A Study on the Identification of Cutting-Edge ICT-Based Converging Technologies

Pang Ryong Kim and Sung Hyun Hwang

It is becoming increasingly difficult to identify promising technologies due to the influx of new technologies and the high level of complexity involved in many of these technologies. Identifying promising information and communications technology (ICT)-based converging technologies holds the key to finding new sources of economic growth and forward momentum. The goal of this study is to identify cutting-edge ICT-based converging technologies by examining the latest trends in the US patent market. Analyzing the US patent market, the most competitive of such markets in the world, can yield certain clues about which of the ICT-based converging technologies may be the next revolutionary technologies. For a classification of these technologies, this study follows the International Patent Classification system. As for ICT, there are 58 related fields at the subclass level and 831 fields at the main-group level. For emerging and converging technologies, there are 75 at the main-group level. From these technologies, a final selection for cutting-edge ICT-based converging technologies is made using a composite index reflecting the converging coefficient, emerging coefficient, and technology impact index.

Keywords: Converging technologies, patent analysis, selection, technology classification, converging coefficient.

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I. Introduction

What is notable in recent innovation trends is the convergence of technologies. Since the 1990s, sectors of the information and communications technology (ICT) industry have tended to converge [1], and, more recently, this phenomenon can be found in mobile IPTV as a cutting-edge convergence of the Internet, mobile communications, and broadcasting [2]. New technologies and services are expected to emerge in the future, standing on various industries. Identifying promising ICT-based converging technologies holds the key to finding new sources of economic growth and momentum to move forward. The goal of this study is to identify cutting-edge ICT-based converging technologies by examining the latest trends in the US patent market. Analyzing the US patent market, the world's most competitive, can yield certain clues about which of the ICT-based converging technologies may end up being the next heavyweights.

Expert panel approaches such as the Delphi panel are popularly used to select technologies with high market potential. Although they offer the advantage of guaranteeing expertise in the decision-making process, they involve rather complex procedures, are time-consuming as well as manpower-intensive, and are costly. Another major disadvantage of expert panel methods is that they are essentially a survey-based form of qualitative analysis, which cannot guarantee complete objectivity of their results. A precise alternative, able to remedy these issues, is patent analysis. The foremost advantage of quantitative analysis using patent databases is that it's better to search for technologies touted as promising and new in such databases than in academic journal databases where they are much harder to come across [3], [4]. The fact that this study is exclusively concerned with technology markets also justifies the choice of using a patent database, which is one of the most comprehensive sources of technology information. Notwithstanding, as not all new technologies are patented, for those technologies absent from a patent database, complementary methods such as an analysis of journals and surveys may be necessary to obtain more complete and valid results.

In section II, existing literature on related topics and the established industry and technology classification system utilized in this study are reviewed. In section III, an operational definition of ICT-based converging technology is provided after reviewing the basic description of a patent information database and selection procedure for optimizing technologies. In section IV, we identify converging technologies, emerging technologies, and emerging and converging technologies using the information from the database described in section III. In section V, we recapitulate the results of research and present directions for future research.

For a classification of technologies, this study follows the International Patent Classification (IPC) system. As for ICT, there are 58 related fields at the subclass level and 831 fields at the main-group level.

What distinguishes this study from other attempts to select promising technologies in terms of methodology is that we have created new constructs, which we call "converging coefficient," "emerging coefficient," and "impact index," and have identified the emerging and converging technologies using comparable multi-criteria. We first make a preliminary selection according to the converging and emerging coefficients and then select an intersecting set of converging and emerging technologies. From this set, the final selection for cutting-edge emerging and converging technologies is made using a composite index consisting of the converging coefficient, emerging coefficient, and impact index. In particular, we analyze a massive quantity of about six hundred thousand patents.

II. Literature Review

Throughout the past decade, convergence between technologies has been increasing [5]. In particular, the ICT sectors are in a rapid process of technological convergence [6]. It is difficult to forecast emerging technologies as there is no historical data available. Daim and others [7] suggested that use of patent analysis had provided useful data in this case.

Among the studies using patent analysis for the selection of promising technologies, one can discern three main categories according to the selection criteria. Studies of the first category are those in which the total number of citations received was used as the key selection criterion. Studies by Carpenter and others [8], Albert and others [9], and Harhoff and others [10] are some of the most representative. In Korean research, a study by Lee [11] is an instance in which the number of citations received was used as one of the key criteria for the selection of promising technologies.

