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A Methodology to Analyze Technology Convergence: Patent-Citation Based Technology Input-Output Analysis

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***Abstract*—**This research proposes a methodology for patent-citation-based technology input-output analysis by applying the patent information to input-output analysis developed for the dependencies among different industries. For this analysis, a technology relationship matrix and its components, as well as input and technology inducement coefficients, are constructed using patent information. Then, a technology inducement coefficient is calculated by normalizing the degree of citation from certain IPCs to the different IPCs (International patent classification) or to the same IPCs. Finally, we construct a Dependency Structure Matrix (DSM) based on the technology inducement coefficient to suggest a useful application for this methodology.

***Keywords*—**Technology spillover effect, technology relationship, IO table, technology inducement coefficients, patent analysis, patent citation.

I. Introduction

GIVEN recent technological innovations, the convergence among technologies is reorganizing industry sectors. In practice, the development of recently converged industries covers a large portion of economic value of those industries that add value "the age of convergence" in the bio-nano age. Thus, to forecast the future of an industry, it is important to evaluate the probability of technological convergence, and to analyze how the technologies in a certain industry sector affect the same or other industry sectors.

From a process perspective, convergence has four stages: knowledge-, technology-, application-, and industry- [1]. This technology convergence combines similar technologies and leads to increase productivity and efficiency by expanding into other fields. Various attempts to improve convenience have been made, and new technologies affect this convergence [2]. For example, IT technology has taken center stage in many industries, such as the automotive, defense, and medical industries.

However, previous studies have dealt mainly with case studies on convergence or the development of a strategy and a policy based on research results [3], [4].

Few efforts have been made to research technology convergence using quantitative data. This investigation uses quantitative data from an objective point of view for a more meaningful understanding of the characteristics of an industry and forecasting the direction of technology development.

This research proposes a methodology of patent-citation -based technological input-output analysis of the relationship among technological fields. To do this, a technology relationship matrix was constructed and then, technology inducement coefficients were developed using patent information. This information is a representative proxy measurement of inventions [5], including the technological and commercial information for analyzing the knowledge flows and relationships among technologies. This patent information can be stored as public documents in a well-structured database. This makes it very suitable for the objective quantitative analysis of technology convergence. Technology inducement coefficients are used to evaluate how the technological development of certain IPC classes affects different IPC classes, and the possibilities of convergence among the technologies. The validity and probability of the application of the methodology proposed in this paper were verified in the IT-BT field, which is important and is considered as a technology convergence sector.

The remainder of this paper is organized as follows. In the next section, we provide a concise review of the evaluation of technology convergence using patent data and input-output analysis. Next, the research methodology of this study described. In the results section, we present the outcomes of illustrated analysis for the methodology and its application in the IT-BT field. Finally, we conclude this paper with its contributions and limitations.

II. Backgrounds

A. Convergence Evaluation using Patent Information

Recent attempts to develop convergence technologies using quantitative data have been carried out based on patent information. In previous studies, patent indices were developed to measure technology convergence. Then, this convergence was evaluated based on the patent indices calculated for each technology field.

The patent information typically used in calculating patent indices can be divided into two types: patent citation information [6], [7] and patent classification information [2], [8], [9]. In this study, patent citation information is used.

Patent citation information represents the number of citations in a specific patent for other published patents. Citation patents show the patents cited in a specific patent. A patent that has more citation patents represents a high possibility of improved

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technologies [10]. Cited patents represent citations in a specific patent and a patent that has more cited patents shows a high possibility of presenting original technologies. Patent citation information is applied to the present knowledge flow among technologies in addition to exhibiting the characteristics of individual technologies. In other words, a technology field that shows active mutual patent citations represents active knowledge flows and a high possibility of technology convergence. In the study performed by Geum et al. (2012), the patent citation information was used to evaluate the convergence between technology fields at a macro level. According to No and Park (2010), the tendency of technology convergence in a nano-bio field was analyzed based on patent citation information.

B. Input-Output Analysis

The technology relationship matrix proposed in this study is developed by introducing the concept of input-output matrixes. The input-output matrix represents a single table for all national economic activities [11]. That is, the industrial relationship matrix summarizes the information on the distribution of the annual money, property, and services created in each industrial field between industries or intermediate and final demand (export, consumption, and other). In Korea, the statistics related to this information are produced by the Bank of Korea and are used as the basic data for implementing different economic analyses, industrial analyses (industrial structures and ripple effects), and establishment policies.

