This study considers patents using the International Patent Classification (IPC) system for technologies. Created to provide a common international system of classification, the IPC system consists of eight upper categories known as sections. Under these eight sections, there are main classes, subclasses, main groups, and subgroups in an ordered hierarchy. Patents at the main group level are considered technology units for analyzing the degree of concentration across technologies, and patents at the subclass level are considered technology units for selecting new technologies. What makes this study different from similar patent-related studies is that an analysis of several hundred thousand patents is conducted, including those in a new category of the ICT industry, absent from the European Commission (EC)'s scheme, that was added to establish concordance with the EC's industry classification system. In particular, ICT technology is reclassified into "nonconverging," "homogeneous converging," and "heterogeneous converging," and an operational definition of ICT-based converging technology is presented by developing an index enabling quantification of related data.

This study examines the nature of converging technologies by finding comparative empirical evidence on converging versus nonconverging technologies in the US patent market. The main issues of the research are as follows: 1) to show that the technological convergence in the ICT field expands over time across different fields, wherein ICT is considered to be a platform for entry into new products as well as an intermediary of technology convergence [11]; 2) to test in the short term whether there is evidence of a higher degree of concentration across technologies and the concentration of patenting activity across firms working with converging technologies (the concentration of patent activity will continue until innovative applications expand over the long term, across different technological fields by a wider number of firms) [6]; and 3) to find the difference between a large applicant and a small applicant or between a for-profit applicant and a nonprofit applicant in terms of R&D effort and knowledge sources.

This paper is structured as follows. Section II presents an operational definition of ICT-based converging technology, followed by a review of the industry and technology classification system, which are the basic factors of the empirical analysis described in the following section. Section III describes the basic description of a patent information database and the empirical methodology used to identify the nature of converging technologies. Section IV examines the nature of converging technologies. In section V, the results of this research are recapitulated and its policy implications presented.

II. Theoretical Discussion

In this section, following a review of the established industry and technology classification system that has been proposed by a number of scholars, an operational definition of ICT-based converging technology is presented and the main issues of converging technologies are discussed. The converging technology conceptualized in this paper is a patented technology used in various industry fields. When performing an economic analysis using patent data, it is necessary to convert the IPC system into an industry classification system that is adapted for the economic analysis, which is the industry and technology classification system dealt with in this paper.

1. Review of Industry and Technology Classification System

IPC, a classification scheme developed primarily to distinguish similar technologies from one another for legal purposes, is not appropriate for direct use in an economic analysis without modification. Other reasons that prevent patent databases from being more widely used for economic or management analyses include the difficulty of comparison between countries, disparities in technology classification units, lack of empirical evidence, and changing industry structures. As a result, patent databases in most countries are currently not actively used for analyses intended to draw economic and management implications.

A study by Kronz and Grevink [12] is considered a major early attempt to link technology with industry. Following the Nomenclature générale des Activitiés économique dans les Communautés Européennes (NACE), this study analyzed patent applications from four countries and linked the technologies with corresponding industries, relying extensively on the intuition of researchers.

Meanwhile, in a study using patent statistics from the Canadian Intellectual Property Office, Evenson and Puttman [13] matched the eight sections of the IPC with 25 industries. The resulting correspondence table is known as the Yale-Canada Patent Flow Concordance. However, their 1988 classification, which considered only section-level categories of IPC codes, is far from concrete. Another shortcoming is that they classified industries based on Canadian industry, which requires that these categories be converted into categories under the International Standard Industrial Classification System (ISIC) or NACE, an extra step that renders the process impractical.

In a study using data from the Finnish Central Statistical Office, Verspagen and colleagues matched 625 subclasses of the IPC system with 22 industry categories under the ISIC, creating the MERIT concordance table [14]. Although their technology-industry concordance table largely improves upon the one in [13] by covering subclasses, which are more detailed categories of the IPC hierarchy, it still retains most of the shortcomings of the table in [13].