In studies falling into the second category, the rate of patent growth in a given technology field was used as the principal criterion. Corrocher and others [12], a fine example of researchers applying a judicious use of this approach, examined patent growth rates of a number of technologies, comparing the data from 1995 through 1996 to that of 1998 through 1999. The technologies, whose rate of patent growth over this period is equal to or exceeds the average growth rate of a sample comprising all relevant technologies, were considered promising. Among Korean researchers, Ko and Rho [13] identified through a patent analysis patent classification codes for which a growing number of patents have been filed or awarded, as well as keywords that have become increasingly popular in recent years. He then matched these codes and keywords with corresponding industries and products using the international industry/product classification system to determine promising technology item groups and assess mega-trends in related technology/industry fields. The rate of patent growth was therefore the main criterion used by Ko and Rho [13] in this analysis.

Studies belonging to the third category use composite indices. Harhoff and others [14], for example, considered not just the number of citations received but also the number of citations made, pointing out that the latter has a strong correlation with the quality of a patent. In Korean research, Kang and others [15], [16] used both the number of patents awarded and the rate of patent growth to predict promising converging technologies. Bae and others [17] reviewed studies on the selection of promising technologies and found that the vast majority of them used a hybrid model created from a number of methods, rather than relying on a single methodology. This is likely due to the fact that researchers realized that no single method takes into account all of the many considerations that are valid for the selection process and thus decided to combine different methods for a more comprehensive and balanced selection.

When performing an economic analysis using patent data, it is necessary to convert an IPC system into an industry classification system that is adapted for the economic analysis. IPC, a classification scheme developed primarily to distinguish similar technologies from each other for legal purposes, is not suitable for direct use in an economic analysis, without modification. Other reasons that prevent patent databases from being more widely used for economic analysis or management analysis include the difficulty in comparing countries, disparities in technology classification units, a lack of empirical evidence, and changing industry structure. As a result, patent databases in most countries are currently not actively used for analyses intended to draw economic and management implications.

Among recent attempts, the work by Schmoch and others [18] is considered the most important study on linking technology and industry. A project carried out in collaboration with three EU research institutions, namely, Germany's Fraunhofer ISI (Fraunhofer Institute for System and Innovation Research), France's OST (Observatoire des Sciences et des Techniques), and the UK's SPRU (University of Sussex, Science and Policy Research Unit), developed a technology-industry concordance table, which was submitted to the European Commission in a report form. In this project, the Fraunhofer ISI was responsible for defining industry and technology categories; the OST, for refining the concordance table; and the SPRU, for testing the concordance table for statistical validity. They matched the 625 categories under the IPC system with 44 manufacturing industries. The method consisted of coupling each IPC category with its most important industrial counterpart, in such a way as to have only one industry matched for any single technology. In Korea, attempts to establish concordance between technologies and industries have been made by Lee and others [19], Seoh [20], and Kang and others [15], [16], all of which used the industry classification scheme proposed by Schmoch and others [18].

As ICT is not listed in the European Commission's industry classification system as an independent category, we extracted related industry activities from the existing 44 categories to create a new category. Unlike in the EC report, in which concordance was established between the IPC scheme and the industry classification system concerning only manufacturing industries, the recently released IPC 8 includes agriculture and fisheries industries, including agriculture, forestry, and fisheries, as well as the construction industry. In light of this, we have also added agriculture and fisheries and construction to our own industry classification scheme, while at the same time introducing a new category, the ICT industry. Even after the addition of these three new industries, notably ICT, the number of industries remains at 44, as in Schmoch and others' original classification, since three of the existing industry categories were absorbed into the ICT industry.

Many different definitions exist for ICT. All sectors related to ICT, including information and communications services, information and communications devices, and software and parts, are normally considered part of the ICT industry. In this study, we include all of these sectors in the ICT industry except information and communications services. Table 1 shows the various ICT industries matched with corresponding main-class IPC categories and subclass categories. Fifty-eight technologies in the subclass IPC categories are included in the ICT industry.

Table 1. Technology 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.

In this study, three ICT-related sectors given separate categories in the EC industry classification system, namely, "accumulators and battery," "semiconductors and other electronic components," and "signal transmission and telecommunications equipment," have been included in the newly created ICT industry category. Meanwhile, some of the technologies qualifying as "special-purpose machinery," "office machinery and computers," "other electrical equipment," "TV and radio receivers, audiovisual electronics," "industrial process control equipment," and "optical instruments" have also been entered into the ICT industry [21].