In this study, a technology relationship analysis is proposed by introducing an input-output analysis. The technology relationship matrix summarizes how the information flows in each technology field. This is presented in the same or different technology fields and is proposed as the basic material for industrial convergence statistics.

III. Research Framework

A. Research Process

Fig. 1 presents the overall research process of this paper. First, a technology relationship matrix and matrix components, input coefficients and technology inducement coefficients were constructed using patent information. This matrix is the core structure of technology input-output analysis, which is a methodology to analyze how knowledge is developed in each technological field and how these flows occur between the same technologies and other technologies. The technology relationship matrix classifies technology groups by IPC class and uses the number of forward citations as core content. The measure of using forward citations computes the extent to which a technology class influences diverse technological fields [7]. All analyses in this paper are based on of this matrix.

Second, the technology inducement coefficients were deduced by the normalization of the degree of citation from certain IPCs different IPCs or to the same IPCs. The purpose of normalization is to avoid a high degree of citation merely due to the large number of issued patents in class.

Finally, we performed the process mentioned previously in practice. For the illustrated analysis, information technology (IT) and bio Technology (BT) patents from a United States Patent and Trademark Office (USPTO) database are used. We collected all the patents registered with the USPTO from 1976 to 2012. Among the collected patents, 1,000 were extracted randomly for trial analysis. We used USPC related with IT and BT fields to start the data collection and converted USPC to IPC in concordance with conversion table provided by WIPS.

Based on the technology inducement coefficients of 1,000 patents, a dependency structured matrix (DSM) was developed. DSM is a methodology for visualizing the relationship of a system. Applying the technology inducement coefficients to DSM and drawing on the technologies with high co-relationships, we were able to extract candidates for promising convergence technology.

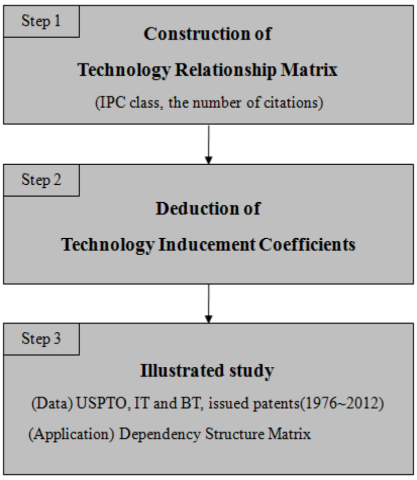

Fig. 1 Overall research process

B. Technology Relationship Matrix

The technology relationship matrix has an IPC class and a number of citations as its core contents. In this matrix, groups of technology are classified according to their IPC sub-class level, such asA01.

The definition of the core contents of the technology relationship matrix are as follow. IPC class Y is citing class X. IPC class X is cited class by class Y. Actually, classes X and Y are same class. However, as differences for the cited and citing, we marked the class X in Y. Cells of the matrix with a bold line mean the number of citation class X cited by class Y. If class X2 is class Y1, then Nx2y1 indicates the number of citations from class X to class Y. The total number of citations of class X is the sum of Nx2y1, Nx2y2, Nx2y3, Nx2y4, and Nx2y5. We can then divide Nx2y1 by the total number of citations for class X2, which means the technology inducement coefficients of IPC class X2 are with class Y1. Input coefficients are the total number of issued patents of class Y. All analyses performed in this research are based on this matrix.

		(A) IPC class Y					(C)
		class Y1 (class X1)	class Y2 (class X2)	class Y3 (class X3)	class Y4 (class X4)	class Y5 (class Y5)	total number of citation of class X
(B) IPC class X	class X1						
	class X2	Nx2y1	Nx2y2	Nx2y3	Nx2y4	Nx2y5	
	class X3						
	class X4						
	class X5						
(D)input coefficients							

Fig. 2 Structure of technology relationship matrix

		IT					BT					number of citation (total)
		A63	B60	G01	G02	G05	H01	H03	A01	A21	A61	
IT	A63	3										6
	B60		95	5	14							393
	G01		1	372		18						1275
	G02											13
	G05		4									123
BT	H01			105	2		434	3				1642
	H03							9				26
	A01										9	36
	A21									2		8
	A61	14		92							9503	16469
input coefficient												

Fig. 3 Technology relationship matrix

IV. Result

A. Degree of Citation

Table I shows the number of citation between the same or different classes. The results show that the number of citing class G08(21) is the best highest, followed by G01(17), A61(16), and H01(15). For four classes, all were evenly cited by IT and BT fields.