Among more recent attempts to link the IPC system with the ISIC system, the work by Johnson [15] stands out. Johnson established concordance between 625 IPC subclasses and 115 manufacturing and retail industries by calculating a probability of correlation. Using Canadian patent data, Johnson developed a concordance program by computing the probability that each of the IPC codes can be classified into a combination of an Industry of Manufacture (IOM) for the industry in which the technology in question was developed and a Sector of Use (SOU) for the industry in which the technology in question is used. This technology-industry concordance scheme, as it is largely subject to individual judgments by patent judges, is potentially prone to technology bias and is also limited in that it is quite disconnected from the latest technology and industry environments, which have evolved extensively owing to developments in recent years. Johnson's concordance scheme, based on the Canadian industry classification system, is inconvenient as well, as it requires conversion into ISIC or NACE categories. However, Johnson's concordance table is generally perceived as much more rational and systematic than similar tables that were developed previously, even though it is yet to be verified for its accuracy.

Schmoch and others [16], in cooperation with three research institutes of the EU (Germany's Fraunhofer Institute for System and Innovation Research, France's Observatoire des Sciences et des Techniques, and the UK's University of Sussex, Science and Policy Research Unit), developed a technology-industry concordance table, which was submitted to the EC in the form of a report. They matched the 625 categories under the IPC system with 44 manufacturing industries. The method used was to couple each IPC category with its most important industrial counterpart in such a way that only one industry was matched with any single technology.

As ICT is not included in the existing EC's industry classification system as an independent category, herein, related industry activities are separated from 44 industries to create a new category. In the EC report, concordance was established between the IPC scheme and the industry classification system related only to manufacturing industries. However, the eighth edition of the IPC includes "agriculture and fishery industries" and "construction industry.[0]" Accordingly, "agriculture and fisheries" and "construction" have been added to the proposed industry classification scheme, while introducing the ICT industry as a new category. Even after the addition of these three new industries, the number of industries remains at 44, as in the original classification by Schmoch and others, as three of the previous industry categories were absorbed into the ICT industry, as shown in Table 1.

Table 1. Industry classification used in this study.

No.	Industry fields
1	Agriculture and fisheries
2	Food products and beverages
3	Tobacco products
4	Textiles
5	Wearing apparel, dressing and dyeing of fur
6	Leather products, luggage and footwear
7	Wood products
8	Pulp and paper products
9	Publishing, printing and reproduction of recorded media
10	Coke, refined petroleum products and nuclear fuel
11	Basic chemicals
12	Pesticides and other agricultural chemical products
13	Paints, varnishes and similar coatings
14	Pharmaceuticals and medicinal chemicals
15	Soaps and detergents, cleaning and polishing preparations, perfumes and toilet preparations
16	Recording media and related chemical products, and other chemical products
17	Man-made fibers
18	Rubber and plastic products
19	Other non-metallic mineral products
20	Basic metals
21	Fabricated metal products (except machinery and equipment)
22	Energy machinery
23	Other general-purpose machinery
24	Agricultural machinery
25	Machine tools
26	Special-purpose machinery
27	Weapons and ammunition
28	Other domestic appliances
29	Office machinery and computers
30	Electric motors, generators and transformers
31	Distribution and control apparatuses of electricity, and insulated wires and cables
32	Electric lamps and bulbs
33	Other electric equipment
34	Television and radio receivers, audiovisual electronics
35	Medical and surgical equipment and orthopedic appliances
36	Instruments and appliances for measuring, testing and navigating and other precision instruments)
37	Industrial process control equipment
38	Photographic equipment and other optical instruments
39	Watches, clocks and timing mechanisms and parts thereof
40	Motor vehicles, trailers and semitrailers
41	Other transport equipment
42	Furniture and other miscellaneous products and processed materials for recycling
43	Construction
44	ICT

There are many different definitions used to explain the abbreviation of ICT. This study includes information or

Table 2. Technological classification of ICT industry.

Technology classification (main class)	Subclass
Performing operations	B07C, B65H, B81B, B81C
Optics	G02B, G02F
Photography, cinematography, analogous techniques using waves other than optical waves, electrography, holography	G03G, G03H
Controlling, regulating	G05F
Computing, calculating, counting	G06C, G06D, G06E, G06F, G06G, G06J, G06K, G06M, G06N, G06Q, G06T
Signaling	G08B, G08C, G08G
Cryptography, display, advertising	G09B, G09C
Acoustics	G10L
Information storage	G11B, G11C
Basic electric elements	H01C, H01F, H01G, H01J, H01L, H01M, H01P, H01Q, H01S
Generation, conversion, or distribution of electric power	H02J
Basic electronic circuitry	H03B, H03C, H03D, H03F, H03G, H03H, H03J, H03K, H03L, H03M
Electric communication technique	H04B, H04H, H04J, H04K, H04L, H04M, H04N, H04Q
Electric techniques not otherwise provided for	H05H, H05K

Source: Edition 8 of the IPC, 2007.

communication devices and software and parts in the ICT industry. Table 2 shows the 58 technologies within the subclass IPC categories included in the ICT industry [17].