III. Methodology

1. An Outline of the Patent Database

For this study, we build a database of ICT-based patented technologies, selected from laid-open patents published by the

United States Patent and Trademark Office (USPTO) between January 2001 and June 2009, using the corresponding IPC categories. After noise removal, the total number of ICT-based patented technologies amounts to 593,071, when counted using IPC subgroups as units. In this study, classification criteria such as patent issue month, IPC classification, first and second assignee, and cited by count are used primarily among the classification criteria provided directly from the USPTO. However, classification for technology (non-converging, homogeneous-converging, and heterogeneous-converging technologies) is newly developed as there has been difficulty in fulfilling the research purpose with these criteria only.

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 technology field with which it is concerned is quite vast and, on the other, to the fact that information technology evolves much faster than other technologies. Data from January 2006 to June 2009 is primarily used in this study, as patent applications have shown a dramatic change in trend since December 2005. However, data from January 2001 to June 2009 is used for the analysis of the technology impact index, as the patent applicants during the past three years have tended to remain uncited.

2. Selection Procedure

The selection of emerging and converging ICT-based technologies is performed in this study, following the steps outlined in Fig. 1. We begin by selecting the exploration areas and build a database on patents belonging to the exploration areas selected. Next, using the information of all the patents at the main-group level of classification in the database, we select converging and emerging technologies first by the number of converging instances and the growth rate of patents and then as an intersection set of these two technologies. From this set, the final selection for cutting-edge ICT-based emerging and converging technologies is made, using the composite index reflecting the converging coefficient, emerging coefficient, and technology impact index.

3. Definition of ICT-Based Converging Technology

In an industrial context, the first use of the term "convergence" is ascribed to Nathan Rosenberg [22], who used the expression to describe processes that are commonly utilized by unrelated industry sectors and different stages of tool production. A foundation for the common understanding of industry convergence equaling technology convergence is laid out through his paper. On the other hand, Kodama [23] used

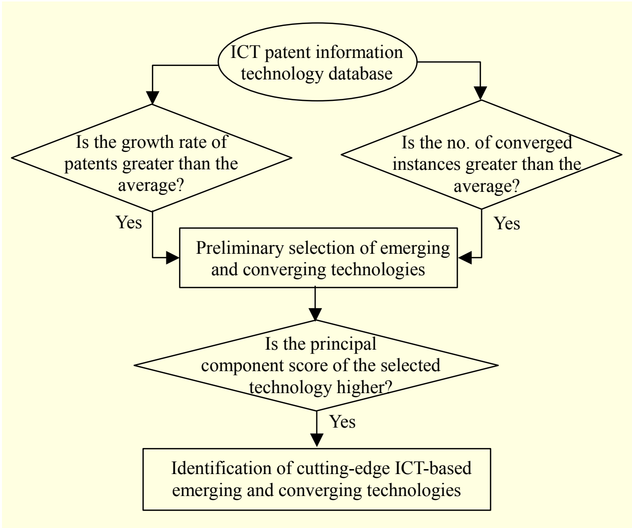


Fig. 1. Steps in selection of cutting-edge technologies.

the term "technology fusion" long before to illustrate a type of innovation that leads to breakthrough functions by combining at two or more existing technologies into hybrid technologies. Recently, Hacklin and others [24] explained four types of convergence: knowledge, technological, applicational, and industrial.

Although Curran and Leker [25] insist that there is a significant difference between the terms "convergence" and "fusion," many scholars do not reference both terms in their papers [26]-[30]. We also use both terms interchangeably. According to earlier studies, scientific convergence may happen long before technological convergence follows. Scientific publications have been found to appear up to 30 years ahead of industrial application. The patent literature is also expected to be an important opportunity for predicting converging industries. Patent works have authoritative advantages over any other form of scientific publication, because they are already systematized to a high degree. Technology convergence can be found in patent data through an increase in patent citations between different subclass categories of the IPC system [31]. Patent analysis has been used in the context of technology-driven convergence of ICT, biotechnology (BT), and other technologies [12], [25], [32], [33], and [34].

Distinct sector boundaries have already largely faded in the ICT industry [31], [32]. Recently, the convergence of different technologies has led to many industry converging products such as iPhones or smartphones. Smartphones enable users to place phone calls, read their e-mails, take pictures, listen to music or the radio, and make their way to unknown places with the aid of their built-in navigation system. These devices are a combination of select components of previously disjointed devices such as mobile phones, media players, cameras, and personal digital assistants [25]. Therefore, ICT can be viewed as a platform for entry into new products as well as an enabler of technology convergence.

Converging technologies are produced from interdisciplinary research. Interdisciplinary research is distinctive from multidisciplinary research, for instance, insofar as the former involves a more fundamental convergence between different technologies than the latter, which falls into the realm of collaborative research [35]. Notwithstanding, this study employs a broad definition of converging technology to include within its scope hybrid coupling technologies. Hybrid coupling technologies are included in a more superficial manner than converging technologies, insofar as they help to overcome the limitations and boundaries of traditional industries.