TABLE I
Degree of Citation (Top Four Classes)

class X	the number of class citing class X	top 3 class Y citing class X excluded same class (field, the number of citation X→Y)
G08 (IT)	21	G08(959) G06(IT, 453) H04(BT, 173) G01(IT, 148)
G01 (IT)	17	G01(371) G02(IT,51) H01(BT, 44) G05(IT, 18)
A61 (BT)	16	A61(BT, 9503) G06(IT, 133) G01(IT, 92) H01(BT, 46)
H01 (BT)	15	H01(BT, 434) G01(IT, 105) H04(BT, 50) G02(IT, 38)

B. Technology Inducement Coefficients

For the calculation of the technology inducement coefficient, we developed the technology relationship matrix(Table I). Among the 1,000 patents collected for analysis, only 10 IPCs are showed in this paper. Therefore, it is possible that the space restraint is reduced and visualization is improved for a more specific understanding.

The results are shown in Table III. Mostly, the technology inducement coefficients(TICs) between the same IPC were high (ex. A61→A61, A63→ A63, A21→ A21). Excluding this, the TIC of A01(to A61) was the best high(=0.25).

		IT					BT					number of citation (total)
		A63	B60	G01	G02	G05	H01	H03	A01	A21	A61	
IT	A63	0.5										6
	B60		0.2417	0.0127	0.0356							393
	G01		0.0008	0.2918		0.0141						1275
	G02											13
	G05		0.03252									123
BT	H01			0.06395	0.00122		0.2643	0.0018				1642
	H03							0.3462				26
	A01										0.25	36
	A21									0.3		8
	A61	0.0009		0.0056							0.577	16469
input coefficien												

Fig. 4 Results of technology inducement coefficients

C. Dependency Structure Matrix

DSM was determined based on the value of TICs. The TIC values were divided into five sections by multiplying them by 100: 0 for below 1; 1 for more than 1 and below 4; 2 for more than 4 and below 9; 3 for more than 10 and below 30; 4 for more than 30 and below 50; and 5 for more than 50. Relationships between the same IPCs were excluded from the matrix that agreed with the structure of DSM. Fig. 2 shows the results of DSM. According to these results, G05, B60, and G01 clustered into one unit. Thus, we can identify this unit as a promising convergence field.

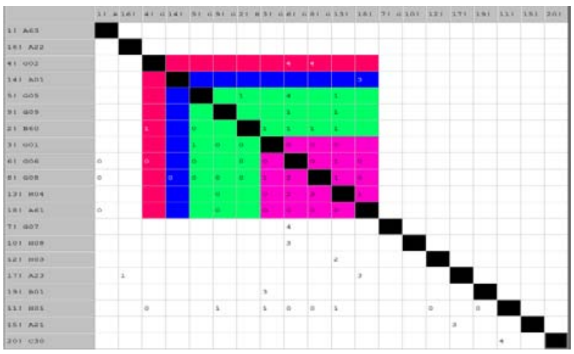

Fig. 5 Structure of DSM

V. Conclusion

This study aimed to propose a methodology for patent-citation-based technology input-output analysis by applying the input-output analysis developed for dependencies among different industries' patent information. We developed this technology relationship matrix TICs to evaluate how technology development of certain IPC classes affects different IPC classes, Which then enables the possibilities of convergence among technologies.

These research results are expected to be implicated as follows. First, the openness perspective could be used to characterize the technologies. Technology openness is the notion of evaluating degree, or how certain technologies co-evolve with other technologies. The greater the technology openness, the greater the attracted investment in technology.

Second, the openness perspective is useful for forecasting the technology spillover effect. That is, the technologies that are greatly influenced by other technologies or that have a significant influence on other technologies are identified. Eventually, the openness perspective can be adopted to forecast how certain technological development could affect other developments. Finally, the openness perspective can be applied to find a promising convergence technology.

Despite its meaningful contribution, this paper has some limitations. First, this research has not considered the time problem that could occur due to the difference in the time a certain patent was cited from other patents. Regardless of the usefulness of the technology, the earlier a patent is registered, the greater the number of citations. Finally, we provided an illustrated study to explain the application of the methodology of this research that covered 1,000 randomly sampled data points. But generalizing the characteristics of the technology convergence in IT-BT fields is not sufficient.

Additional research is needed for more in-depth studies that solve the time problem with patent and citation analysis and to extend the scope of the industry fields and patent data to make more effective and pragmatic suggestions.

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