2. Definition of ICT-Based Converging Technology

The term "convergence" has been used to describe a phenomenon in which two or more distinctive items move toward uniformity or a case in which there is a blurring of the boundaries between at least two disconnected areas of science, technology, the market, or industry [18]. To clarify this concept, previous research attempted to classify a variety of definitions of convergence. Utilizing the paradigm of evolutionary theory, Hacklin [19] divided the process of convergence into four stages: knowledge, technology, application, and industry.

The first use of the term "convergence" in the context of industry is attributed to Rosenberg [20]. He used the expression to describe processes commonly utilized by different stages of tool production and unrelated sectors of industry. A foundation for the common understanding of industry convergence equaling technology convergence is explained in his paper. Since the unveiling of Rosenberg's notion of industry convergence [20], many researchers have tried to develop a similar concept of convergence [7], [19], [21], and [22]. On the other hand, Kodama [23] used the term "technology fusion" long before this to describe a type of innovation that leads to breakthrough functions by combining at least two or more existing technologies into hybrid technologies. Although Curran and Leker [7] insist that there is a significant difference between the terms "convergence" and "fusion," many scholars have not referenced both terms in their papers [24]-[26]. The terms are used interchangeably in this paper.

Converging technology is the product of interdisciplinary research. Interdisciplinary research is different from multidisciplinary research because the former involves a more fundamental convergence between different technologies than the latter [27]. Despite this distinction, the current study employs a broad definition of converging technology to include within its scope hybrid technologies that connect technologies in a more superficial manner than converging technologies.

Converging technology has been thus far defined in rather general terms. For the purposes of this study, we define converging technology in a more specific manner by developing an index enabling the quantification of related data. When IPC subclasses assigned to a patented technology belong to various industry fields, this means that the technology is a converging technology with a wide industrial application. In this study, a patented technology is classified as a nonconverging technology when it has only one subclass category that belongs to the ICT industry. A patented technology is considered a homogeneous converging technology when it has plural subclass categories belonging to the ICT industry without any other category belonging to a non-ICT industry. On the other hand, a patented technology is considered a heterogeneous converging technology when it has one or more subclass categories belonging to a non-ICT industry, while its main subclass IPC belongs to an ICT industry [17].

Convergence between homogeneous technologies, occurring in the same field, generally implies a combination of several technologies to bundle multiple functions. Telecommunications products and services, such as camera phones, portable PCs, and IPTVs, are good examples of homogeneous converging technologies, in which different technological subsystems interact and function as a technically integrated end-to-end system that provides the user with a range of voice, data, and imaging services [28]. Convergence between heterogeneous types of technologies creates a combination of technologies aiming at resolving issues existing in the different technology fields. Bioinformatics, a human interface, and nanobiosensors are great examples of convergence of this type from recent years, combining ICT with biotechnology or nanotechnology.

III. Empirical Method

After introducing an outline of the patent database used in this paper, this section describes a methodology for measuring the characteristics of converging technologies by finding the comparative empirical evidence on converging versus nonconverging technologies in relation to the following issues: patent application trends, concentration of patent activity across technologies and firms, R&D efforts, and knowledge sources.

1. Outline of Patent Database

A database of ICT-based patented technologies selected from application patents published by the USPTO from January 2001 to June 2009 is constructed using the corresponding IPC categories. After removing noise, the total number of ICT-based patented technologies amounts to 593,071 at the IPC subgroup level. In this study, such classification criteria as IPC classification, patent issue month, first and second assignee, and cited by count are used primarily among the classification criteria provided directly from the USPTO. However, the following additional criteria are newly developed because there has been difficulty achieving the research purpose with these criteria only: classification for technology (nonconverging, homogeneous converging, and heterogeneous converging technologies), classification for patent applicant patterns (for-profit and nonprofit), and classification for size (large and small).