Technological convergence can occur either between technologies of similar categories or between technologies of diverging types. Convergence between homogeneous technologies, occurring in the same field, generally means 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 technology, whereby different technological subsystems interact and function as technically integrated end-to-end systems that provide the user with a range of voice, data, and image services [36]. Convergence between heterogeneous types of technologies is a combination of technologies most often aimed at resolving issues existing in the related technology fields. Bio-informatics, human interface, and nanobiosensors are great examples of this type of convergence from recent years, combining ICT with BT or nanotechnology (NT).

In the EU, technology convergence is understood as a phenomenon that can occur across all sectors, including ICT, BT, NT, and cognitive science (CS), as well as the humanities and social science fields. For this reason, the EU definition of a converging technology is very comprehensive. The dominant tendency in the US is to limit the scope of technological convergence to ICT, BT, NT, and CS. Compared to the US definition, the EU definition of technological convergence, although eminently reasonable, is weakened by its very comprehensiveness. By stretching the definition of convergence beyond the fields of science and technology to include ideologies and social institutions, the EU definition potentially blurs the conceptual boundary of this notion. According to the Korean converging technology development master plan [34], converging technologies are defined as "innovative technologies resulting from the combination and merger between diverse academic disciplines and technologies of heterogeneous types, aimed at resolving future economic and social issues." The Korean domain of converging technology is narrower than both that in the EU and US and includes only ICT, BT, and NT. The Korean definition of converging technology, although due to its narrowness will have to be continuously updated and expanded as scientific and technological progress widens the scope of convergence, is appropriate for the country's current level of technological competitiveness and social and cultural characteristics.

As it transpires from what has been described above, converging technology has been thus far defined in rather general terms. For the purposes of this study, we define converging technology in a more concrete fashion by developing an index enabling the quantification of related data. When IPC subclasses assigned to a patented technology belong to various industry fields, it means that the technology is a converging technology with wide industrial application. In this study, any ICT-based patented technology susceptible to falling into one or more subclass category of the IPC system, other than one that belongs to the ICT industry, is considered an ICT-based heterogeneous-converging technology. On the other hand, a patented technology is classified as an ICT-based homogeneous-converging technology if it has plural subclass categories belonging to the ICT industry without any other category that belongs to a non-ICT industry.

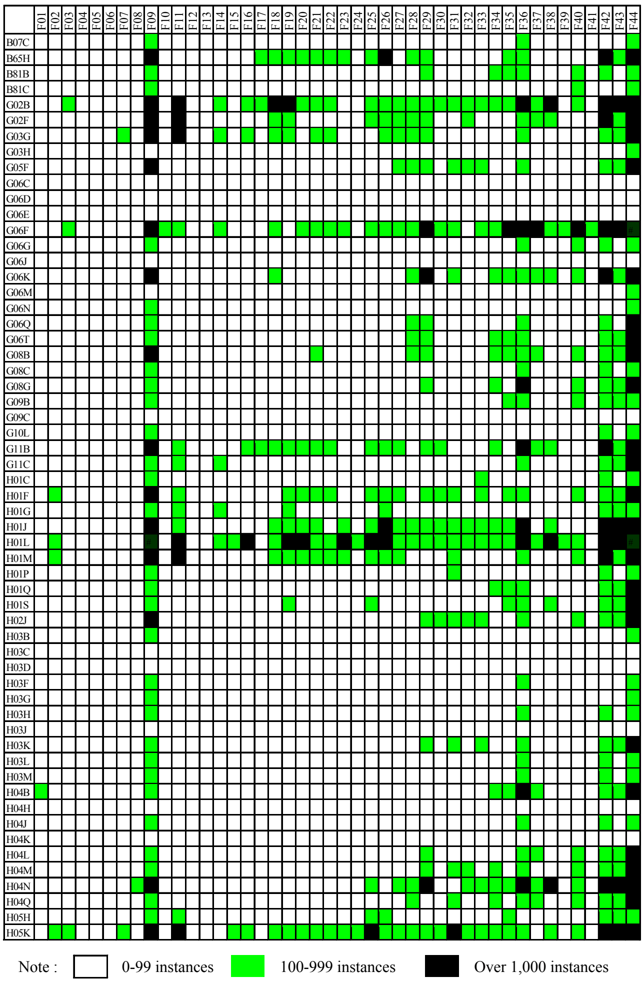
IV. Identification of ICT-based Emerging and Converging Technologies

1. Definition of Converging Coefficient and ICT Technology-Industry Linkage Table

An ICT technology-industry linkage table has been created by aligning ICT technologies in a row and all the industries linked to ICT technologies through convergence in a column. Table 2 is a linkage table based on the IPC subclass categories, consisting of 58 rows and 44 columns. The linkage relationships can be re-expressed into a table of 831 rows and 44 columns, according to the IPC main-group categories. Due to size constraints, we use different shades to mark the range of numbers of IPC instances, instead of inserting the number. The darker the shade, the more numerous the IPC instances issued. Meanwhile, the numbers in the top row of the table are the industry codes, as listed in Table 3.