Although periods covered by a patent analysis can be extended, in many cases, up to 10 years or longer, these cases are generally studies dealing with narrow and specific technology fields. The period covered in this study is somewhat shorter, due on the one hand to the fact that the related field of technology is quite vast and on the other to the fact that ICT evolves much more rapidly than other technologies. The data from January 2006 to June 2009 is primarily used for the analysis of patent application trends, concentration of patent activity across technologies and firms, and R&D efforts in this study, as patent applications have shown dramatic changes in the trends from December 2005. However, the data from January 2001 to June 2009 is used for an analysis of the technology impact index, as a long-pending patent tends to be cited more than a recently filed patent.

2. Measurement of Convergence

Measuring convergence is related to two streams of literature, one of which measures firm diversification and the other measures technology relevance. The former generally uses case studies focusing on industry convergence, while the latter adopts measures based on patent data to analyze technology convergence [29]. Patent works are expected to provide an important opportunity for discovering occurrences of the convergence phenomenon and/or predicting converging industries [30]-[32]. The patent literature has authoritative advantages over any other form of scientific publications because it is already systematized to a high degree. Patent analysis has been undertaken in the context of technology-driven convergence of ICT, biotechnology, and other technologies [7], [17], [22], [33]-[36]. Technological convergence can be found in patent data through an increase in patent citations between different subclass categories of the IPC system [37].

In prior patent studies, three main methods have been used to analyze technological convergence: keyword, patent citation, and classification analyses. Keyword analyses consist of extracting related words from a database by professional indexers. For example, Coulter and others [38] selected descriptors chosen by professional indexers, considering that their experience guarantees a correct procedure for keyword selection. Corrocher and others [33] examined the convergence of technologies related to ICT by identifying relevant words from patent abstracts. Patent citation analysis has long been applied to grasp linkages between industries or technologies, as patent citations reflect the influence of their technological innovation and the pervasiveness of their technological information [39]. Karvonen and colleague [22] used patent citations as a tool for analyzing the initial stages of convergence. Patent classification analyses refer to the manner in which the examiners of a patent office arrange patent documents according to the technical features of inventions. By adopting the degree of co-occurrence of classes, it is possible quantitatively to analyze the convergence of technologies. A relevant method was suggested in the 1960s and was later applied in a science and technology context [40]. This paper uses the second and third methodologies described above. It takes IPC classification codes as the unit of analysis, considers citations as a proxy for knowledge sources, and uses the technological impact index utilizing the cited patents to detect the sources of knowledge of converging technologies.

A. Patent Application Trends

This paper examines the US patent applications between January 2006 and June 2009 to find a technological converging trend for ICT technologies. Patent applications in the ICT field showed very different patterns before December 2007 and since, as shown in Fig. 1. Taking these points into consideration, we examine the trends in the area of ICT, dividing the

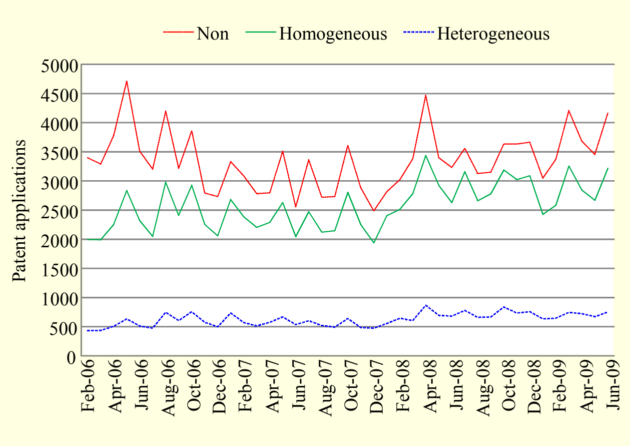

Fig. 1. Patent application trends by technology.

assessment into two periods: January 2006 to December 2007 as the first period and January 2008 to June 2009 as the second.

B. Concentration of Patent Activities

There are 58 related fields at the subclass level and 831 fields at the main group level. This study considers patents at the main group level in the IPC system as technologies. In this paper, 831 IPC classes at the main group level are used to calculate the degree of concentration across technologies. The Hirfindahl index, $\mathrm{HT}_i=\sum(P_{ij}/P_i)^2$, illustrates the concentration of patents across k IPC classes for technology i, where P_i is the number of patents related to technology i, and P_{ij} is that of patents applied for in technology i belonging to IPC class j. Accordingly P_{ij}/P_i shows j's share of patents related to technology i. This paper uses the normalized Hirfindahl index, $\mathrm{NHT}_i=(k\mathrm{HT}_i-1)/(k-1)$, where k=831, and corrects the upward bias in an ordinary Hirfindahl index by converting indices ranging from "1/k" to "1" into those ranging from "0" to "1." Through the same procedure, we can obtain the Hirfindahl index denoting the concentration of patenting activity across n firms, $\mathrm{HF}_i=\sum(P_{iz}/P_i)^2$, where P_{iz} is the number of patents applied for in technology i belonging to firm z. The normalized Hirfindahl index, $\mathrm{NHF}_i=(n\mathrm{HF}_i-1)/(n-1)$, is also used in this paper.

C. R&D Efforts and Sources of Knowledge

To detect the difference in R&D efforts and knowledge sources on converging technologies according to the pattern of patent applicants, we examine the related issues by dividing applicants into the following pattern: for-profit and nonprofit, and large and small. In this paper, universities and public research institutions are grouped as nonprofit and private enterprises, and research institutes attached to the firm are grouped as for-profit agencies. A patent applicant is classified as a large applicant if its number of patents is above the average of the sample, which includes all patent applicants, and, if it is not, it is classified as a small applicant. The average for the whole sample is 10.18.

We use the technological impact index to detect the sources of knowledge of converging technologies. Here, the impact index of technology i, $\mathrm{MT}_i=[\sum C_{ij}/(N_i/12)]/P_i$, denotes the annual average number of cited patents per patent. Here P_i is the number of patents related to technology i, C_{ij} is that of cited patents from technology i belonging to IPC class j, and N_i is the number of months elapsed since the initial publication of technology i. Using the impact index in a patent analysis offers, among other things, the advantage of eliminating bias in which the longer the duration of a patent application, the higher the number of citations it receives.

Table 3. Patent application trends by technology.

	Total no. of patent applications	Monthly avg. no. of patent applications 1st period (A)	Monthly avg. no. of patent applications 2nd period (B)	Growth rate (B–A)/A
Non	140,796	3,241	3,500	0.0799
Homogeneous	107,545	2,331	2,867	0.2302
Heterogeneous	26,144	560	705	0.2582
Total	274,485	6,132	7,073	0.1533

IV. Results

1. Patent Application Trends

Table 3 shows in detail the changes in the number of patent applications over time by each technology. Throughout the entire period from January 2006 to June 2009, most patent applications were made in nonconverging technologies, followed by homogeneous converging and heterogeneous converging technologies.

The interesting result is that the rate of growth of nonconverging technologies with the most patent applications is the lowest among the three technologies, but the heterogeneous converging technologies with the least number of patent applications have the highest growth rate. The monthly average growth rate of the heterogeneous converging technologies and that of the homogeneous converging technologies is 25.82% and 23.02%, respectively, while that of nonconverging technologies is 7.99%. This implies that a general purpose technology, such as ICT, increasingly tends to be fused with other technologies over time across different fields.

Table 4. Average normal Herfindahl indices according to each pattern of convergence.

	Index across technologies	Index across firms
Non	0.0809	0.0081
Homogeneous	0.0943	0.0085
Heterogeneous	0.0658	0.0037

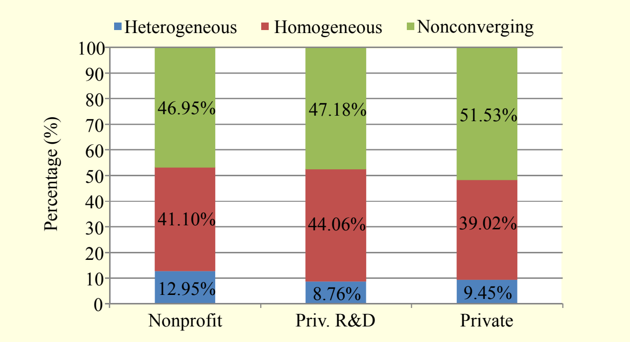

Fig. 2. Ratio of patent applicants (for-profit vs. nonprofit).