The converging coefficient more accurately determines technologies and industries in which ICT is used extensively. In Table 2, row i corresponds to the i-th ICT field, and 58 IPC subclass categories are assigned to each row. Meanwhile, the 44 columns correspond to 44 industries, including the ICT

Table 2. ICT-based technology-industry linkage table.



industry, with column j assigned to the j-th industry. The sum of the rows, therefore, provides an indicator as to the extent to which ICT is converged with other industry fields. On the other hand, the sum of the columns denotes the degree of convergence with ICT in an industry.

For instance, the converging coefficient for technology i, FU_i, is the value having the sum of values in row i as the numerator and the sum of total cells of all 44 industries divided by 58 as the denominator. On the other hand, the coefficient of convergence for industry j, FU_j, is the value having the sum of values in column j as the numerator and the sum of total cells of all 44 industries divided by 44 as the denominator. Here, the sum of total cells is greater than that of the total patents because the former is the total sum of IPC subclasses awarded to each patent.

$$FU_j = \frac{\sum_{i=1}^{58} b_{ij}}{\sum_{j=1}^{44}\sum_{i=1}^{58} b_{ij} \Big/ 44}.$$

$$FU_i = \frac{\sum_{j=1}^{44} b_{ij}}{\sum_{i=1}^{58}\sum_{j=1}^{44} b_{ij} \Big/ 58}.$$

In the above equations, i is the classification of ICT, j is the industry classification, and b is the number of IPC. The converging coefficient for technology i is the percentage rate indicating technology i's degree of convergence, compared to the average of the overall technology. On the other hand, the converging coefficient for industry j is the percentage rate indicating industry j's degree of convergence, compared to the average of the overall industry. Accordingly, when an industry (technology) sector's convergence coefficient is greater than 1, it means that the degree of convergence in this sector surpasses the average of the overall industry (technology).

2. Identification of ICT-Based Converging Technologies and Industries

Out of the 58 technologies, the converging coefficient of 16 technologies, including H01L, appears to be greater than one, and that of 42 technologies appears to be smaller than one. This phenomenon implies that a relatively small number of technologies is driving technological convergence in the ICT field. In particular, homogeneous convergence has appeared overwhelmingly in H01L (semiconductor devices) and G06F (electric digital data processing), displaying a sum of column F44 of over 10,000. Column F44 is considered an indicator denoting the degree of homogeneous convergence. Table 2 shows that 58 technologies belonging to the ICT industry are largely distributed in F44 (ICT industry), except for a few minority technologies. On the other hand, columns from F1 through F43 are considered indicators denoting the degree of heterogeneous convergence. In this case, H01L and G06F are also denoted as ICT fields with the most convergence with other industries.

ICT fields with a comparatively active level of convergence with other industries, according to the IPC subclass classification, are as follows: H01L (semiconductor devices, 12.88), G06F (electric digital data processing, 6.13), G11B (information storage based on relative movement between record carrier and transducer, 3.11), H04N (pictorial communication, 3.10), H05K (printed circuits, casings or construction details of electric apparatuses, manufacturing of assemblages of electrical components, 2.65), G02B (optical elements, systems, or apparatuses, 2.37), G02F (devices or arrangements for the control of the intensity, color, phase, polarization, or direction of light, 2.15), G11C (static stores, 1.97), H01J (electric discharge tubes or discharge lamps, 1.88), H04Q (selecting, 1.79), H04L (transmission of digital

Table 3. Converging coefficients and most used type of ICT by industry.