2. Concentration of Patent Activities

Table 4 shows the monthly average of normalized Hirfindahl indices for converging and nonconverging technologies. Throughout the entire period, the concentration of patent activities across technologies in homogeneous converging technologies represents a relatively high value compared with the other two technologies, and this pattern also appears in the concentration of patent activities across firms. Here, normalized average Hirfindahl indices denoting the concentration of patent activities across technologies and firms display a statistically significant difference among the three technologies. This means that homogeneous converging technologies are facing a situation far more monopolistic than the other technologies at the firm and technological levels. On the other hand, we find that heterogeneous converging technologies, compared to the other two technologies, are placed in a competition situation at the firm level as well as at the technological level. As a result, we suggest that technology concentration by a few large firms is being intensified in homogeneous converging technologies.

3. R&D Efforts According to Pattern of Patent Applicants

Figure 2 shows that nonprofit agencies, such as universities and public research institutions, file patent applications relatively more frequently than for-profit agencies in heterogeneous converging technologies, private research institutions in homogeneous converging technologies, and private enterprises in nonconverging technologies. This implies that private firms tend to produce and develop products based on nonconverging technologies in the present but concentrate on the research and development in homogeneous converging technologies through the research institute attached to the for-profit firm creation in the near future. On the other hand, we find that universities and public research institutions that have long-term points of view concentrate on research in heterogeneous technologies to apply ICT technologies to other technologies.

In dividing patent applicants into large and small applicants, we tend to find that a large applicant applies for a relatively higher ratio than a small one for homogeneous technologies and that a small applicant files for a relatively higher ratio than a large one for heterogeneous technologies, as shown in Fig. 3. On the other hand, there is not a huge difference in the R&D efforts between large and small applicants in nonconverging technologies.

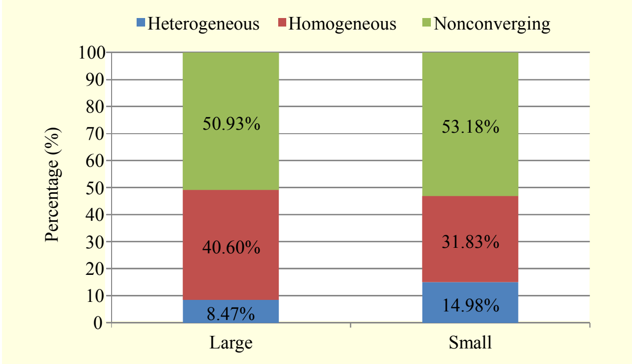

Fig. 3. Ratio of patent applicants (large vs. small).

Table 5. Technology impact indices for technologies and patent applicants.

	Private	Priv. R&D	Nonprofit	Weighted total
Non	0.4566	0.4768	0.2914	0.4533
Homogeneous	0.5984	0.4858	0.4513	0.5924
Heterogeneous	0.5605	0.7538	0.4776	0.5623
Weighted total	0.5319	0.5509	0.4010	

4. Knowledge Sources Using Technology Impact Index

Table 5 presents technology impact indices according to a combination of patent applicants and technologies. Homogeneous converging and heterogeneous converging technologies have a higher technology impact index compared

Table 6. Multiple comparisons of impact indices between technologies.

I	*J*	Mean difference (*I* – *J*)	Std. error	Sig.
Non	Homogeneous	–0.1390948*	0.0097242	0.000
	Heterogeneous	–0.1089554*	0.0109286	0.000
Homogeneous	Non	0.1390948*	0.0097242	0.000
	Heterogeneous	0.0301394*	0.0111875	0.007
Heterogeneous	Non	0.1089554*	0.0109286	0.000
	Homogeneous	–0.0301394*	0.0111875	0.007

*Mean difference is significant at 0.05 level.

with nonconverging technologies. The technology impact index of homogeneous converging technologies is greater than that of heterogeneous converging technologies, though the difference is not large.

These indices have a statistically significant difference across three technologies in the weighted total criteria, as shown in Table 6. This finding reveals that converging technologies have more originality compared with nonconverging technologies.

For the patent applicant criteria, private research institutions have the highest technology impact index, but there is no statistically significant difference in technology impact indices between private research institutions and private enterprises. However, there is a statistically significant difference in technology impact indices between for-profit agencies, such as private research institutions and private enterprises, and nonprofit agencies.