Industry category	Converging coefficients (subclass)
1. Agriculture and fisheries industry	0.01
2. Food products and beverages	0.04
3. Tobacco products	0.04
4. Textiles	0.03
5. Wearing apparel, dressing, and dyeing fur	0.01
6. Leather products, luggage, and foot-wears	0.00
7. Wood and wood products	0.03
8. Pulp, paper and paper products	0.02
9. Publishing, printing, and reproduction of recorded media	2.16 (H01L** B65H*G02B* G02F* G03G* G05F* G06F* G07K* G08B* G11B* H01F* H01J* H01M* H02J* H04N* H05K*)
10. Coke, refined petroleum products, nuclear fuel	0.02
11. Basic chemicals	0.61 (G02B* G02F* G03G* H01L* H01M* H05K*)
12. Pesticides and other agricultural chemical products	0.01
13. Paints, varnishes, and similar coatings	0.01
14. Pharmaceuticals and medicinal chemicals	0.07
15. Soaps and detergents, cleaning and polishing preparations, perfume and toilet preparations	0.04
16. Recording media and related chemical products, and other chemical products	0.07 (H01L*)
17. Man-made fibers	0.04
18. Rubber and plastic products	0.17 (G02B*)
19. Non-metallic mineral products	0.22 (G02B* H01L*)
20. Basic metals	0.15 (H01L*)
21. Manufactured metal products except machinery and equipment	0.16
22. Energy machinery	0.09
23. General purpose machinery	0.15 (H01L*)
24. Agricultural machinery	0.05
25. Machine tools	0.28 (H01L* H05K*)
26. Special purpose machinery	0.38 (B65H*)
27. Weapons and ammunition	0.14
28. Other domestic appliances	0.24
29. Office machinery and computers	0.50 (G06F* G08K* H04N*)
30. Electric motors, generators, and transformers	0.10
31. Distribution and control apparatuses of electricity, and insulated wires and cables	0.23 (H05K*)
32. Electric lamps and bulbs	0.12
33. Other electric equipment	0.15
34. Television and radio receivers and audiovisual electronics	0.17
35. Medical and surgical equipment and orthopedic appliances	0.27 (G06F*)
36. Instruments and appliances for measuring, testing, and navigating and other precision equipment	0.85 (G02B*G06F* G08G*G11B*H01J* H01L* H04B* H04N*)
37. Industrial process control equipment	0.15 (G06F*)
38. Photographic equipment and other optical instruments	0.26 (G02B*H01L*H04N*)
39. Watches, clocks and timing mechanisms and parts thereof	0.05
40. Motor vehicles, trailers, and trucks	0.23 (G06F*)
41. Other transportation equipment	0.03
42. Furniture and other miscellaneous products and processed materials for recycling	1.32 (B65H*G02B*G02F* G06F*G09K*G11B* H01J*H01L*H01M* H04N*H05K*)
43. Construction	0.66 (G02B* G06F* H01J* H01L* H04N* H05K*)
44. ICT	33.68 (G06F***H01L*** 65H**G02B**G02F** G05F**G06K**G11B** G11C**H01J**H01M** H01Q**H01S**H03K** H03M**H04B**H04J** H04L**H04M**H04N** H04Q**H05K**B81B* G03G*G06G*G06N* G06Q*G06T*G08B* G08C*G08G*G09B* G10L*H01C*H01F* H01G*H01P*H02J*H03F* H03H* H03L* H05H*)

*1,000-9,999 instances **10,000-99,999 instances
***100,000 or more instances

information, 1.62), H01M (processes or means for the direct conversion of chemical energy into electrical energy, 1.53), H04B (transmission, 1.52), G06K (recognition of data, presentation of data, record carriers, and handling record carriers, 1.29), H04M (telephonic communication, 1.27), and H01S (devices using stimulated emission, 1.12). Here, the numbers in parentheses indicate the size of the converging coefficients.

Meanwhile, G06C (digital computers in which all the computations are effected mechanically), G06D (digital fluid-pressure computing devices), G06E (optical computing devices), G06J (hybrid computing arrangements), G09C (ciphering or deciphering apparatuses for cryptographic or other purposes involving the need for secrecy), and H04H (broadcast communication) are among those technology fields in which there have been very few attempts to converge with technologies from other industries. However, the cause of such scarcity of convergence activities involving these technologies is yet to be exactly determined; in other words, whether or not convergence is a practical option concerning the above fields or a realistic option that simply has not been explored or sufficiently used is unclear. If the latter is the case, this warrants the effort to promote convergence initiatives between these ICT-based technologies and other industry fields in order to capitalize on synergy effects.

Table 3 lists the converging coefficients of all 44 industries, along with the ICT categories (IPC subclasses) that are used in each of the industries, in 1,000 or more instances. The converging coefficient of the ICT industry is 33.68, by far representing the largest value compared with other industries. Except for the ICT industry, only two out of 43 industries (F9 and F42) have a greater than 1 converging industry coefficient. This means that ICT technologies have been intensively used in very few industries until recently. Following the ICT industry, ten industry sectors with a comparatively active level of convergence with ICT technologies are as follows: F9 (publishing, printing, and reproduction of recorded media), F42 (furniture and other miscellaneous products and processed materials for recycling), F36 (industrial process control equipment), F43 (construction), F11 (basic chemicals), F29 (office machinery and computers), F26 (special purpose machinery), F25 (machine tools), F35 (medical and surgical equipment and orthopedic appliances), and F38 (photographic equipment and other optical instruments). The converging coefficient of the construction industry is seen to be at a high level, which reflects the fact that a lot of ICT technologies have been used in the construction sector in recent years. The ICT technologies often used in the construction industry are as follows: H01L (semiconductor devices), H05K (printed circuits, casings, or constructional details of electric apparatuses, manufacturing of assemblages of electrical components), G06F (electric digital data processing), H04N (pictorial communication), and G02B (optical elements, systems, or apparatuses).

One noteworthy fact is that agriculture and fisheries and related manufacturing industries have a much lower converging coefficient. The converging coefficients of industries such as F1 (agriculture and fisheries), F2 (food products and beverages), F3 (tobacco products), F4 (textiles), F5 (wearing apparel, dressing and dyeing fur), F6 (leather products, luggage and foot-wear), F7 (wood and wood products), F8 (pulp, paper, and paper products), F12 (pesticides and other agricultural chemical products), and F24 (agricultural machinery) are below 0.1, which is less than one-tenth of the overall industry average.

3. Identification of ICT-based Emerging and Converging Technologies

We have selected a group of emerging and converging technologies by considering the total number of patent convergences and rate of patent growth, simultaneously. More specifically, emerging and converging technologies are those technology fields, according to the main-group classification under the IPC system, in which the converging and emerging coefficients exceed 1, respectively.

The emerging coefficient is measured as the value of the monthly average number of patent applications in the second period divided by that of the first period. We have examined emerging trends in the ICT technological markets, dividing January 2006 to December 2007 into the first period and January 2008 to June 2009 into the second period because patent applications in the ICT field show a very different pattern before and after December 2007.

The number of technologies with a converging coefficient greater than 1 is 122 in the main-group classification under the IPC system, corresponding to about 14.68% of all 831 ICT-based technologies, and the number of technologies with an emerging coefficient greater than 1 is 395, corresponding to about 47.53% of all ICT fields. The total number of promising technologies qualified as both an emerging and converging technology is 75, representing 9.03% of all ICT-based technologies.

Emerging and converging technologies have been standardized by rescaling the emerging coefficient, converging

Table 4. Principal component scores for top 13 emerging and converging technologies.

	Emerging coefficient	Converging coefficient	Impact index	Scores
H01L21	0.04	100	50.97	2.25
H04L12	0.68	15.12	95.02	2.08
G06Q30	2.70	0.40	100	1.87
H04L01	0	0.21	81.22	1.39
G08G001	1.18	1.25	80.25	1.32
G06F17	0.58	39.63	57.18	1.31
G06K19	0.48	0.39	74.03	1.14
G06F09	0.6	27.74	57.09	1.09
G06K07	0.21	2.76	65.46	0.92
H01L23	0.10	23.7	49.77	0.80
H01L51	0.58	1.95	62.81	0.80
H04Q07	7.67	43.13	48.27	0.74
G11C11	0.60	6.15	58.5	0.73

coefficient, and impact index. Next, we perform a principal component analysis on these main-group level IPC categories, and measure their principal component scores. The emerging and converging technologies in Table 4 are listed in the order of principal component scores. Here, the impact index of technology i, $MT_i = [C_{ij}/(N_j/12)]/P_i$, denotes the annual average number of cited patents per patent. P_i is the number of patents related to technology i, C_{ij} is that of cited patents from technology i, belonging to the IPC class j, and N_i is that of the 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 the bias in which the longer a patent has been laid open, the higher the number of citations it receives.

We find from Table 4 that those technologies with a higher converging coefficient have a high principal component score, but those technologies with a lower converging coefficient do not. The distribution of the 75 ICT-based emerging and converging technologies, filtered first by the number of converging instances and the growth rate of the patent, then by the score of the composite index, reflecting the impact index and converging and emerging coefficients, is concentrated in four fields in terms of the IPC subclass categories: G06F (electric digital data processing, 9), G02B (optical elements, systems, or apparatuses, 8), H01J (electric discharge tubes or discharge lamps, 6), and H01L (semiconductor devices, 5). Here, the numbers in parentheses indicate the number of the technological class in terms of the IPC subclass categories. The converging coefficients of H01L (12.88) and G06F (6.13) are much higher than the average of the overall technology, and those of G02B (2.37) and H01J (1.88) are also greater than 1. Here, the numbers in parentheses indicate the converging coefficient of each technology. H01L21 (data switching networks) is the most promising of all the emerging and converging technologies, as shown in Table 4.