We have previously indicated that private enterprises file for a relatively higher ratio of nonconverging technologies, as private research institutions do for homogeneous converging technologies and nonprofit agencies for heterogeneous converging technologies. However, the degree of R&D effort does not correspond to the size of the technological influence. The patented technology of private research institutions has an overwhelmingly large technological influence compared with the other agencies, followed by private enterprises and nonprofit agencies in heterogeneous converging technologies. The patented technology of private enterprises has a relatively large technological influence compared with the other agencies for homogeneous converging technologies. On the other hand, the technology impact index of private research institutions is shown to be greater than that of nonprofit agencies, but a statistically significant difference does not exist between them. The technology impact indices of for-profit agencies are shown to be greater than those of nonprofit agencies in the nonconverging technologies, but a statistically significant difference does not exist between private enterprises and private research institutions.

A noteworthy fact is that universities and public research institutions have a low technology impact compared with private enterprises and private research institutions in all fields of technology. This means that for-profit agencies are leading research and development in fields with a high level of technological originality. To verify whether the technology impact index rises with the increasing scale of patent size, the correlation between the number of patents and the technology impact index has been analyzed in about 50,000 agencies. The correlation coefficient between these two variables is very small (–0.0018) and statistically not significant, suggesting that no correlation exists between the number of patents and the technology impact index.

V. Conclusion

In this paper, the characteristics of converging technologies were analyzed by finding comparative empirical evidence on converging versus nonconverging technologies, the results and implications of which can be summarized as follows.

First, when dividing the ICT technologies into nonconverging, homogeneous converging, and heterogeneous converging technologies, the rate of growth of the nonconverging technologies with the most patent applications is the lowest among the three, but the heterogeneous converging technologies with the least patent applications have the highest growth rate. This reflects the fact that many companies make more of an effort to develop ICT-based converging technologies, especially heterogeneous converging technologies, to realize their economic benefits.

Second, the concentration of patent activity across technologies and firms for homogeneous converging technologies represents a relatively high value compared with the other two technologies, which suggests that the technology concentration by a few large firms on homogeneous converging technologies is intensifying.

Third, technological influence appears to be high in the order of homogeneous converging, heterogeneous converging, and nonconverging technologies. Based on a patent application, for-profit agencies, including private enterprises and private research institutions, have a relatively higher technological influence than nonprofit agencies including universities and public research institutions.

Fourth, we observed a very small and statistically insignificant correlation between the number of patents by each applicant and the technology impact index. This suggests that a correlation between the agency size and the technology impact index practically does not exist.

Finally, we found that the degree of R&D effort by each applicant does not correspond to the size of its technology impact. The patented technology of private research institutions has an overwhelmingly large technological influence compared to other agencies for heterogeneous converging technologies, and private enterprises have a relatively large technological influence compared to other agencies for homogeneous converging technologies. A noteworthy fact is that nonprofit agencies have a lower technological impact compared to for-profit agencies in all fields of technology, meaning that for-profit agencies are leading the research and development in the technology field with a high level of originality. We recognize the government's challenge on how to adjust the direction for future research and development. The government should provide incentives so that universities and public research institutions, which make relatively large research efforts in the development of heterogeneous technologies, may increase their productivity.

The main contribution of this paper is to reclassify converging technologies into homogeneous converging and heterogeneous converging technologies and to investigate the nature of ICT-based converging technology by utilizing its operational definition. The findings of this study confirm those of previous research in that such general-purpose technologies as ICT tend to be converged with other technologies over time and that for-profit agencies have a relatively higher technological influence than nonprofit agencies. However, the observation that a correlation between the agency size and its technological influence does not exist does not correspond to what the Schumpeterian Hypothesis suggests.

The limitations of this study and directions for future research are as follows. This paper integrated and reclassified industry fields under EC's industry classification table by introducing the ICT industry as an independent one. However, the scope of the ICT industry can vary depending on the researcher, and its results may also differ in accordance with the scope of the ICT industry selected. Meanwhile, we adopted a quantitative approach, using a patent database, as an alternative to a qualitative approach, such as a Delphi panel analysis. A patent analysis is limited, however, in that new technologies for which no patent has been applied or issued are left out of consideration. Therefore, future research can obtain more valid results by complementing the method used in this study with other methods, such as a journal analysis and/or survey. On the other hand, this paper focuses on an analysis of US patents. To generalize the findings of this paper, it would be necessary to extend the scope of research into more countries, such as South Korea, Japan, China, and Europe, for example.

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