The noteworthy fact is that the technology impact index is the most influential index on the principal component scores. The top 10 technologies in terms of technology impact are all included in the top 13 principal component scores. The reason the technology impact index has a relatively large impact on the principal component scores is because the majority of emerging and converging technologies are distributed within a number of low scores in the emerging and converging coefficients but are evenly distributed in all the scores from 0 to 100 in the technology impact index. The average emerging and converging coefficients of 75 technologies are 2.68 and 9.14, respectively, but the average coefficient of the technology impact index amounts to 37.27.

From the above discussions, it can be inferred that the higher the technology impact index and converging coefficient, the greater the principal component score of the emerging and converging technologies. In fact, the Pearson correlation coefficient between the converging coefficient and principal component score is 0.366, and that between the technology impact index and the principal component score is 0.797, each of which is significant within 1% (Table 5). On the other hand, we can infer that the technology with a higher degree of convergence is likely to be quoted a lot more than other technologies from the fact that some correlation exists between the technology impact index and the converging coefficient. Accordingly, investment in research and development for a converging technology is needed to increase economic benefits because the market value of the technology in which citations take place more often is that much greater.

Table 5. Correlations for converging coefficient, impact index, and scores.

		Converging coefficient	Impact index	Scores
Converging coefficient	Pearson corr.	1	0.124	0.366**
	Sig. (2-tailed)		0.289	0.001
	N	75	75	75
Impact index	Pearson corr.	0.124	1	0.797**
	Sig. (2-tailed)	0.289		0.000
	N	75	75	75
Scores	Pearson corr.	0.366**	0.797**	1
	Sig. (2-tailed)	0.001	0.000	
	N	75	75	75

** Correlation is significant at the 0.01 level (2-tailed).

V. Conclusion

Many firms are seeking to obtain patents on their intellectual properties, not just because of the legal protection, but also because of their economic value. In this paper, we attempted to find ICT-based emerging and converging technologies by analyzing patented ICT-based technologies. We succeeded in identifying promising ICT-based converging technologies through a patent analysis. The number of patented technologies classified into the ICT field is 58 in subclass IPC categories, and 831 in main-class categories. According to the main-group classification of the IPC scheme, the number of converging technologies whose instances of convergence are higher than the average is 122, corresponding to about 14.68% of all ICT categories. A total of 395 fields corresponding to approximately 14.68% of all ICT categories are selected as emerging technologies, in which the growth rate of patent applications is higher than the average. The number of emerging and converging technologies, an intersection set of these two technologies, is 75, accounting for 9.03%. The most promising of all emerging and converging technologies is H01L12 (data switching networks).

We found that the higher the technology impact index and converging coefficient, the greater the principal component score of the emerging and converging technologies. In addition, there was a high correlation between the technology impact index and the converging coefficient. We were able to infer that converging technologies are likely to be quoted much more from other technologies. Accordingly, much higher investments for research and development on converging technologies are needed for the realization of economic benefits, as a greater number of citations for a technology indicates that its market value is that much greater.

Until now, a relatively small number of technologies, such as "semiconductor devices" and "electric digital data processing," have been driving technological convergence in the ICT field, and technologies belonging to the ICT industry are intensively being utilized in very few industries. Meanwhile, technologies such as "digital computers in which all the computations are conducted mechanically," "digital fluid-pressure computing devices," "optical computing devices," "hybrid computing arrangements," "a ciphering or deciphering apparatus for cryptography," and "broadcast communication" have had very few opportunities to converge with technologies from other industries. The cause of such scarcity of convergence activities involving these technologies has yet to be precisely determined; therefore, it is important to verify whether or not convergence is a practical option concerning the above fields or a realistic option that simply has not been explored or used sufficiently. If the latter is the case, this warrants the effort to promote convergence initiatives between these ICT-based technologies and other industry fields so as to capitalize on synergy effects.

In this study, we re-classified industry fields under the EC's industry classification table by separating ICT-related sectors from existing categories and regrouping them under a separate category, "ICT industry." However, the scope of the ICT industry can vary depending on the researcher, and the results may also differ according to the scope of the ICT industry chosen. Meanwhile, as an alternative to a Delphi panel analysis, which has shortcomings related to decision-making, we adopted a quantitative approach using a patent database. However, patent analysis was limited in that new technologies for which no patent was applied for or issued were not considered. Therefore, more valid results can be obtained through future research by complementing the method used in this study with other methods, such as a journal analysis and survey.

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